

The climate gap: environmental health and equity implications of climate change and mitigation policies in California—a review of the literature

Seth B. Shonkoff · Rachel Morello-Frosch ·
Manuel Pastor · James Sadd

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Abstract Climate change is an issue of great importance for human rights, public health, and socioeconomic equity because of its diverse consequences overall as well as its disproportionate impact on vulnerable and socially marginalized populations. Vulnerability to climate change is determined by a community's ability to anticipate, cope with, resist, and recover from the impact of major weather events. Climate change will affect industrial and agricultural sectors, as well as transportation, health, and energy infrastructure. These shifts will have significant health and economic consequences for diverse communities throughout California. Without proactive policies to address these equity concerns, climate change will likely reinforce and amplify current as well as future socioeconomic disparities, leaving low-income, minority, and politically marginalized groups with fewer economic opportunities and more environmental and health burdens. This review explores the disproportionate impacts of climate change on vulnerable groups in California and investigates the costs and benefits of the climate change mitigation strategies specified for implementation in the California Global Warming Solutions Act of 2006 (AB 32). Lastly, knowledge gaps, future research priorities, and policy implications are identified.

S. B. Shonkoff

Department of Environmental Science, Policy, and Management, Division of Society and Environment, University of California, Berkeley, 137 Mulford Hall, MC 3144, Berkeley, CA 94720, USA

R. Morello-Frosch (✉)

Department of Environmental Science, Policy and Management & School of Public Health, University of California, Berkeley, 137 Mulford Hall, MC 3114, Berkeley, CA 94720, USA
e-mail: rmf@berkeley.edu

M. Pastor

Departments of Geography and American Studies and Ethnicity, University of Southern California, 3620 S. Vermont Ave, KAP-462, Los Angeles, CA 90089-0255, USA

J. Sadd

Department of Environmental Science and Geology, Occidental College, 1600 Campus Rd., Los Angeles, CA 90041, USA

1 Introduction—the climate gap: environmental health and economic equity

The *Climate Gap* refers to the disproportionate and unequal implications that climate change and climate change mitigation hold for people of color and the poor (Pastor et al. 2010b; Morello-Frosch et al. 2009; Shonkoff et al. 2009b). Vulnerability to climate change is determined by the ability of a community or household to anticipate, cope with, resist, and recover from the direct and indirect impacts of extreme weather events and geophysical shifts such as sea level rise (Pacific Institute 2009), hurricanes (Greenough and Kirsch 2005), floods (Greenough et al. 2001), heat waves (Knowlton et al. 2009), air pollution (O'Neill et al. 2008), and infectious diseases (Gage et al. 2009). Therefore, to understand concerns regarding the climate gap, it is critical to explore disparities in the costs and benefits of climate change, the abilities of different groups to adapt to it, and the equity dimensions of the mitigation strategies imposed to attenuate it in order to better inform policy and regulatory action.

This review focuses on the current and projected disparate impacts of climate change and climate change mitigation policies on groups of lower socioeconomic status (SES)¹ in California. We begin with a review of the disproportionate health and economic impacts of climate change itself and examine differences in the capacity of certain groups to adapt to its direct and indirect effects, such as extreme weather events, increased or re-located air pollution, infrastructure impacts, and major economic shifts. Second, we review a subset of the health and economic equity implications of different climate change mitigation strategies, with an emphasis on those included in The Global Warming Solutions Act of 2006 (AB 32) in California. We end with a discussion of the implications of this wide-ranging body of literature for future policy-relevant research on the climate gap.

2 Environmental health inequities and climate change

Globally, climate change and climate change mitigation strategies hold a variety of implications for differential environmental health outcomes across socio-demographic strata. In the California context, the primary climate change exposures that pose risks for population health are increases in the incidence and duration of extreme weather events, such as heat waves and the exacerbation and changing patterns of outdoor air pollution. We thus focus our review of health implications of climate change in California on these two factors.

2.1 Extreme weather events—heat

Extreme weather events, such as heat-waves and floods are expected to increase in frequency and intensity over the next hundred years (Solomon et al. 2007). This could amplify the risk of associated morbidity and mortality for populations that are not able to adapt to, or protect themselves against, such events.

Regarding heat wave mortality, in a study of nine California counties from May through September of 1999–2003, Basu and colleagues (2008) found that for each 10°F (5.6°C)

¹ The term *socioeconomic status* or *socioeconomic position* (used synonymously) will refer to the position of an individual or group along the spectrum of access to the resources necessary to maintain their health and economic livelihoods. Socioeconomic status thus encompasses variables such as income level, inherited wealth, educational status, beneficial social networks, and race/ethnicity.

increase in ambient temperature, there is a 2.6% (95% confidence interval [CI]: 1.3, 3.9) increase in cardiovascular mortality with ischemic heart disease being the most dominant of these outcomes (Basu et al. 2008). In this analysis mortality risks were highest for African Americans at 4.9% (95% CI: 2.0, 7.9) (Basu and Ostro 2008).

In terms of heat-wave morbidity, a study on the 2006 California heat wave (July 15–August 1, 2006) estimated an excess of 16,166 emergency department visits and 1,182 excess hospitalizations statewide, compared with a temporally-proximate summer referent period (July 8–14 to August 12–22, 2006) (Knowlton et al. 2009). Emergency department visits for heat-related causes (i.e., acute renal failure, diabetes, cardiovascular diseases, electrolyte imbalance, and nephritis) increased across the state (relative risk [RR] 6.30; 95% CI 5.67–7.01), especially in the Central Coast, which includes San Francisco. Elevated rate ratios of emergency department visits of 1.05 (95% CI: 1.04–1.07) and 1.03 (95% CI: 1.02–1.04) were found for children (0–4 years of age) and the elderly (≥ 65 years of age) respectively (Knowlton et al. 2009).

2.2 Intrinsic and extrinsic risk factors for heat-associated mortality and morbidity

Although heat exposure alone is implicated in increased morbidity and mortality, physiological, social and economic factors are also fundamental to understanding the uneven distribution of these adverse heat-specific health outcomes across diverse populations (Klinenberg 2002). Thus, risk factors for heat-associated mortality and morbidity can be categorized as intrinsic (i.e., age, disability, medical status) or extrinsic (e.g., housing, access to cooling centers, transportation) and low SES groups are disparately affected by both of these risk categories.

In terms of intrinsic factors, people suffering from chronic medical conditions have an elevated risk of death during heat waves (Kilbourne 1997; Kovats and Hajat 2008) compared with those who are healthy. In fact, a study on heat specific mortality during the 2003 heat wave in France reported that over 70% of the victims found at home had pre-existing medical conditions, particularly cardiovascular and/or psychological illnesses (Poumadere et al. 2005). Because low SES groups are disproportionately affected by medical conditions partially due to their lack of access to technological, informational, and social resources to cope with these conditions (Phelan et al. 2004), they tend to be most adversely affected by extreme heat events.

In terms of extrinsic risk factors, low-income urban communities and communities of color are particularly vulnerable to increased frequency of heat waves and higher temperatures because they are often segregated in the inner city (Schulz et al. 2002; Williams and Collins 2001), which is more likely to experience “heat-island” effects (Harlan et al. 2008). Heat-island effects occur in urban areas when lighter-colored (higher albedo) materials such as grass, trees, and soil are replaced by darker-colored (lower albedo) materials such as roads, buildings, and other surfaces, leading to increased absorption of sunlight. This increased absorption of sunlight decreases the dissipation of heat, thus warming the local area (Oke 1973). A recent land cover analysis (Shonkoff et al. 2009a) shows a positive relationship between the proportion of impervious land cover in neighborhoods and an increasing proportion of residents living in poverty, as well as a negative relationship between the amount of tree canopy coverage and the proportion of residents living in poverty in four California urban areas (Fig. 1). Further, there is a positive relationship between the proportion of neighborhood residents of color and the proportion of impervious land cover and a negative relationship between the proportion of people of color and the amount of tree cover (Fig. 2). These data suggest a

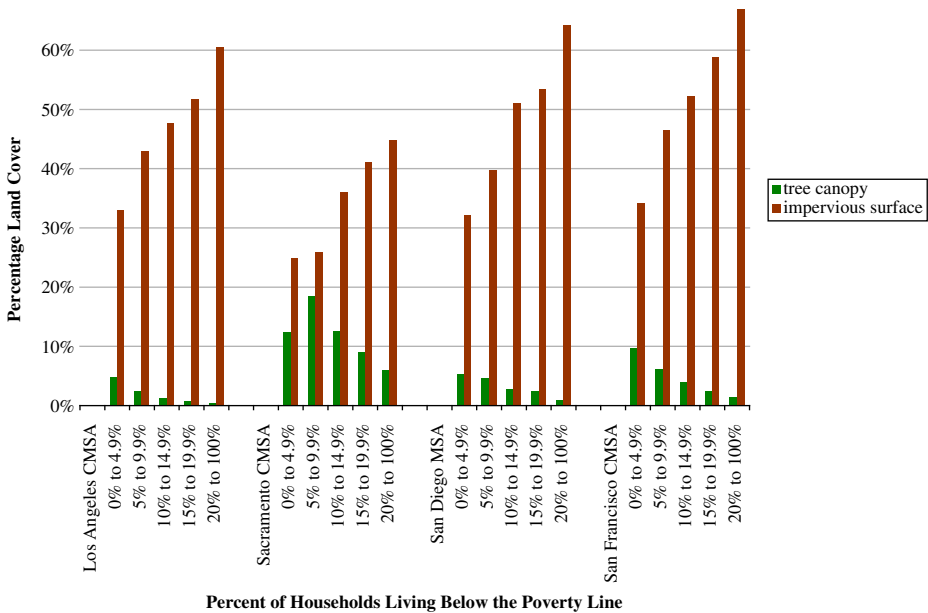


Fig. 1 Land cover characteristics across comparable neighborhood poverty groups. Cited From: Shonkoff et al. (2009a, b)

disproportionate exposure to heat-island risk factors on communities of color and low income.

From home building materials to devices used to heat and cool living environments, technologies are employed by all communities to protect themselves from exposure to weather and climate fluctuations. In terms of technological adaptation as an extrinsic factor in heat-associated health outcomes, studies have documented that lack of access to air conditioning is correlated with risks of heat-related morbidity and mortality among urban elderly of low SES in the United States (Kovats and Hajat 2008; Semenza et al. 1996; Knowlton et al. 2009). In the Los Angeles-Long Beach Metropolitan Area, for example, a higher proportion of African-Americans do not have access to home air conditioning compared to the general population (59% vs. 40%, respectively). Similar trends hold for Latinos (55%) and communities living below the poverty line (52%) (USCB 2004) (Table 1). Although these data do not fully explain the drivers of observed racial and SES disparities in air conditioner ownership, the differential proportions of ownership of these technologies is important because some households may rely on air conditioning during extreme heat events and days when communities are instructed to stay indoors and avoid outdoor pollution exposures.

Further, nearly 84% of residents in the Los Angeles metropolitan area rely on cars to commute to work compared to 7% of residents who rely on public transportation (ACS 2007). The paucity of public transit options makes residents extremely reliant on car ownership to meet basic transportation needs.² During extreme heat events, households

² Since the 1930s when National City Lines, a holding company run by corporate partners in the automotive industry, bought and dismantled a considerable portion of the public transit infrastructure in Los Angeles, residents without a personal automobile in the Los Angeles-Long Beach Metropolitan Area have been at a severe disadvantage (Kunzli et al. 2003).

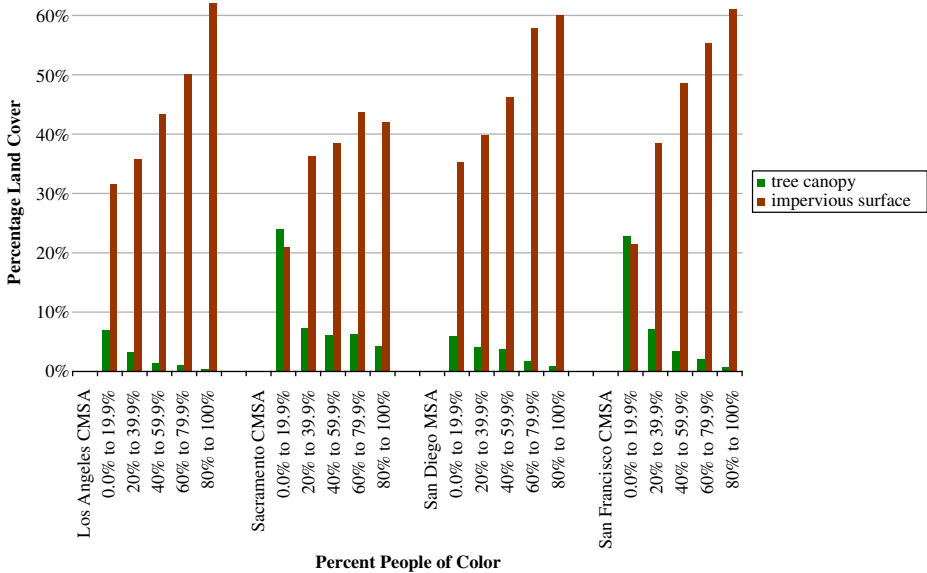


Fig. 2 Land cover characteristics across comparable neighborhood racial/ethnic minority groups. Cited From: Shonkoff et al. (2009)

without air conditioning may need to relocate to cooler areas and government-sponsored cooling stations, which can be a logistical challenge for those without access to a car or adequate public transportation. In the Los Angeles-Long Beach Metropolitan Area, elevated proportions of African-American (20%), Latino (17.1%), and Asian (9.8%) households do not have access to a car, compared to white households (7.9%) (USCB 2004).

Using heat-wave data from Chicago, Detroit, Minneapolis, and Pittsburgh, O’Neill et al. (2005) found that African Americans had a 5.3% higher prevalence of heat-related mortality than Whites and 64% of this disparity is potentially attributable to disparities in prevalence of central air conditioner technologies (O’Neill et al. 2005). These results are bolstered by other studies that found associations between being African American and lack of air conditioning as an indicator for vulnerability to heat-related poor health outcomes (Curriero et al. 2002; Greenberg et al. 1983; O’Neill et al. 2003; Rogot et al. 1992; Semenza et al. 1996; Whitman et al. 1997). It should be noted that this same analysis found that both Asian and Hispanic groups suffer a lower mortality burden than that of white groups in Los Angeles.

Material and socioeconomic deprivation, especially in the inner city, is highly correlated with heat-wave and heat-stroke mortality risk in the United States, including California (English et al. 2007; Kovats and Hajat 2008; Klinenberg 2002). For example, the heat wave in Phoenix, Arizona, in 2006 was responsible for 13 heat-stroke-related deaths, 11 of which were homeless people who tend to lack access to material and social resources (Kovats and Hajat 2008).

This is in line with other findings that African American Los Angeles residents have a projected heat-wave-mortality rate that is nearly twice that of the Los Angeles average under different GHG emission scenarios (Fig. 3) (Cordova et al. 2006).

Because SES is fundamentally associated with occupation, it is important to note that California’s agricultural and construction workers experience severe heat-related morbidity and mortality with data pointing towards possible increasing trends in recent years (English et al. 2007; MMWR 2008). Mexican and Central American immigrants who come to

Table 1 Proportion of households without access to any air conditioning by race and SES—Los Angeles-Long Beach Metropolitan Area, California (2003)

	Total number of households (General Los Angeles population)	Total occupied units (General Los Angeles population)	Black (not Hispanic)	Hispanic	Elderly (65 years or older)	Below poverty level
All Occupied units	3,131,000	39.7%	58.5%	54.6%	37.5%	51.5%
Renters	1,608,900	48.1%	59.1%	58.4%	38.7%	56.3%
Homeowners	1,522,100	30.9%	57.4%	48.9%	36.8%	38.8%

Percentages are likely an underestimate of the true value due to the fact that more than one category may apply to a single unit in the dataset

Adapted from: American Housing Survey for the Los Angeles-Long Beach Metropolitan Area 2004 (USCB 2004)

California to work in the agricultural and construction sectors are particularly vulnerable because of the cumulative impacts of their long workdays under strenuous conditions, low capacity to protect themselves on the job and assert labor rights, and exposure to chemicals such as pesticides. Between the years 2003–2006, 71% of the crop-workers that died due to heat-associated complications were identified as Mexican, Central or South American and 72% of these deaths were in adults aged 20–54 years, a population typically considered at low-risk for heat illnesses (MMWR 2008). As heat-wave incidence and intensity increases, disparities will persist among those with high levels of material and social deprivation that characterize the context within which low-SES groups live and work.

2.3 Air pollution

The literature on outdoor (ambient) air pollution in California has primarily focused on tropospheric ozone (O₃), nitrogen oxides (NO_x), and chemically undifferentiated particulate matter (PM). Hence, we focus our review on these three pollutants. It is nonetheless

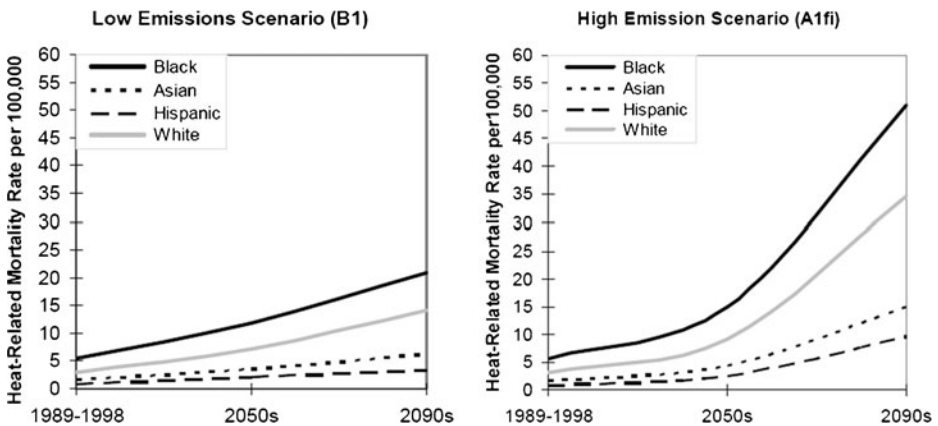


Fig. 3 Relative heat-wave mortality rates by race/ethnicity for Los Angeles. Actual historical values (1989–1998) and projected future values (2050s and 2090s) for high-emissions (A1fi) and low-emissions (B1) scenarios. (HadCM3 projections only). Cited from: Cordova et al. (2006)

important to mention that other greenhouse gas (GHG) co-pollutants such as sulfur dioxide (SO_x), black carbon (BC) (Smith et al. 2009) and carbon monoxide (Kaur and Nieuwenhuijsen 2009) are associated with: population health disease burdens as well as additional climate forcing.

Five of the ten most ozone-polluted metropolitan areas in the United States are in California (Los Angeles, Bakersfield, Visalia, Fresno, and Sacramento) (ALA 2011). Because of this, Californians suffer a relatively high air pollution associated disease burden, including 18,000 (95% CI: 5,600–32,000) premature deaths each year and tens of thousands of other illnesses (CARB 2008a). Primarily due to the combustion of fossil fuel among mobile sources and the stationary energy sectors, California's levels of NO_x, PM, O₃, and a myriad of other health damaging air pollutants are very high, particularly in California's Central Valley and South Coast Region where ambient levels frequently exceed National Ambient Air Quality Standards (US EPA 2010). As mentioned above, these sectors not only emit criteria air pollutants but also climate altering pollutants (i.e., CO₂, NO_x, BC, O₃) that contribute to additional climate forcing on local, regional and global scales (Smith et al. 2009). In turn, elevated temperatures interact with NO_x and sunlight and lead to increases in ambient O₃ concentrations in urban and suburban areas. This contributes to both respiratory health effects (Jerrett et al. 2009) as well as even more climate forcing (Meleux et al. 2007; Stathopoulou et al. 2008; Smith et al. 2009).

In California, the five smoggiest cities are also the locations with the highest projections of climate change induced ambient ozone increases as well as the highest densities of people of color and low-income residents (Cordova et al. 2006). A recent study projects a dose–response relationship in which for each 1 degree Celsius (1°C) rise in temperature in the United States, there is an estimated 1,000 (CI: 350–1800) excess air-pollution-associated deaths (Jacobson 2008). About 40% of the additional deaths may be due to the exacerbation of ozone production due to increased temperatures and the rest to particulate matter—which increases due to CO₂-enhanced stability, humidity, and biogenic particle mass—annually (Jacobson 2008).

3 Disproportionate economic impacts of climate change on low SES groups

On scales from the global to the local, climate change holds direct and indirect implications for the strength of economic systems as well as the distribution of their impacts and benefits. This section reviews how climate change could have negative implications for the economic prospects of lower SES groups in California compared with their higher SES counterparts. We focus our equity analysis on three issues: 1) Increased prices of basic necessities such as water, food, and household energy; 2) Downturns in productivity and employability in the agricultural sector; and 3) Increased infrastructure damage from extreme weather events, sea level rise, and wildfires.

3.1 Price of basic necessities

Under a business-as-usual scenario it is estimated that between the years 2025 and 2100, the cost of providing water to the western United States will increase from \$200 billion to \$950 billion per year, representing an estimated 0.93–1% of the United States' gross domestic product (GDP) (Ackerman and Stanton 2008). Under the same scenario annual U.S. energy expenditures (excluding transportation) could be \$141 billion higher in 2100 than they would be if today's climate conditions continued throughout the century

(Ackerman and Stanton 2008). This increase is approximately equal to 0.14% of US GDP, an economically significant figure (Ackerman and Stanton 2008). Four climate change impacts—hurricane damage, energy costs, real estate losses, and water costs—alone are projected to cost 1.8% of the GDP of the United States, or, just under \$1.9 trillion (2008 U.S. dollars [USD]) by the year 2100 (Ackerman and Stanton 2008).

Low-income groups spend the highest proportion of their income on basic necessities such as water, household energy (electricity), and food (BLS 2002) and price increases due to these climatic shifts may lead to increases in necessity prices. There is nearly a three-fold difference in the proportion of the sum of expenses allocated to water between the lowest- and the highest-expenditure quintiles of the US population. Households in the lowest economic quintile use more than twice the proportion of their total expenditures on electricity than do those households in the highest economic quintile. Similarly, food, the commodity that represents the largest portion of total spending out of all the basic necessities in the expenditure quintiles, shows a two-fold discrepancy between the lowest and the highest economic quintiles (Fig. 4) (BLS 2002).

3.2 Disproportionate impact of climate change on agricultural employment in California

The majority of jobs in sectors that will likely be significantly affected by climate change in California, such as agriculture are held by low-income people of color (EDD 2004; USCB 2005). In the event of climatic shifts that impact the productivity or location of agriculture, these workers would be the first to lose their jobs. The literature suggests that climate change will affect employment within the agricultural sector in two main ways: (1) Increases in the frequency and the intensity of extreme weather events will expose agriculture to greater productivity risks and possible revenue losses that could lead to abrupt layoffs (Costello et al. 2009; Howitt et al. 2009); and (2) Changing weather and precipitation patterns could require expensive adaptation measures such as the relocation of crop cultivation, the modification of the composition or type of crops (Jackson et al. 2009), and the increase in agricultural inputs, such as pesticides, to adapt to changes in ecological composition.

Latinos comprise 77% of the U.S. agricultural workforce and the majority of these men and women are also categorized as low-income (EDD 2004). In California, as of 2003, agriculture provided approximately 500,000 jobs with 315,000 of them being held by Latinos (EDD 2004). The majority of these jobs are seasonal, pay very low wages, and do not provide health insurance or job security. Because of the low wages and the seasonality of the work, agricultural counties are among the poorest in the state. As climate change affects agricultural

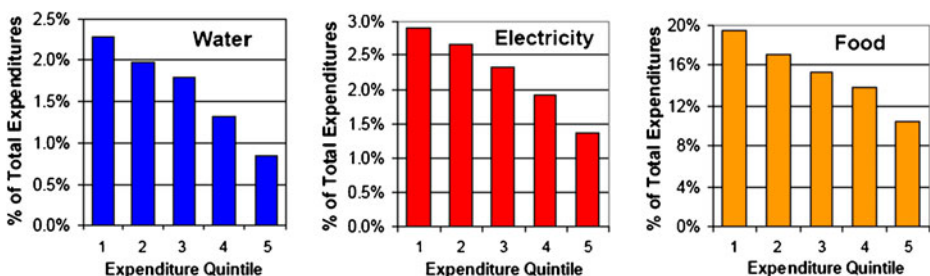


Fig. 4 Household expenditures on water, electricity, and food by income group (as percentage of total expenditures). Expenditure quintile is a proxy for income with quintile 1 representing the lowest-income households and quintile 5 representing the highest-income households. Adapted From: BLS 2002; Cited from: Cordova et al. (2006)

productivity in California, agricultural laborers could be increasingly affected by job losses. For example, the two highest-value agricultural products in the \$30 billion California agriculture sector are dairy products (milk and cream, valued at \$3.8 billion annually) and grapes (\$3.2 billion annually) (CASS 2002). Climate change is expected to decrease dairy production by as much as 7–10% under the IPCC B1 scenario and 11–22% under the A1fi scenario by the end of the century (Pittock et al. 2001). It is also expected to adversely impact the ripening of wine grapes, substantially reducing their market value (Hayhoe et al. 2004). These data suggest that communities in the Central Valley and other crop growing areas, where agriculture is most concentrated and low-income Latino communities are most common, would be the hardest hit by these climate change impacts.

3.3 Infrastructure, SES, and insurance access

As extreme weather events such as sea level rise, wildfires, and storms become more frequent and severe, California's infrastructure will be increasingly threatened and damaged. The literature suggests that the capacity of households and communities to prepare for and adapt to these risks is a function of their income, access to infrastructure insurance and other SES-related factors. For example, sea level rise, due to climate change is expected to put the California coast at increased risk of property damage (Pacific Institute 2009). An analysis by the Pacific Institute (2009) indicates that there is likely to be disproportionate impacts on low-income households in 13 of the 20 counties that lie along the California coast because of disparities in abilities to purchase emergency preparedness materials, buy insurance policies, and obtain needed building reinforcements.

Increased risk of property and financial damage from wildfires are also correlated with socioeconomic position. For example, Ojerio and colleagues (2010) found that in Arizona, low income households are less likely to have control over ignitability of their property, are more likely to be located in districts with less wildfire suppression capability, and have less access to federal government resources to mitigate wildfire risks than their more wealthy community counterparts.

Although the issue of insurance is a large question and a detailed analysis is beyond the scope of this review, the literature indicates that those in low socioeconomic positions are consistently underinsured (Blaikie et al. 1994; Fothergill and Peek 2004). Households that have home or renters' insurance can, relatively rapidly, recuperate and resume living much in the same way as prior to the disaster. In contrast, low-income households—who are often under-insured—may spend the rest of their lives struggling to recover from property damage related to an extreme weather event (Blaikie et al. 1994; Fothergill and Peek 2004; Thomalla et al. 2006). As the frequency and intensity of extreme weather events increase, the price of disaster insurance will also likely increase. This could make disaster insurance even more prohibitively expensive for low-income people thus decreasing the ability of this group to cope with infrastructure and property losses. Swiss Re (2006) indicates that insurance losses have been on an upward trend since 1985. During the years 1987–2004 property insurance losses due to natural disasters averaged USD 23 billion per year and in 2005, losses rose to USD 83 billion, of which USD 60 billion was due to hurricanes (Katrina, Rita, and Wilma) alone (Swiss Re 2006). Increases in the price of disaster insurance will add insult to injury to those who are already disproportionately affected by these events.

Lastly, disproportionate impacts of extreme weather events on low SES households have the potential to exacerbate homelessness, especially in urban areas. This would be largely due to the lack of access to insurance and emergency credit, lower amounts of savings, fewer personal resources, and the accumulated suffering from previous economic stresses of

low-income groups (Bolin and Bolton 1986; Fothergill and Peek 2004; Tierney 1988). It is also possible that increased government spending on infrastructure protection could hold deleterious consequences for low-income communities due to a diversion of funds away from educational and social programs, public transportation projects, population health initiatives, and other services (CRAG 2002).

4 Implications of climate change policies for low-SES groups

Because low SES groups are disproportionately affected by climate change, they could significantly benefit from sound climate change policies that are sensitive to demographic distribution of economic and health vulnerabilities. This section examines the equity dimensions embedded in the most prominent climate change mitigation strategies included in California's climate change law to be implemented by the California Air Resources Board (CARB) (AB 32) (CARB 2008b). We discuss two overarching themes: (1) The economic implications of different climate change policies on low-SES households; and (2) Positive and negative human health implications of different mitigation strategies for low-SES communities and households.

4.1 Economic costs and benefits of different climate change mitigation strategies

A major concern with regard to policies to reduce emissions is that they will be regressive; the burden of costs that arise from mitigation will fall disproportionately on lower-income households (Hassett et al. 2008; Walls and Hanson 1996). For example, the Congressional Budget Office projects that a United States-wide cap-and-trade scenario aimed to cut carbon dioxide emissions by 15% could cost 3.3% of the average income of households in the lowest income quintile as opposed to only 1.7% of the average income of households in the top income quintile (CBO 2007).

Substantial equity issues are raised by how pollution credits are allocated to facilities as well as—in the case of policies that include fees on emissions or the auctioning of emission credits—how revenues generated from these programs are redistributed to society and individual consumers. Under cap-and-auction or fee-based strategies, the sale of emission credits to polluters could generate sizable revenues that could help to offset the potentially regressive qualities of the emission cap program (Hepburn et al. 2006). These funds could be distributed to the public through tax cuts, tax-shifting, investments in clean energy, education, or through direct periodic dividends to consumers (CBO 2007), assuaging the regressive impacts that could accrue if the prices of necessities increase. Other investments generated from cap-and-auction or fee-based revenues could include investments in public transportation that could both reduce the emissions of greenhouse pollutants while simultaneously adding the co-benefit of reductions in emissions of health damaging co-pollutants due to lowering the numbers of mobile sources on the road. These types of programs should, however, be geographically targeted to reduce the pollution from the most air pollution-impacted areas—the majority of which are found in areas with low SES populations and people of color (Morello-Frosch and Jesdale 2006).

4.2 Health concerns of cap-and-trade policies

While cap-and-trade, under certain circumstances, is efficient at reducing GHGs and their associated co-pollutants on a regional basis, the strategy makes no guarantee

about the reduction of these emissions from any one source (O'Neill 2004). Hence, low-SES communities geographically situated in highly polluted areas are concerned about the persistence and potential exacerbation of co-pollutant hotspots at the local community level. The bundles of measures that CARB has already begun to implement to reduce GHG emissions could also contribute to notable reductions in co-pollutants such as SO_x, PM, ozone, and other health damaging contaminants and toxic air pollutant precursors (CARB 2008b). These measures could hold the most notable benefits for low-income groups and people of color who are disproportionately segregated in neighborhoods in close proximity to highways, ports, and other sections of transportation and goods-movement corridors where air quality has been noted as poor (CARB 2006b, 2008c; Morello-Frosch and Jesdale 2006; Morello-Frosch and Lopez 2006).

Cap-and-auction (assuming that fewer than 100% of permits are auctioned) reduces, and fees eliminate the need for emissions trading in comparison to free-allocation programs because industry is likely to buy only what it needs (Hepburn et al. 2006). Auctioning credits also decreases financial incentives to keep old polluting facilities open by eliminating the grandfathering in of old facilities. It also decreases the problem of over-allocation and excessive banking and trading of emission credits. An over-allocation of credits paired with excessive emission credit banking and trading could possibly lead firms to not reduce local GHG emissions. This could lead to the under-achievement of significant co-pollutant benefits in communities that are currently highly impacted by multiple pollution sources (Ellerman and Buchner 2007).

An example of such an emission reduction underachievement is the Regional Clean Air Incentives Market (RECLAIM), an emission trading system employed to lower NO_x emissions in Southern California. Data suggests that this program may have increased NO_x emissions in Wilmington, California, while region-wide emission levels declined (Lejano and Hirose 2005). Further, under Rule 1610, licensed car scrappers could purchase old, polluting vehicles and destroy them, and in return receive emission credits through the South Coast Air Quality Monitoring District (SCAQMD) that could be sold to oil refineries (Drury et al. 1999). The majority of the emission credits were purchased by four oil companies: Unocal, Chevron, Ultramar, and GATX to avoid the cost of installing pollution-reduction technologies that would capture volatile organic compound (VOC) gases forced out of oil tankers into the air when being loaded. These refineries are all located in close proximity to one another in the City of Wilmington and San Pedro except for the Chevron facility located in El Sugundo (Drury et al. 1999). In their analysis, Drury et al. (1999) indicate that this mobile-to-stationary trading program led to a situation where workers and local community residents were unnecessarily exposed to benzene, a known human carcinogen, and other VOCs that were contained in the emissions. These emissions could have been remediated by pollution reduction technologies that were already in widespread use in similar operations along the West Coast.

4.2.1 Co-benefits of AB 32 measures

As mentioned, GHG reduction measures under AB 32 are predicted to greatly reduce health damaging co-pollutant emissions (Bailey et al. 2008). For example, NO_x emissions, a precursor of ozone formation and a group of health damaging pollutants in their own right, are expected to be reduced by 86,000 t by 2020, more than three-quarters of which will be achieved through regulatory requirements for cleaner cars and trucks (Bailey et al. 2008).

Under AB 32, projected PM and NO_x reductions together are estimated to prevent approximately 400 premature deaths, 11,000 fewer cases of asthma-related and other lower

respiratory symptoms, 910 fewer cases of acute bronchitis, and 67,000 fewer work days lost in California (CARB 2008b). These health benefits are projected to be valued at \$1.4 billion to \$2.3 billion in 2020 alone (Bailey et al. 2008). A review by CARB (2008a) indicates that there is a 10% (CI: 3% to 20%) increase in the number of premature deaths per 10 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ exposure (CARB 2008a). CARB (2008a) also estimates that diesel PM contributes to 3,500 (CI: 1,000–6,400) premature deaths statewide on an annual basis. These projections could be an underestimate of the actual health and economic impacts of diesel PM because many emission reduction measures and public health benefits such as reduced cancer risks have not been accounted for in their calculation (Bailey et al. 2008). Some known carcinogens, that were not included in these analyses, such as benzene, formaldehyde, and toluene may be reduced by the implementation of GHG reduction measures because they are predominantly produced, directly and indirectly, by mobile sources and by the refinement and combustion of fossil fuels (EPA 2005). From an environmental equity perspective, the reduction of air toxics may be important as several studies indicate that communities of color and the poor bear a disproportionate burden of health risks associated with air toxics exposures (CARB 2008b, c; Morello-Frosch and Jesdale 2006; Morello-Frosch and Lopez 2006; Morello-Frosch et al. 2002).

4.2.2 Co-benefits of AB 32 early action and other mitigation measures

AB 32 also includes Early Action Measures (EAMs) (CARB 2008b) that regulate the inputs and functions of landfills, types of motor vehicle fuels, varieties of refrigerants in cars, types of port operations, and many other processes that are involved in emissions of climate altering pollutants. It is estimated that if all EAMs are adopted, 52,000 tons of NO_x and PM pollution would be removed from the air. This would avert approximately 250 additional premature deaths, thousands of cases of asthma and other lower respiratory symptoms, and could save an estimated \$1.1 to \$1.8 billion in health costs in 2020 alone (Bailey et al. 2008). Table 2 shows the CARB analysis of the health co-benefits of these actions. These measures could benefit low-SES groups that tend to be segregated in neighborhoods that may be host to significant industrial and transportation emission sources.

4.2.3 Fuel switching

The Low Carbon Fuel Standard (LCFS) was adopted as an EAM under AB 32 (CARB 2008b). The goal of the LCFS is to reduce lifecycle GHG emissions from transportation by at least 10% (CARB 2008b). One of the primary foci of this EAM is to transition from mobile source reliance on pure gasoline to partial or pure biofuels such as ethanol (CARB 2008b). However, some studies suggest that biofuel refineries could negatively impact the health of adjacent communities by exposing them to chemical as well as microbial byproducts of the distillation processes necessary for fuel production (Madsen 2006).

Widespread use of biofuels may also hold implications for outdoor air pollution concentrations. For instance, Jacobson (2007) predicts that E85 (85% ethanol, 15% gasoline) may increase ozone-related mortality, hospitalization, and asthma by 9% in Los Angeles and 4% nationwide if used to power vehicles. In fact, E85 may prove to have as much or more of a public health impact than the use of 100% gasoline (Jacobson 2007). This suggests that low-income and minority communities that live closest to highways and goods transport corridors could bear disproportionate health burdens if these fuels prove to be more toxic than gasoline.

Table 2 Estimates of statewide air quality-related health benefits in 2020 Cited from: (CARB 2008b)

Health endpoint	Health benefits of existing measures and 2007 SIP mean	Health benefits of recommendation in the proposed scoping plan mean
Avoided premature death	3,700	400
Avoided hospital admissions for respiratory causes	770	84
Avoided hospital admissions for cardiovascular causes	1,400	150
Avoided asthma and lower respiratory symptoms	110,000	11,000
Avoided acute bronchitis	8,700	910
Avoided work loss days	620,000	67,000
Avoided minor restricted activity days	3,600,000	380,000

Lastly, it should be noted that growing crops for use as fuel will likely raise prices of food crops (Tenenbaum 2008). This could prove to be regressive, damaging socioeconomic prospects of low-income consumers and low-income agricultural laborers who are most vulnerable to job loss and hunger (Tenenbaum 2008).

5 Future research needs and implications for policy development

Research on climate equity ranging from health effect estimates to economic impacts remains a nascent field with substantial knowledge deficits. Empirical and theoretical approaches in the fields of climate science, industrial ecology, epidemiology, environmental health, sociology, economics, geographic information system (GIS) spatial analysis, and statistics are key to understanding and predicting the socioeconomic, cultural, and health implications of complex ecological, meteorological, and air pollution phenomena. Moreover, these diverse analyses will also be integral to the determination of which policies and mitigation practices could most effectively narrow the climate gap.

5.1 Expanding climate gap research: climate change

Research that sheds light on the state of the climate gap, as it pertains to climate change directly is in high demand. Substantial arguments ensue over the scale at which measurements of localized impacts and co-pollutants should be evaluated in order to meet the intent and requirements of AB 32. In order to design effective policies and to monitor the efficacy of those policies in regards to localized impacts, future research should: (1) explore how to characterize, quantify, and maximize co-benefits of pollution reductions in existing or new “toxic hotspots”; (2) determine the geographic scale at which these evaluations should take place given the data available; and (3) identify the data necessary to improve future evaluations.

More research is needed to investigate the rates and impacts of climate change events that are projected to occur specifically in California. The identification of possible adaptation strategies that could be used to evade morbidity and mortality burdens from climate change impacts specifically in California is also important foci for future analyses.

Although much research has been done to characterize the geographic and demographic characteristics that increase the risk of heat-associated health impacts

of communities (Knowlton et al. 2009), fewer studies have shed light on how to best deliver targeted messages about extreme heat exposure. As the literature suggests, heat-related mortality and morbidity is borne disproportionately by groups of older residents, children, and those of low SES (Basu and Ostro 2008; English et al. 2007; Knowlton et al. 2009). Strategies to prevent heat-related illness should include messages targeted toward parents and caregivers of young children, the elderly and, most importantly, to socially isolated populations.

Differential exposures to the health-damaging impacts of climate change, such as excessive heat, extreme weather events, and increases in air pollution could be examined from a geo-equity perspective by using GIS maps overlaid with vulnerability models and current socioeconomic, racial/ethnicity, and cultural group distributions in California. Interaction between these data layers should be taken into account when developing climate change policies so as to reduce the likelihood that future policies would create or amplify disproportionate burdens on vulnerable populations.

5.2 Expanding climate gap research: climate mitigation policies

Important foci for climate change mitigation strategy development are: (1) To conduct multi-level policy scenario comparisons to evaluate combinations of regulations and mechanisms that produce the most efficient, effective, and equitable outcomes with the most health and economic co-benefits on the local level (Shonkoff et al. 2009b); (2) To investigate the ways that impacted communities could play a role in climate change mitigation policy and regulatory deliberations; (3) To develop tools to measure the socioeconomic, environmental, and population health benefits and impacts of an expanded green economy; (4) To identify which climate altering pollutant source sectors will, most cost-effectively, be able to reduce pollution with the least amount of socioeconomic disruption and health impact; (5) To develop robust methods to characterize and quantify the co-benefits of health damaging pollution reductions in new or pre-existing air pollution hotspots.

Under cap-and-trade policies, it is essential to develop analytical tools to track where carbon credits are traded in order to assess the subsequent burden of co-pollutant emissions that may increase or decrease on local and regional levels. Building on these analyses, climate gap research should characterize patterns of human population exposure that results from local sources of pollution in a variety of settings, especially in population dense urban areas.

Health and economic risks of fuel switching and fuel innovations (i.e., ethanol) as specified in the LCFS should be characterized and presented in policy-relevant formats. For example, epidemiologic studies should better assess the effects of exposure to new fuels and their externalities during combustion (Jacobson 2007) as well as during production and distillation—for which there are no studies available. More research must also focus on the dangers of food shortages and food price increases associated with the production of ethanol and other biofuels (Tenenbaum 2008).

5.3 Cumulative impacts screening to guide decision-making

AB 32 requires that, prior to implementation, there be consideration and prevention of cumulative or additional impacts on already disproportionately impacted communities (CARB 2006a). However, no established method for identifying these communities currently exists. Researchers continue to develop environmental justice or cumulative impact screening methods that employ GIS-based mapping to consider risks from criteria

and toxic air pollutants, proximity to sources of pollution, and socioeconomic factors (Sadd et al. 2011). Such tools could be useful to evaluate community-level cumulative impacts from climate change itself as well as the implications of mitigation policies. Research to expand upon this work could develop a screening method that provides consistent monitoring and evaluation across air districts and cities to insure that all communities are assessed using similar metrics (Pastor et al. 2010a; Su et al. 2009). Such screening tools could be valuable for the evaluation of permitting, land-use change, and growth pattern decisions that are made at multiple scales; such data can also assist decision-makers to more accurately assess the local implications of regional planning strategies that address climate change.

6 Conclusions

Climate change is not only an environmental issue; it also has human rights, public health, and social equity dimensions. This review indicates that climate change is likely to disproportionately impact the health and economic stability of Californian communities that are least likely to cope with, resist, and recover from the impacts of climate change. This review also finds that low-income and minority communities could be disparately affected by the economic shocks associated with climate change both in price increases for basic necessities (i.e., water, energy, and food) and by threats of job loss due to economic and climatic shifts that affect important industries in California such as agriculture. Without proactive climate change mitigation policies that are sensitive to their economically regressive potential and their distribution of benefits, these strategies could potentially reinforce and amplify current as well as future socioeconomic and racial disparities in California. The consistency of racial and SES disparities as they relate to climate change has made these issues of mounting concern to regulators, policy-makers, researchers, and environmental justice advocates.

As California moves closer to a full implementation of AB 32, it will become a national and international leader in the development of aggressive strategies to reduce greenhouse gas emissions. Ensuring that climate equity is part of the equation will be critical to this implementation process. Research on climate equity—ranging from health effects to economic impacts—remains in its infancy. Interdisciplinary approaches are key to understanding the drivers of the climate gap and to specify which policies and mitigation practices would best address equity concerns. To proactively attenuate disproportionate environmental health burdens borne by the poor and people of color, agency officials and policy makers should ensure that vulnerable communities play a significant role in the development of future solutions to climate change. Non-technical knowledge, such as local expertise, community experience, and other contextual information is important to supplement technical knowledge as policy formation is underway (Minkler and Wallerstein 2003). In other words, researchers who hope to generate climate change-impact information that is sensitive to community-specific concerns should employ community-engaged approaches in their study designs (Minkler and Wallerstein 2003; Corburn 2005, 2009).

Although this paper is a comprehensive review of the environmental health and equity implications of climate change and climate change mitigation policies in California, limitations in the data exist. More extensive research on the mechanisms that underlie associations between inequities and climate change as well as mitigation policies should be undertaken as other competing risk factors that could confound relationships between race, SES, and climate change impacts may exist.

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