Climate Change Mitigation: Climate, Health, and Equity Implications of the Visible and the Hidden

By,

Seth Berrin Shonkoff

A Dissertation Submitted in Partial Satisfaction of the
Requirements for the degree of
Doctor of Philosophy
in
Environmental Science, Policy, and Management
in the
Graduate Division
of the
University of California, Berkeley

Committee In Charge:

Rachel Morello-Frosch, Chair
Kirk R. Smith
Alastair Iles

Spring 2012

Climate Change Mitigation: Climate, Health, and Equity Implications of the Visible and the Hidden

by

Seth Berrin Shonkoff

Abstract

Climate Change Mitigation: Climate, Health, and Equity Implications of the Visible and the Hidden

by

Seth Berrin Shonkoff

Doctor of Philosophy in Environmental Science, Policy, and Management

University of California, Berkeley

Professor Rachel Morello-Frosch, Chair

Anthropogenic climate change and the mitigation strategies aimed to attenuate it are both issues of great importance for human rights, public health, and socioeconomic equity. To understand these concerns and to better inform policy and strategic action it is critical to explore: 1) the disparities in the costs and benefits of climate shifts; 2) the abilities of different populations to adapt to these shifts; and 3) the social and health equity dimensions of the climate change mitigation strategies imposed. The health and equity implications associated with anthropogenic climate change mitigation are multi-scaled and range from the household level (i.e., in the case of household-level energy efficiency and fuel switching projects); to the regional and community levels (i.e., in the case of communities that benefit and are impacted by California's Global Warming Solutions Act, or AB 32); to the national and international levels where resource transfers from more developed nations to less developed nations are key to reaching climate mitigation goals.

Critical to the generation of sound and equitable climate mitigation policy is the manner in which climate change mitigation efforts are measured, monitored and evaluated. In other words, methods and metrics determine what is seen and what is rendered invisible. These measurements act as a partial determinant of the observed outcomes and subsequently, the policy decisions that are guided and bolstered by their results. It is therefore crucial to unpack the methodologies and metrics used to measure and evaluate climate change mitigation strategies in order to understand and predict impacts and benefits, and to assess the equity dimensions of different mitigation measures.

Chapter 2 focuses on the environmental health and equity dimensions of both anthropogenic climate change and the California Global Warming Solutions act of 2006 (AB 32) in California. I argue here that anthropogenic 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. It is clear that that anthropogenic climate change will affect industrial and agricultural sectors, as well as transportation, health, and energy infrastructure and these shifts hold 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.

Chapter 3 explores the rapidly expanding scientific literature that describes black carbon (BC) emissions and their climatic and human health effects. In addition to scientific uncertainties due to differences in atmospheric models and how to sort out regional effects, inconsistencies in definitions, metric and measurement methods, data collection and characterization, system boundaries, and time horizons, have led to confusion about the importance of BC as a climate-forcing and health-damaging agent relative to other climate-altering and health-damaging pollutants.

The focus on metrics and measurement issues in Chapter 3 leads into Chapter 4 where I shift my gaze to the carbon-offset market and look at accountability components of the monitoring and evaluation (M&E) of cookstove carbon offset projects. While many studies focus on accountability mechanisms between social actors in the carbon-offset arena, there are no studies that have looked at M&E requirements as a source of accountability themselves. I contend that the Gold Standard Foundation (GSF), the primary certifying body of carbon credits on the voluntary market could develop metrics and M&E requirements to discipline evaluators and project developers into more responsible and accountable behavior. This in turn may produce M&E results with a higher standard of veracity to be reported to the certifying institutions and other stakeholders. I identify the existing accountability flaws in the GSF monitoring methodology and make recommendations to improve the M&E requirements. These improvements could further strengthen the authoritativeness of the GSF, make the accountability system more influential, and hopefully lead to more trusted carbon credits, more effective emission reductions, and greater sustainable development gains.

To my parents for their unconditional love and unfaltering belief that I can do whatever I put my heart and my mind to. And to my brother, Sam who is my best friend.

Acknowledgments

This dissertation and my doctoral training in general would not have been possible without the generous support and input from many people throughout my life. If it were not for my dissertation chair, Rachel Morello-Frosch and the formative opportunities, honest guidance, and inspiring words that she offered, I may not have completed this degree. Kirk R. Smith was nothing short of an outstanding mentor who provided me with integral training on how to work at the science-policy interface, especially in the fields of health and climate. Alastair Iles provided me with integral training and guidance in how to think through the theoretical underpinnings of my research. Our qualifying exam meetings in his office over tea, and our dissertation meetings over good red wine were wonderful and expanding. David Winickoff inspired me and opened my mind to the world of STS. His graduate seminar was, hands down, the best course I took at UC Berkeley; my understanding of the world will never be the same. Professor Jason Corburn taught me to always ground theory in empirical cases and pushed me to critically examine tacit categories of health, environment, and social justice. Nap Hosang encouraged me to focus and hone my skills and taught me how to recognize and act upon a good opportunity. David Pennise and Dana Charron at the Berkeley Air Monitoring Group provided generous opportunities for me to go into the field. My little home on Richmond Avenue in Oakland (*The Mahal*) is where this all began and I am especially grateful for the emotional and intellectual support that I received from my good friend Oren Kroll-Zeldin throughout that time. I could never have created this without my truly amazing and devoted community of family and friends who make it all worth it. In particular my mom, my dad and my brother have been with me every step of the way and have never ceased to amaze me with their capacity to support and believe in me. Last but not least, Ariella has been a patient, dedicated, and playful partner who I am lucky to come home to.

Chapter 1: Dissertation Introduction

Anthropogenic climate change and the mitigation strategies aimed to attenuate it are both issues of great importance for human rights, public health, and socioeconomic equity. Vulnerability to climatic shifts themselves are determined by the ability of a community or household to anticipate, cope with, resist, and recover from the impacts of extreme weather events and geophysical shifts such as sea level rise (Pacific Institute 2009), hurricanes (Greenough and Kirsch 2005), floods (Greenough, McGeehin et al. 2001), heat waves (Knowlton, Rotkin-Ellman et al. 2008), air pollution (O'Neill, Kinney et al. 2008), and infectious diseases (Gage, Burkot et al. 2008). To understand the concerns of anthropogenic climate change for human systems, it is critical to explore disparities in the costs and benefits of climate change, the abilities of different populations to adapt, and the equity dimensions of the mitigation strategies imposed to attenuate it in order to better inform policy and strategic action.

My dissertation focuses on climate change mitigation, or the strategies implemented to reduce emissions of anthropogenically generated climate active pollutants (CAPs) to the atmosphere. Climate change mitigation strategies primarily fall in two categories: 1) Centralized governmental policies (i.e., the Kyoto Protocol, California's AB 32); and 2) Decentralized strategies that are often market-based and can be bolstered by regulatory pressure (i.e., the Clean Development Mechanism of the Kyoto Protocol).

The health and equity implications associated with climate change mitigation are multi-scaled and range from the household level (in the case of household-level energy efficiency and fuel switching projects), to the regional and community levels (in the case of communities that benefit and are impacted by California's AB 32), to the national and international levels where resource transfers from more developed nations to less developed nations are key to reaching climate mitigation goals.

Critical to all of this is the manner in which climate change mitigation efforts are measured, monitored and evaluated. Methods and metrics determine what is seen and what is invisible, thus acting as a partial determinant of the observed outcomes and subsequently, the policy decisions that are guided and bolstered by their results. It is therefore crucial to unpack the methodologies and metrics used to measure and evaluate climate change mitigation strategies in order to understand and predict impacts and benefits, and to assess the equity dimensions of different mitigation measures.

My dissertation covers a breadth of topics and scales, while remaining under the umbrella of health, economic, and policy implications of climate change mitigation strategies. The work is deeply interdisciplinary and aims to identify innovative intersections and processes that are often thought of as disparate. As opposed to an exclusive focus on depth within one subject, the strength of this work is to provide deep knowledge across multiple disciplines, boundaries, and geographies.

My dissertation has three primary aims:

1. To elucidate how the mitigation of anthropogenic climate change is not only important to environmental issues, but is also critical to population health and socioeconomic equity outcomes.
2. To understand the connections between atmospheric, public health, and policy oriented knowledge of black carbon and how different understandings and confusion lead to different conclusions about mitigation effects. Central to this are the choice of metrics, the assumptions used to construct emission inventories, and what is made visible and invisible in the climate change mitigation and environmental health arena.
3. To argue that the ways in which metrics – which underpin the ability of project developers and carbon offset certification schemes to determine whether climate change mitigation strategies meet their stated climate, health, and sustainable development goals or not – are central to market-based carbon markets.

Chapter 2 is focused on the environmental health and equity implications of anthropogenic climate change and the California Global Warming Solutions act of 2006 (AB 32) in California. I argue here that anthropogenic 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. Further, vulnerability to climatic shifts is determined by a community's ability to anticipate, cope with, resist, and recover from the impact of major weather events. It is clear that that anthropogenic climate change will affect industrial and agricultural sectors, as well as transportation, health, and energy infrastructure and these shifts hold 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.

Chapter 3 explains the rapidly expanding scientific literature that describes black carbon (BC) emissions and their climatic and human health effects. In addition to scientific uncertainties due to differences in atmospheric models and how to sort out regional effects, inconsistencies in definitions, metric and measurement methods, data collection and characterization, system boundaries, and time horizons, have led to confusion about the importance of BC as a climate-forcing agent relative to other climate-altering and/or health-damaging pollutants. I systematically investigate four categories of BC confusions in order to show the tensions between the atmospheric science, health science, and climate policy arenas. The four categories are (1) definitions and measurement methods for BC; (2) Inconsistent Methods for Estimating BC Emission Inventories and Implications for Radiative Forcing Estimates; (3) associated organic carbon aerosols; and (4) differentiation between toxicological and epidemiological risks. Fueled by these inconsistencies, total global BC emissions estimates can vary by more than a factor of two, with much larger variations by sector.

The focus on metrics and measurement methods in Chapter 3 leads into Chapter 4 where I shift my gaze to the carbon-offset market and look at accountability components of the monitoring and evaluation (M&E) of carbon offset projects. Many studies focus on the accountability mechanisms between social actors in the carbon-offset arena, yet there are no studies that have looked at the M&E requirements as a source of accountability themselves. Metrics and indicators are important tools to show progress, and performance in activities, such as environmental restoration, public health interventions, social services, etc. (Metzenbaum 2001). An indicator is defined as something that provides useful information about a physical, social, or economic system, usually in numeric terms (Farrell and Hart 1998). Ideally, metrics help to provide evidence for the efficacy and effectiveness of the interventions and projects that individuals, workplaces, governmental agencies, etc. undertake in order to know if they are functioning and efficient given their purported goals. For example, if we are to overhaul our carbon-based economy and move towards more renewable or diversified energy portfolios, it is imperative to measure the effects of these decisions on a variety of systems and populations.

I contend that the Gold Standard Foundation (GSF), the primary certifying body of carbon credits on the voluntary market could develop metrics and monitoring requirements to discipline evaluators and project developers into more responsible and accountable behavior. This in turn could produce M&E results with a higher standard of veracity to be reported to the certifying institutions and other stakeholders. I identify the existing accountability flaws in the GSF monitoring methodology and make recommendations to improve the M&E requirements. These improvements will further strengthen the authoritativeness of the GSF, make the accountability system more influential, and hopefully lead to more trusted carbon credits, more effective emission reductions, and greater sustainable development gains.

I end my dissertation with a discussion of future research needs in the area of climate and health along with the need for more specialization in the ability to think and act across disciplines in order to engage with transdisciplinary problem solving. Indeed specialists that function deeply within one discipline will always be crucial to understanding environmental and human health problems. However, far too often, specialists of this order fail to make connections between intellectually disparate, yet intrinsically related topics in other areas. A primary thrust of this dissertation is to not only generate knowledge on climate change mitigation, its co-benefits, and its co-disbenefits, but also to demonstrate the importance of engaging across and between silos of knowledge and action and science and policy in order to more completely understand how to move towards solutions that benefit the environment, human health, social systems, and theoretical endeavors.

Chapter 2: The Climate Gap: Environmental Health and Equity Implications of Climate Change and Mitigation Policies[1]

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 literature 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 and future research priorities are identified.

1. Introduction

Anthropogenic climate change presents a complex set of environmental stressors in the form of extreme weather events and geophysical shifts such as sea level rise (Pacific Institute 2009), hurricanes (Greenough and Kirsch 2005), floods (Greenough, McGeehin et al. 2001), heat waves (Knowlton, Rotkin-Ellman et al. 2008), air pollution (O'Neill, Kinney et al. 2008), and infectious diseases (Gage, Burkot et al. 2008). Vulnerability to these shifts are determined by the interactions between intrinsic and extrinsic risk factors and partially determine the relative abilities of individuals, households and communities to anticipate, cope with, resist, and recover from the direct and indirect impacts.

Vulnerability to environmental stressors can be divided into two general categories: intrinsic vulnerability and extrinsic vulnerability. While intrinsic vulnerability is sourced from physiological risk factors such as age, disabilities, poor medical status, etc., extrinsic vulnerability concerns social and environmental risk factors such as poor housing quality, lack of access to transportation, living in a flood plain, and air and water pollution) (Shonkoff, Morello-Frosch et al. 2009). A broad body of literature supports the understanding that minorities and groups of low socioeconomic status are disparately negatively impacted by these two categories both separately and synergistically compared with their wealthier counterpart (Su, Jerrett et al. 2012).

The Climate Gap, refers to the disproportionate and inequitable impacts that both anthropogenic climate change and climate change mitigation can hold for people of color and the poor compared to less socioeconomically vulnerable groups (Morello-Frosch, Pastor et al. 2009;

[1] Note: this chapter contains language from my manuscript previously published in the Journal, *Climatic Change*.

Shonkoff, Morello-Frosch et al. 2009; Pastor, Morello-Frosch et al. 2010). Thus, in order to understand and characterize the climate gap, it is critical to explore the following issues: 1) the disparities in the social, economic, and health costs and benefits of anthropogenic climate change; 2) the abilities of different demographics to adapt to it; and 3) the differential exposure, risk, and health dimensions of the mitigation strategies imposed to attenuate it in order to better inform policy and regulatory action.

Health and economic equity analyses that look at responses to anthropogenic climate change and the mitigation strategies aimed to attenuate it have tended to focus on the international scale, citing developing countries as the most vulnerable and disproportionately affected (Patz, Campbell-Lendrum et al. 2008; Liverman 2010). However, fewer studies focus on the intra-national context within industrialized countries and the potentially disparate impacts of anthropogenic climate change and mitigation strategies on lower socioeconomic groups and communities of color. As industrialized nations decide on climate change mitigation options, the health and economic equity dimensions of climate change and the policies aimed to address them are important for decision makers to consider. Indeed, without proactively addressing present as well as future equity concerns, climate change and climate change mitigation policies could reinforce and amplify existing disparities, leaving currently low-income, minority, and politically marginalized groups with fewer economic opportunities and similar or exacerbated environmental health burdens within the industrialized country context (Shonkoff et al. 2009).

In this paper I explore the climate gap through a review of the literature on the current and projected disparate impacts of climatic shifts and climate change mitigation policies on groups of lower socioeconomic status (SES)[2] in California. I begin with a review of the current and projected disparities in health and economic impacts projected in response to climate change itself and then 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, I 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. I 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

[2] 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.

exacerbation and changing patterns of outdoor air pollution. I 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 their frequency and intensity in the next hundred years (IPCC 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 (4.7°C) increase in mean daily apparent 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, Feng et al. 2008). In a case-crossover analysis – in which each case acts as its own control – elevated risks of cardiovascular mortality were found for African Americans to be 4.9% (95% CI: 2.0, 7.9) higher than for the general California population (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, Rotkin-Ellman et al. 2008). 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, Rotkin-Ellman et al. 2008).

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 that are healthy. In fact, a study on the 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, Mays 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, Link et al. 2004), they tend to be most adversely affected by extreme heat events. Epidemiologic studies of heat-associated mortality show an increased risk among those older than ~50 years of age (Kovats and Hajat 2008), lending evidence to the assertion that older age is an intrinsic risk factor and this group should thus be seen as vulnerable to heat-associated illness.

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 (Williams and Collins 2001; Schulz, Williams et al. 2002), which is more likely to experience "heat-island" effects (Harlan, Brazel 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, Morello-Frosch et al. 2009) 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 (Figure 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 (Figure 2). These data suggest a disproportionate exposure to heat island risk factors on communities of color and low income.

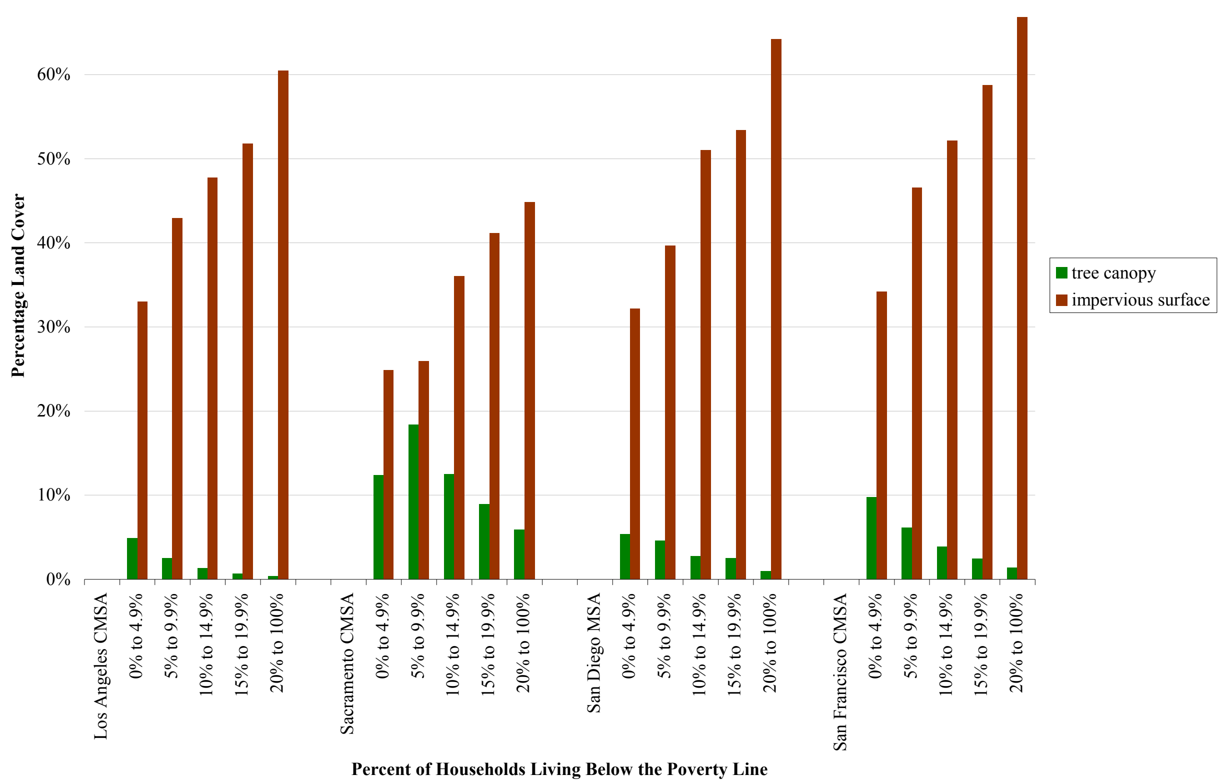


Figure 1. Land Cover Characteristics Across Comparable Neighborhood Poverty Groups

Cited From: (Shonkoff et al. 2009)

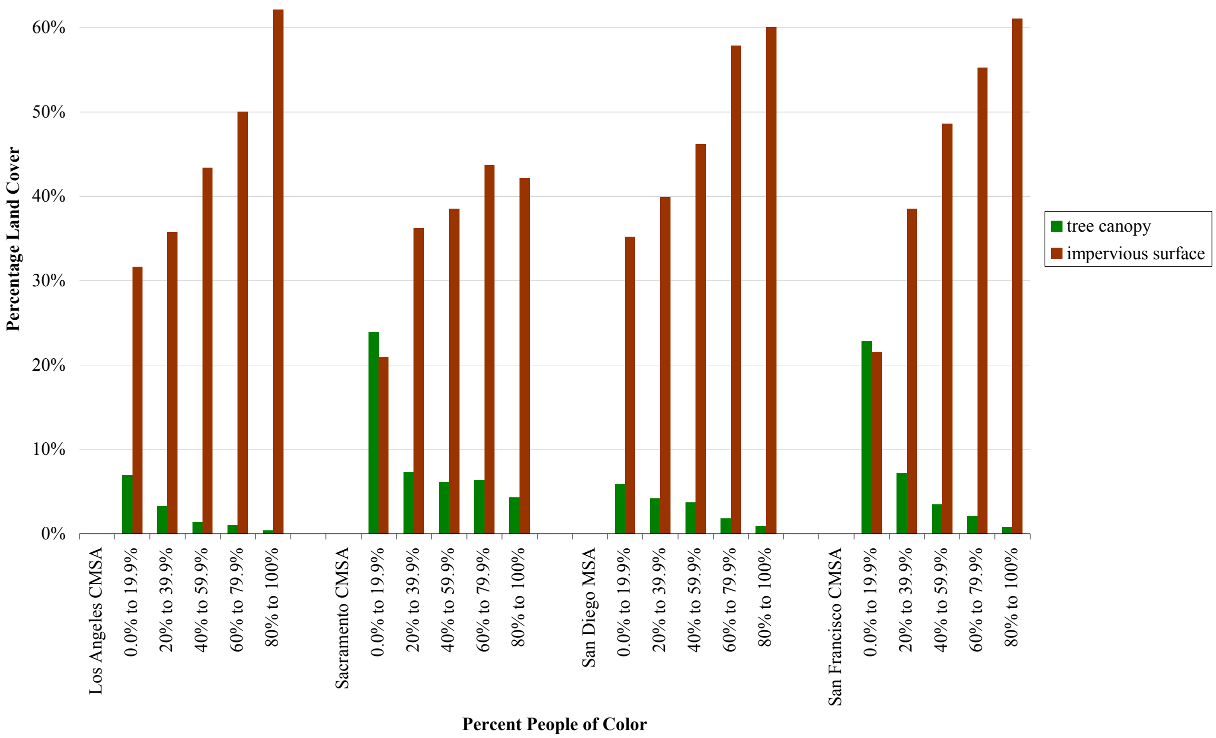


Figure 2. Land Cover Characteristics Across Comparable Neighborhood Racial/Ethnic Minority Groups

Cited From: (Shonkoff et al. 2009)

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 (Semenza, Rubin et al. 1996; Knowlton, Rotkin-Ellman et al. 2008; Kovats and Hajat 2008). In the Los Angeles-Long Beach Metropolitan Area, for example, a higher proportion of African-Americans do not have access to 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 poor air quality days when communities are instructed to stay indoors and avoid outdoor pollution exposures.

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).

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.[3] In extreme heat events, households without air conditioning may need to relocate to cooling centers, 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, compared to White households (7.9%), elevated proportions of African-American (20%), Latino (17.1%), and Asian (9.8%) households do not have access to a car (USCB 2004), thus restricting their capacity to move to cooler areas and government-sponsored cooling stations during extreme heat events.

In a study, using heat-wave data from Chicago, Detroit, Minneapolis, and Pittsburgh, O'Neil, Zanobetti 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 (AC) technologies (O'Neill, Zanobetti et al. 2005). These results are bolstered by other studies that found associations between being African American and lack of AC as an indicator for vulnerability to heat-related poor health outcomes (Greenberg, Bromberg et al. 1983; Rogot, Sorlie et al. 1992; Semenza, Rubin et al. 1996; Whitman, Good et al. 1997; Curriero, Heiner et al. 2002; O'Neill, Zanobetti et al. 2003). Although these data are likely generalizable to the California context, future research is needed to assess the impacts of heat events on African American populations in California.

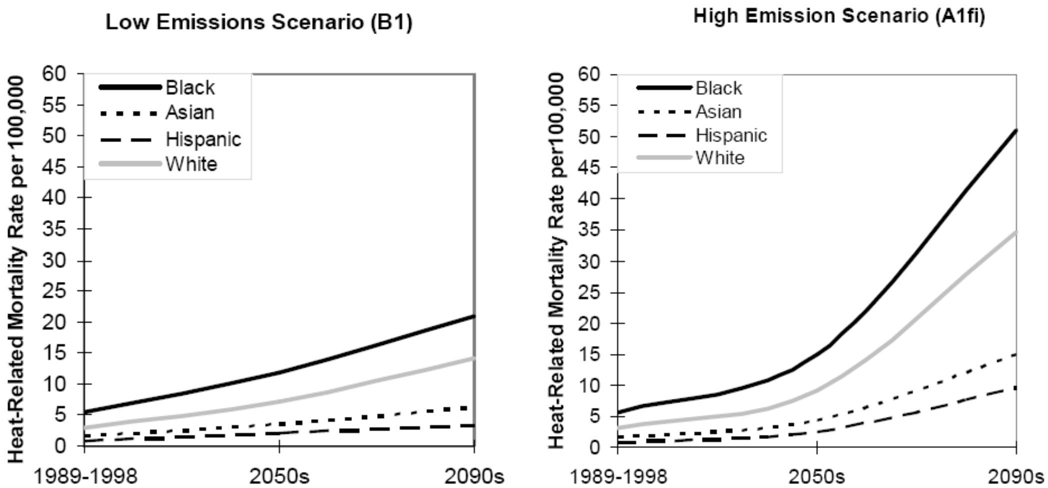
Material and socioeconomic deprivation, especially in the inner city, is highly correlated with heat wave and heat-stroke mortality risk in the United States, including California (Klinenberg 2002; English, Fitzsimmons et al. 2007; Kovats and Hajat 2008). For example, the heat wave in

[3] 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).

Phoenix, Arizona, in 2006 was responsible for thirteen heat-stroke-related deaths, eleven of which were homeless people who tend to lack access to these types of protective material and social resources (Kovats and Hajat 2008).

Evidence strongly suggests that African American groups bear a burden of heat wave-associated mortality that is elevated above burdens of the general population largely due to extrinsic risk factors. For instance, African American Los Angeles residents have a projected heat-wave-mortality rate that is nearly twice that of the Los Angeles average (Figure 3) (Cordova, Gelobter et al. 2006). 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.

Figure 3. Land Cover Characteristics Across Comparable Neighborhood Racial/Ethnic Minority Groups [a]



[a] 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, Gelobter et al. 2006; Shonkoff, Morello-Frosch et al. 2009)

Because SES is fundamentally associated with occupation, it is important to note that California's agricultural and construction workers have experienced severe heat-related morbidity and mortality with data pointing towards possible increasing trends in recent years (English, Fitzsimmons et al. 2007; MMWR 2008). The socioeconomic status of predominantly Mexican and Central American immigrants who come to 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 ozone (O_3), nitrogen oxides (NOx), and chemically undifferentiated particulate matter (PM). Hence, I focus this review on these three pollutants. It is nonetheless important to mention that there exist other greenhouse gas co-pollutants such as sulfur dioxide (SO_x), black carbon (BC) (Smith, Jerrett et al. 2009) and carbon monoxide (Kaur and Nieuwenhuijsen 2009) that have been implicated as factors in population health disease burdens as well as 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 2008). 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, O_3, 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 include criteria air pollutants but also greenhouse pollutants (i.e., CO_2, NO_x, BC, O_3) that contribute to climate forcing on local, regional and global scales (Smith, Jerrett et al. 2009). In turn, elevated temperatures interact with NO_x and sunlight and lead to increases in ambient O_3 concentrations in urban and suburban areas. This contributes to both respiratory health effects (Jerrett, Burnett et al. 2009) as well as elevated levels of climate forcing (Meleux, Solmon et al. 2007; Stathopoulou, Mihalakakou et al. 2008; Smith, Jerrett 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, Gelobter 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 CO_2-enhanced stability, humidity, and biogenic particle mass – annually (Jacobson 2008).

3. Disproportionate Economic Impacts of Climate Change on Groups of Low Socioeconomic status

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. I focus this equity analysis on three issues: 1) Increases in prices of basic necessities; 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 equal to approximately 0.14% of the United State's 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 (BLS 2002) and price increases due to these climatic factors 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. 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 (Figure 4) (BLS 2002).

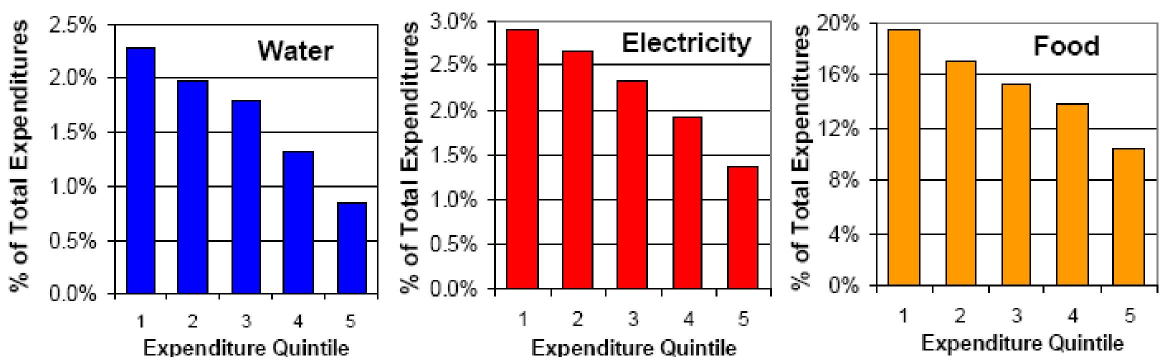


Figure 4. Household Expenditures on Water, Electricity, and Food by Income Group (as Percentage of Total Expenditures) [a]

[a] 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, Gelobter et al. 2006)

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, Deschênes et al. 2009; Howitt, Medellín-Azuara 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, Santos-Martin et al. 2009), and the increase in agricultural inputs, such as pesticides, to adapt to changes in ecological composition.

Latinos comprise 77% of the 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 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, Wratt et al. 2001). It is also expected to adversely impact the ripening of wine grapes, substantially reducing their market value (Hayhoe, Cayan 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 mitigate 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.

Increases in risks of property and financial damage from wildfires are also correlated with socioeconomic position. A recent analysis by 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 (Ojerio, Moseley et al. 2010).

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, Cannon 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, Cannon et al. 1994; Fothergill and Peek 2004; Thomalla, Downing T 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 that 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; Tierney 1988; Fothergill and Peek 2004). 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 groups of low socioeconomic status

Because low SES groups are disproportionately affected by climate change, they could significantly benefit from sound climate change policies that are sensitive to the demographic distribution of economic vulnerabilities and health damaging co-pollutants that may have localized impacts. This section examines the equity dimensions embedded in the most prominent climate change mitigation strategies included in California's climate change law (AB 32) (CARB 2008d). I 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 (Walls and Hanson 1996; Hassett, Mathur et al. 2008). 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 have the potential to generate sizable revenues that could help to offset the potential regressive qualities of the emission cap program (Hepburn, Grubb 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 Costs and Benefits of Different Climate Change Reduction Strategies

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 of those greenhouse gases such as SO_x, PM, ozone, and other health damaging contaminants and toxic air pollutant precursors (CARB 2008d). 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 (Morello-Frosch and Jesdale 2006; Morello-Frosch and Lopez 2006; CARB 2006c; CARB 2008c).

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, Grubb 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 by the South Coast Air Quality Monitoring District (SCAQMD) that could be sold to oil refineries (Drury, Belliveau 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, Belliveau 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.

4.2.2 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, Knowlton 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 tons by 2020, more than three-quarters of which will be achieved through regulatory requirements for cleaner cars and trucks (Bailey, Knowlton 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 2008d). These health benefits are projected to be valued at \$1.4 billion to \$2.3 billion in 2020 alone (Bailey, Knowlton 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 $\mu g/m^3$ increase in $PM_{2.5}$ exposure (CARB 2008a). The California Air Resource Board (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, Knowlton 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 (Morello-Frosch, Pastor et al. 2002; Morello-Frosch and Jesdale 2006; Morello-Frosch and Lopez 2006; CARB 2008b; CARB 2008c).

4.2.3 Co-Benefits of AB 32 Early Action and Other Mitigation Measures

AB 32 also includes Early Action Measures (EAMs) (HSC §38560.5, Health and Safety Code Section 38560–38565) 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 GHPs. It is estimated that if all EAMs are adopted, 52,000 tons of NO_x and PM pollution would be removed from the air, which would decrease human exposure to these air pollutants (Bailey, Knowlton et al. 2008). CARB estimates that the EAMs could remove 16 tons of NO_x emissions and 15 tons of $PM_{2.5}$ emissions per day. Table 2 shows the CARB analysis of the health co-benefits of these actions. Further, the EAMs of AB 32 are projected to prevent an additional $1.1 billion to $1.8 billion in health costs in the year 2020 alone (Bailey, Knowlton et al. 2008). 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.

Table 2. Estimates of Statewide Air Quality-Related Health Benefits in 2020

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 Hosptial 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

Cited from: (CARB 2008d)

<u>Fuel Switching</u>

The Low Carbon Fuel Standard (LCFS) was adopted as an EAM under AB 32 (CARB 2008d). The goal of the LCFS is to reduce lifecycle GHG emissions from transportation by at least 10% (CARB 2008d). 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 2008d). 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.

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 (English, Fitzsimmons et al. 2007; Basu and Ostro 2008; Knowlton, Rotkin-Ellman et al. 2008). 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, Morello-Frosch et al. 2009); (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 GHP 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. 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 (Su, Morello-Frosch et al. 2009; Pastor, Morello-Frosch et al. 2010). 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 disproportionally 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; Corburn 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.

Transition to Chapter 3: Metrics, Black Carbon, Climate, and Health

It is now clear that climate change mitigation policies, strategies, and technologies hold a variety of implications for environmental health and equity. To be effective and politically sustainable, any climate change mitigation intervention should balance its CAP emission reductions with its associated co-benefits and co-disbenefits. As demonstrated by the case of AB 32, economic sector-wide policies to reduce emissions of longer-lived GHGs, such as CO_2 and CH_4 could generate sizable co-benefits, especially for populations disproportionately exposed to elevated local air pollution, poverty, and heat events exacerbated by the urban heat island effect.

Another climate change mitigation option that currently receives much interest from the media, the atmospheric science community, and policymakers, but has not, thus far, been built into any formalized climate change mitigation policy or treaty is a focus on the shorter-lived climate active pollutant, black carbon (BC). BC has piqued the interest of the climate change mitigation community because of its elevated global warming potential above CO_2 under short time horizons (Bond and Sun 2005), its controllability in a variety of sectors through the use of proven and affordable technologies and regulatory frameworks (Bahadur, Feng et al. 2011), and its associated co-benefits (health and economic) coupled with BC emission reductions (Smith, Jerrett et al. 2009).

Despite the overwhelming interest in BC abatement as a viable climate change mitigation option, uncertainties, confusions, and information gaps have proliferated in the literatures between the atmospheric science, public health, and policy arenas. In the following chapter I systematically explore these confusions and make recommendations on how to ameliorate these inconsistencies.

Chapter 3: Black Carbon Inconsistencies: Implications for Health and Climate Policy Development[4]

ABSTRACT

The scientific literature describing black carbon (BC) emissions, and their climatic and human health effects, is growing rapidly. Remaining scientific uncertainties center around differences in atmospheric models and in how to sort out regional effects of radiative forcing from BC. In addition, the policy implications of BC as a climate-forcing agent, relative to other climate-altering pollutants (CAPs) and/or health-damaging pollutants, remains unclear due to inconsistencies in definitions, measurement methods, data collection and system boundaries, and the time horizons used to describe BC emissions. Here I investigate four categories of confusions: (1) definitions and measurement methods for BC; (2) Inconsistent Methods for Estimating BC Emission Inventories and Implications for Radiative Forcing Estimates; (3) associated organic carbon aerosols; and (4) differentiation between toxicological and epidemiological risks. Fueled by these inconsistencies, total global BC emissions estimates can vary by more than a factor of two, with much larger variations by sector. I end with a discussion of improvements that could make BC emission inventories more consistent with those for other CAPs, thus promoting more accurate treatment of BC in scientific, policy, and popular discussions. Because of persistent use of incommensurate metrics of effect, I find no immediate resolution at the global level to bridge the different perspectives on health and climate implications.

1. Introduction

The scientific literature describing black carbon (BC) emissions and their climatic and human health effects is growing rapidly. In addition to scientific uncertainties due to differences in atmospheric models and how to sort out regional effects of radiative forcing, inconsistencies in definitions, measurement methods, data collection, system boundaries, and time horizons, have led to confusion about the importance of BC as a climate-forcing agent relative to other climate-altering and/or health-damaging pollutants. Here, I investigate four categories of confusions:

1. Definitions and measurement methods for BC
2. Inconsistent Methods for Estimating BC Emission Inventories and Implications for Radiative Forcing Estimates
3. Consideration of associated organic carbon aerosols
4. Differentiation between toxicological and epidemiological risks

I end with a brief discussion of improvements that would reduce these inconsistencies and provide for more consistent treatment of BC in scientific, policy, and popular discussions.

2. Confusion I: Measurements and Definitions of Black Carbon

[4] This chapter will be submitted to a peer-reviewed journal with co-authors Zoe Chafe, MPH, Thomas Kirchstetter, PhD and Kirk Smith, PhD, MPH.

The term "black carbon" was introduced about thirty years ago to refer to light absorbing aerosol species (Rosen and Novakov 1977; Yasa, Amer et al. 1979). Yet there remains considerable uncertainty about how and where to measure BC, which, in turn, holds implications for how it is defined. Unlike carbon dioxide (CO_2), a well-defined and precisely measured greenhouse gas, BC is a particle-phase pollutant of imprecise chemical and physical characteristics that lacks consistent methods of measurement. Indeed, unlike "carbon," "black" is not a conserved chemical property. Scientists have resorted to comparing measurement methods in lieu of calibration with an established BC standard (Reid, Hobbs et al. 1998; Slowik, Cross et al. 2007). Wide differences among BC measurement methods suggest that BC is operationally defined by each measurement method. Adding to the confusion, BC and the closely related term "elemental carbon" (EC) are often used interchangeably despite numerous studies showing that EC measurements are also imprecise and the relationship between the two species is not consistent across studies (Watson, Chow et al. 2005). An additional challenge arises when evaluating historical trends. Unlike $CO_{2,}$ for which concentrations are relatively homogenous and long-term measurements exist, BC concentrations are relatively heterogeneous, varying with geography, season, and altitude. Furthermore, only sparse measurements have been made throughout the last thirty years. Longer term BC trends must derive historical data from earlier metrics of light-absorbing particulate matter that serve as reasonable proxies of BC, such as coefficient of haze (Kirchstetter, Agular et al. 2008)[,7] and black smoke index (Novakov and Hansen 2004; Ramanathan and Carmichael 2008; Moffet and Prather 2009; Moffet and Prather 2009). Further confusion arises when evaluating the climate impact of BC, which depends on the optical properties of BC in addition to its mass, because the sunlight extinction efficiency of BC changes as BC becomes mixed in the atmosphere with other chemical species (Ramanathan and Carmichael 2008; Moffet and Prather 2009)[,](Moffet and Prather 2009)[,](Schwarz, Spackman et al. 2008).

3. Confusion II: Inconsistent Methods for Estimating Black Carbon Emission Inventories and Implications for Radiative Forcing Estimates

Existing BC inventories used by the atmospheric science community (Penner, Eddleman et al. 1993; Cooke and Wilson 1996; Cooke, Liousse et al. 1999; Junker and Liousse 2008; Bond 2009; EDGAR 2009) are not directly comparable to the greenhouse gas (GHG) inventories used by the Intergovernmental Panel on Climate Change (IPCC) to track the longer-lived climate-altering pollutants (CAPs) considered under the Kyoto Protocol (the so-called "Kyoto gases"): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The lack of commensurability across inventories is due to: 1) inconsistency in which emission sources are included, for instance, natural versus anthropogenic, pre-industrial versus industrial, and controllable versus uncontrollable; and 2) time scales considered. While the IPCC third (TAR) and fourth (AR4) assessment reports contain standardized guidelines for the development of Kyoto gas inventories, guidelines for the construction of BC inventories have not yet been created. This has led to inconsistency across existing inventories and consequently has posed challenges for developing a scientific consensus around BC radiative forcing (RF) estimates.

3.1 Natural versus Anthropogenic Emissions

BC inventories developed by the atmospheric science community usually include emissions of both natural and anthropogenic origin. From the atmospheric science perspective, this is appropriate since once in the atmosphere the source of BC matters little in terms of climatic effects. Climate *policy*, on the other hand, strives to understand which emissions could be controlled (anthropogenic) and to which political zones and economic sectors the responsibility for emission abatement should be assigned.

The IPCC GHG inventories include only anthropogenic emissions (Forster, Ramaswamy et al. 2007). Thus, the inclusion of both natural and anthropogenic emissions in many BC inventories overstates the magnitude of BC emissions in comparison to the Kyoto GHGs. Both the Kyoto GHGs and BC have natural sources, such as forest and savannah fires; natural sources are included in BC inventories but not IPCC inventories. By comparison, if IPCC accounted for CH_4 and CO_2 with the same system boundaries as are currently used for BC, their inventories would be much larger – perhaps 50% more for CH_4 and a factor of 100 for CO_2 (IPCC 2007). Adding natural sources of CH_4 and CO_2 to IPCC inventories would not assist with policy-making, since most natural emissions are not relevant to emission control. However, BC inventories should be constructed with adherence to similar inventory rules if BC emissions are to be compared to Kyoto gas emissions.

3.2 Pre-Industrial versus Industrial Emissions

Even though anthropogenic CH_4 and CO_2 (and N_2O) emissions existed well before the industrial age, the IPCC established 1750 as the starting year, or cut point, to delineate anthropogenic vs. "background" contributions. Sources before 1750 are considered natural; in other words, out of the calculus of the anthropogenic climate change occurring in today's world. Not all scholars agree that this is the right approach (Ruddiman 2006), but 1750 does represent a point in time just before significant use of fossil fuels and most other polluting industrial activities had begun (IPCC 2007).

Similarly, BC was anthropogenically produced before as well as after 1750. Therefore, to enable the inventories to be commensurate, the BC emission sources before 1750 should be left out of today's inventories, as they are for CH_4 and CO_2. From a policy standpoint, this is not a scientific question, per se, but rather a way to make the treatment of BC consistent in terms of the policy challenges at hand (i.e., for the negotiation of climate treaties[5]).

3.3 Controllable versus Non-Controllable Emissions

Based on the logic above, scientists and policymakers might be tempted to ignore the importance of pre-1750 emissions. However, through technological innovations, some CAP emission sources that existed before 1750 and persist today now have the potential to be controlled. For example, solid biomass used for household heating and cooking has been a source of BC and CH_4 emissions for the last 350,000 years (Roebroeks and Villa 2011) and remains a daily reality for more than 40% of the world's population (Pope, Mishra et al. 2010). Nevertheless,

[5] It should be noted that the atmospheric lifetimes of the different species are not the issue here, but rather the distribution of emission sources over time.

household emissions of CAPs can now be greatly reduced with the use of cleaner burning and more energy efficient stoves and fuels.

The controllable versus non-controllable distinction overlaps with, but is not the same as, the temporal and natural versus anthropogenic categorization schemes listed above. To determine exactly which fraction of the natural or pre-industrial emissions are controllable is not straightforward. For example, it is possible that some CAP emissions could be reduced through cleaner-burning stoves, but it is unlikely that all forest fires (which produce "natural" emissions) could be or should be prevented, since fires are integral to the maintenance of many ecosystems and species distributions. Similarly, although termites generate a notable proportion of global CH_4 emissions, even if possible, society would not want to eliminate them because of ecosystem implications. The scientific issues surrounding the system boundaries have not yet been addressed for BC in a consensus scientific process, as they have for the Kyoto gases.

By applying hypothetical controllability coefficients to the most widely used total BC inventory (summarized in Table 1), I illustrate the impact of different boundaries on BC inventory source attribution (Figure 1).

Table 1. Annual Global Emission Estimates of BC and OC (Gg/yr)

Fuel/Sector	Black Carbon	Organic Carbon	BC:OC
Open burning			
Open burning (forest)	1238	11293	0.11
Open burning (savanna)	1715	12147	0.14
Open burning (crop res)	328	1567	0.21
Contained combustion			
coal (power generation)	7	5	1.40
diesel fuel (on-road)	792	292	2.71
Wood (residential)	880	3506	0.25
Agricultural waste (residential)	393	1492	0.26
Animal waste (residential)	208	750	0.28
Coal (industry)	642	450	1.43
Diesel fuel (residential)	85	28	3.04
Coal (residential)	480	422	1.14
Diesel fuel (off-road)	579	288	2.01
Gasoline (transport)	125	904	0.14
Other	478	776	0.62
Total	**7950**	**33866**	**0.23**

Adapted from (Bond 2009)

Figure 1 illustrates the effect of considering 1) all BC emissions; 2) just those emissions that are possibly controllable, which is taken as half the forest and grassland portion; 3) definitely controllable, which excludes forests, grasslands, and agricultural burning; and 4) post-1750 emissions only (i.e., just from fossil fuels). In AR4, the IPCC (IPCC 2007) considers open biomass burning to be essentially uncontrollable. The range of total anthropogenic emissions that might be considered thus ranges over a factor of two (from 3.5 to 7.9 megatons annually) and dramatically changes the relative contributions from different sectors (Figure 1). For example, household biomass use is responsible for about one-fifth of total global BC emissions, nearly one-third of definitely controllable emissions and, of course, zero percent of fossil fuel emissions (post-1750). Without a scientific consensus on system boundaries, as was secured by the IPCC for CH_4 and CO_2, there is no authoritative way to choose among these different options.

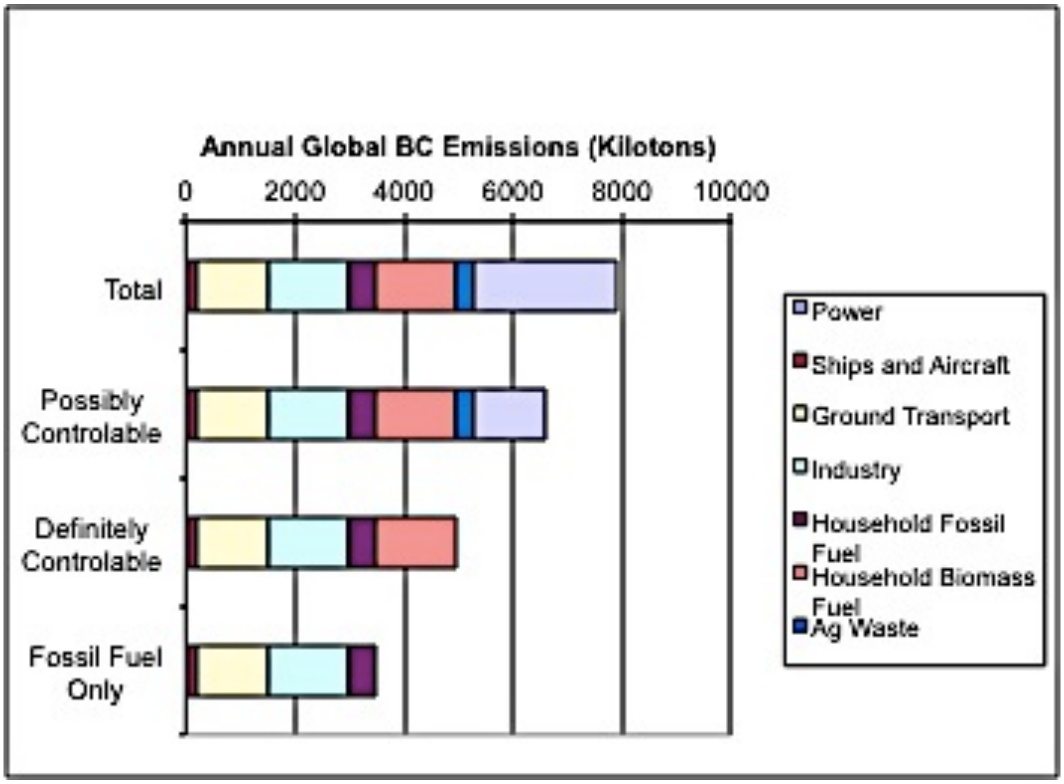


Figure 1. Variations in the Global BC Inventory Depending on the System Boundaries Chosen.
Data Source: (Bond 2009)

3.4 Black Carbon Inventory Uncertainties

BC emission inventories are also inherently more uncertain than those for some of the other CAPs (Bond, Streets et al. 2004) because of their dependence on uncertain emission factors (EFs). Currently, the inventories are calculated based on this simplified formula: ∑(Fuel consumption/activity*intensity of activity)×(EF), with the EF defined as the mass of BC emitted per fuel consumed/activity. EFs are currently impossible to simulate using combustion models, and are highly dependent on local combustion conditions and thus must be measured in the field. Unfortunately, the limited number of measurements worldwide indicates that EFs can vary by orders of magnitude, even for the same fuel and technology, due to slight changes in combustion conditions.

Estimates of some other important CAP emissions do not vary to the same degree, since they are within envelopes imposed by relatively well-known parameters. For example, carbon and sulfur contents in fuels transform during burning with relatively low variability to quantities of emitted CO_2 and SO_2. However, BC EFs from heavy diesel trucks in the US span two orders of magnitude (Ban-Weiss, Lunden et al. 2008). Also easily estimated are the halocarbons/HFCs, which come exclusively from manufacturing and thus can be monitored with more precision. Inherent variability and associated uncertainties in the inventories of the other CAPs (CO_2 from land use changes, carbon monoxide, methane, non-methane halocarbons, nitrogen oxides, and organic carbon) are of intermediate size.

3.5 Black Carbon Radiative Forcing Estimates

Researchers have reported a wide range of radiative forcing (RF) estimates for BC. Here I focus on the temporal and source boundary as opposed to the optical properties (Schwarz, Spackman et al. 2008) and geographic emission issues that affect the estimates.

RF, by definition, is the incremental addition of forcing beyond a non-anthropogenic baseline and thus, there should be a defined referent baseline on top of which the RF of BC is estimated no matter which timescale is used. Many researchers (Ramanathan and Carmichael 2008; Unger, Shindell et al. 2008; Unger, Bond et al. 2010) estimate the total RF of BC in the atmosphere based on current emissions because BC's atmospheric residence time is 7-21 days. From an atmospheric science perspective, this makes sense, however from a policy perspective, it is important to make BC RF estimates commensurate with the RF estimates of other CAPs. When compared to the RF of CO_2 and CH_4, for example, the current approach implicitly assumes that there were *no* BC emissions at the referent (i.e., 1750) baseline and that all emissions are controllable.

One approach to reach consistency would be to apply the instantaneous RF from estimated emissions in 1750 or other justifiable temporal baseline (Lamarque, Bond et al. 2010) and compare its RF to the current instantaneous RF. Because of the wide difference in life times among CAPs, however, it is unlikely that a completely objective approach exists and thus some process to reach scientific consensus is needed.

4. Confusion III: Black Carbon is not Emitted By Itself

Unlike the Kyoto GHGs, BC is essentially never emitted in pure form, but instead is co-emitted with varying proportions of organic carbon (OC) and other aerosols (See Table 1). While BC is a light-absorbing, climate-warming species, OC is a light-scattering and generally climate-cooling species that shares, with BC, uncertainties surrounding indirect effects on clouds(Ramanathan and Carmichael 2008). Not only are BC emissions hard to estimate, but also the BC:OC ratio is highly variable by emission source and combustion conditions (Table 1). It is often poorly characterized due, in part, to measurement problems and inherent variability (Novakov and Hansen 2004). Additionally, from a BC:OC perspective, certain sectors have more elevated RF than others. For instance diesel transport, combustion of household solid fuels, and forest fires have high, intermediate, and low BC:OC ratios, respectively (Unger, Bond et al. 2010).

Under certain circumstances it is valuable to treat BC and OC separately in atmospheric models, however, it makes less sense to do so in policy analyses because currently no method exists to control BC separately from OC in a consistent fashion. For example, researchers found that, using the same woodfuel as used in three-stone fires in Kenya, a subset of "improved" stoves simultaneously increased energy efficiency, decreased total particulate matter (PM) emissions, and emitted more than twice the fractional BC:OC content in its PM emissions (15.5%) compared to the three stone fire (7.2%) ($p<0.01$) (Berkeley Air Monitoring Group 2011).

5. Confusion IV: Toxicological vs. Epidemiological Differences

Toxicological studies of BC, performed predominantly under controlled laboratory conditions, indicate that pure BC, defined as elemental carbon, may not be particularly toxic compared to particles of similar size but different composition (Oberdoerster, Stone et al. 2007). Toxicity is known to exist with other low-solubility, low-toxicity materials such as titanium dioxide and polystyrene beads (Oberdoerster, Stone et al. 2007). It is generally accepted that, chemical composition being equal, the toxicity of small particles is greater than that of larger particles due to their ability to penetrate deeper into the lungs and possibly the vascular system (Donaldson, Tran et al. 2005). Although freshly emitted BC-containing particles are generally small, etiological links between particle size and respiratory and cardiovascular outcomes are not specific to BC.

Although highly relevant to its climate impacts, the color of a substance is not relevant to health risk. Instead, the chemical composition, particle size, and particle number *are* metrics of interest to health; to a certain degree, they are of interest to climate science as well. Since BC in the environment is usually internally and externally mixed with other atmospheric constituents that adsorb to their surfaces, BC particles may act as vehicles for toxic substances to be deposited deep in the respiratory system (Donaldson, Tran et al. 2005) and thus, epidemiologic studies tend to focus on in situ exposures. Although BC particles increase in size soon after emissions (within a couple of hours), aggregating beyond their previously nano-size, they are often still within the range of the most epidemiologically meaningful size range (<2.5 um in diameter) for the majority of their atmospheric lifetime (Moffet and Prather 2009).

Partly because routine government monitoring is undertaken in insufficient numbers of locations and, as noted, no common measurement method is agreed upon, the epidemiologic evidence between measured BC and health outcomes is scarce. Smith et al. (2009) published the first comprehensive review of the health effects of BC, which includes a meta-analysis of time-series studies and the only published cohort study of the long-term health effects of BC exposure in 66 US cities over 18 years. This study found that BC is health damaging, potentially more so than exposure to undifferentiated particles, but that the evidence is not unequivocal (Smith, Jerrett et al. 2009). Nevertheless, all major reviews of the health effects of combustion particles to date have concluded that there is insufficient evidence to ascribe a higher general health hazard to BC compared to undifferentiated combustion particle mixtures, although research continues (WHO, EPA, UNEP). Given that thousands of studies of the most important health-damaging combustion mixture, tobacco smoke, have not yet been able to determine which particle constituents are most deleterious to health, it is unlikely that air pollution studies will be able do so in the near future.

Similar to the geographic dimensions of BC impacts on climate and, in particular, glaciers, the locations and timings of BC emissions largely determine human exposure and health impacts.

Longer-lived CAPs, such as CH_4, persist in the environment long enough to become globally mixed, thus exerting their primary and secondary climate and health effects in wider regional and often global geographic reaches. BC, on the other hand, falls out of the atmosphere in a matter of days and thus emissions in one area do not significantly affect populations and ecosystems many thousands of kilometers away. When BC is emitted with other products of incomplete combustion from household solid fuels, in close proximity to people, there is a larger intake fraction, i.e., there is more exposure per unit pollution emitted. Conversely, emissions outdoors that are far from humans, result in a lower intake fraction. Urban vehicle emissions are intermediate in intake fraction (Apte, Kirchstetter et al.) and, when from diesel fuel, have high BC/OC ratios.

6. Discussion

For climate, the biggest sources of BC-related inconsistencies arise from the differences in the framing of BC by the policy/regulatory and atmospheric science communities. In health, the greatest confusion arises from apparent discrepancies between toxicological and epidemiologic evidence (i.e. in the environment BC is an indicator of mixtures, not an isolated species). There is a fundamental and probably irreconcilable inconsistency in the naming of the substance at hand: "blackness" is not relevant to health, but it is to climate. Both climate and health policy, however, suffer from inconsistencies in how BC is measured and defined.

Further, with current understanding, reducing particle emissions of any sort always has a health benefit – all small particles are health damaging, even if some are more harmful than others. Yet this statement is not true from a climate perspective. Indeed, one of the main conclusions of IPCC AR4 was that the net impact of all aerosols, including sulfates, in the atmosphere currently is cooling, although with considerable uncertainty (See Figure 2.21 in Solomon et al. 2007) (Solomon, Qin et al. 2007). Thus, if somehow humanity were to eliminate all combustion-related particle emissions (including sulfates), millions of premature deaths would be avoided annually (GEA 2011), but the climate would warm faster than before.

6.1 Policy Development and Scientific Updates

Differential RF and mass emission estimates, such as those that exist for BC, raise a thorny and important issue with regard to the use of any scientific information in the construction of sound policy: how to incorporate updates in scientific knowledge over time. Although by no means perfect, the IPCC assessments represent major international scientific efforts to reach consensus on the many difficult aspects of climate change science and policy. As such, these assessments hold authority well beyond that of any individual study because they are integrated and systematic across multiple aspects of the issue. No individual study can achieve this combination of integration and consensus. Thus, even if the newer studies may be seen by some to be more scientifically valid within the aspect of the individual issues(s) they address, serious complications arise when policy adopts them one at a time.

For illustration, there have also been post-AR4 studies of RF from CH_4 that have reached different conclusions from AR4 (Shindell, Faluvegi et al. 2009). Should these newer studies be adopted into current policy discussions? If we take one such study why not entertain others that may not have found changes from AR4? Also, if we change the RF of BC and CH_4, how do we reconcile this with our understanding of the overall relationship of total CAP RF to observed temperature change (i.e., the climate sensitivity)? Only a fully integrated assessment can achieve this and only the IPCC assessments, at this point, reach this level of integration.

As another example, air pollution regulations are based on regular but widely spaced reviews of all evidence, which, in the US, is aggregated into extensive review documents undertaken and peer reviewed by many scientists. If a new study, published after one of these assessments, showed particle air pollution to be more (or less) damaging than the last review, would this be grounds to modify the regulation? The answer is, in most cases, no; instead it would be included along with the pre-existing and other new evidence in the next review and evaluate it in an integrated context.

6.2 Towards Science Policy Reconciliation

Table 2 provides a summary of the four categories of inconsistencies discussed in this paper, with the emission inventory and radiative forcing estimate categories disaggregated for clarity. I do not mean to imply that any of these analytical choices are equally justifiable and some (e.g. RF estimates) require consensus scientific review in an integrated context to resolve. Similarly, the inconsistencies in measurement methods will best be resolved by international agreement as to which monitoring method best represents "black carbon." At this point, there seems to be no obvious resolution of the differences between the climate and health perspectives. Instead, it is clear that mixtures with similar toxic properties can have quite different radiative forcing properties, and vice versa.

Nonetheless, I offer recommendations to arrive at the best choice among two of the other categories in Table 2: to more consistently construct emission inventories and to calculate RF estimates that account for the intrinsic linkage of BC with OC more consistently and accurately.

Table 2. Summary of Major Inconsistencies Across Categories

Category	Inconsistency	Level of Uncertainty[a]
Definition and measurement methods for BC	The definition of BC depends on the type of measurement. Some, but not all, of the inter-method comparisons yield consistent results.	***
	There are no agreed upon calibration standards for measurement, which inhibits the development of a concise definition.	
Emission Inventories Development	The BC inventories used by the atmospheric science community are not directly comparable to those used by the IPCC to track the primary long-lived CAPs	***
	Atmospheric Science Accounting: inventories often include anthropogenic, natural, controllable, and non-controllable BC emissions.	
	IPCC Accounting: The IPCC contains only anthropogenic emissions.	
	The primary long-lived CAPs are tracked after 1750 as a referent point, however there exists no referent point for BC, as the short-lived nature of BC is often used to justify using current emissions as a proxy for global radiative forcing, further rendering atmospheric science inventories incommensurable with IPCC inventories.	
Radiative Forcing Estimates	RF refers to the incremental addition of forcing beyond a background non-anthropogenic baseline. However, most analyses use current BC emissions as a proxy for RF. This relies on an implicit assumption that there were no BC emissions at the referent (i.e., 1750) baseline, rendering current BC RF calculations incommensurable with other CAPs tracked by the IPCC.	***
	BC emission estimates are inherently more uncertain than other CAPs due to the fact that BC emission factors can vary by orders of magnitude, even for the same fuel and technology, due to slight changes in combustion conditions. For instance, it is simple to know the CO_2 emission factor from diesel fuel, simply by knowing the carbon content. However, there exists two orders of magnitude difference in emission factors of BC across diesel-powered trucks	
	There is an inherent policy issue in how to incorporate scientific knowledge updates -- through systematic and rigorous consensus or through the newest, most scientifically sound study. However, new BC RF estimates that have not be subjected to rigorous consensus efforts have found traction in the media and policy debates, which is problematic.	
Associated Organic Carbon Aerosols	Inconsistencies exist in how analyses incorporate the relationship between BC emissions and the associated cooling aerosols, such as OC. These confusions arise because the BC:OC ratio is highly variable by emission source and combustion conditions (Table 1) and often poorly characterized, in part due to measurement problems.	***

	Thus, although it makes sense to treat BC and OC separately in atmospheric models and associated inventories, it makes less sense to do so in policy analyses because there is no known way to control BC separately from the associated OC.	
Toxicological and epidemiologic risks	From a health perspective, the optical characteristics of black carbon are not important since color alone is not, in itself, a concern for health. Thus, some of the subtleties of measurement with regard to the climate implications of BC are irrelevant for health.	*
	From a **toxicological** perspective, pure BC is not very toxic in human and animal studies at typical ambient concentrations	
	From an **epidemiological** perspective, BC is rarely found in its pure form and is most often found internally and externally mixed with other atmospheric constituents that may be toxic. Thus, BC has been found to be at least as toxic as undifferentiated PM and possibly more so.	
	The **geography** of BC emissions matter for human exposure and the intake fraction, i.e., the amount of the emission that is breathed into the lungs of a population.	

[a] Ranges from * = somewhat uncertain to *** = very uncertain.

6.3 Emission Inventory Recommendations:

To be more consistent with how other CAPs are treated by the IPCC and in the consequent international treaties and national inventory protocols, it seems appropriate to adopt the approach taken in the second level of inventory accounting in Figure 1 – to assume that a proportion of grassland and forest fires are anthropogenic and controllable and the rest non-controllable. This accounting assumes that all agricultural burning is controllable, which could only occur with a major international effort that is highly unlikely to transpire this century. Nonetheless, abatement efforts targeted at glacial airsheds, where BC climate impacts are most notable, could be more feasible. Europe has already moved in this direction through the requirement that all agricultural residues be collected for centralized burning with good combustion. Of course, this practice produces other lifecycle emissions, for example from trucking, which would need to be considered. The fraction of grassland and forest fires to be considered controllable should be ascertained in a scientific consensus activity, but until then perhaps assuming 50% controllability, as in Figure 1, is reasonable.

6.4 Black Carbon and Organic Carbon Accounting Recommendations

To provide a more realistic signal of the net effect of particle emission reductions, it would seem most straightforward to assume the BC:OC ratio in each source category remains the same during control efforts. This is not always the case, but as noted it is not currently possible to predict these emission factors a priori.

Figure 2 shows the resulting total radiative forcing from net BC-OC (the negative RF of OC subtracted from the positive RF of BC) accounting in comparison to that of other major CAPs as indicated in AR4. Also shown is the addition that would be implied by taking the higher radiative forcing value for BC from Ramanathan and Carmichael (2008). Not shown are the uncertainties, which increase dramatically from top (CO_2) to bottom (BC-OC). Also excluded are the indirect aerosol impacts such as on clouds, which remain even more uncertain.

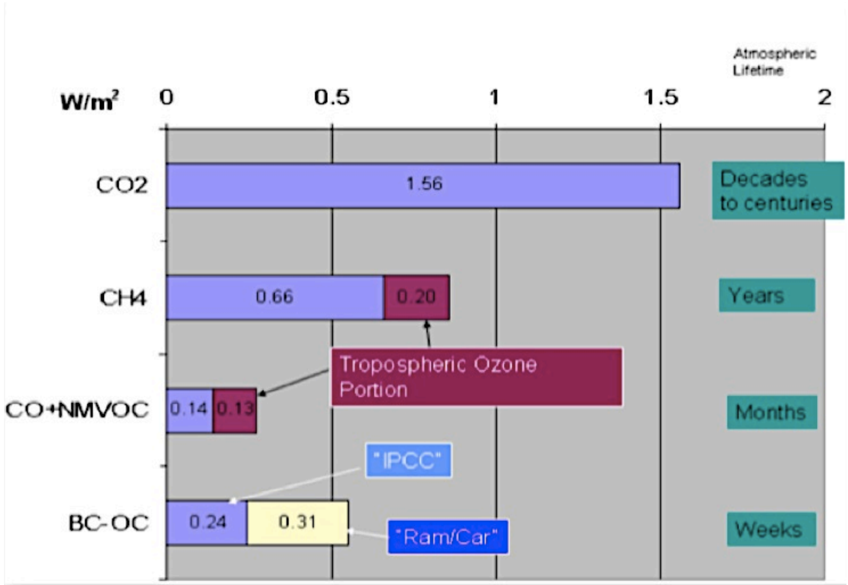


Figure 2. Recommended Accounting: Radiative Forcing (RF) of Controllable Products of Incomplete Combustion Plus CO_2.*

* Except as noted, the RF estimates are from AR4. Not portrayed are post-AR4 estimates for CAPs besides BC, for example methane.

Note: "Ram/Car" refers to Ramanathan and Carmichael (2008)

Data Sources: (Forster, Ramaswamy et al. 2007; Forster, Ramaswamy et al. 2007; Ramanathan and Carmichael 2008)

6.5 Finding Common Ground: Meeting Climate Change and Health Goals in BC Reductions

In exposure assessment, intake fraction is the ratio of the mass of a pollutant inhaled or ingested to the mass of the pollutant emitted. This measurement of pollution can be used in the determination of environmental health impact. From a health perspective, BC abatement policies might focus their reduction efforts on indoor and other household emissions and densely populated urban areas where the intake fraction of ambient BC, is generally the highest. The framing of intake fraction can also be extended to climate mitigation policies as well. For example, because BC exerts its most notable effects in cryospheric regions, BC reduction strategies focused on the attenuation of climate impacts could focus on the reduction of BC in geographic regions where the highest fraction of the BC emission will be deposited on glaciers. A metric that captures the proportion of BC emissions that fall on glaciers could be termed the "deposition fraction" and could be calculated in a similar manner to the intake fraction.

Moreover, the impact of BC on climate and human health does not exist in isolation and the climate and health dimensions are not mutually exclusive. For example, increases in melting rates of glaciers that supply year-round water sources to human populations is a population health issue as it can lead to droughts as well as floods and landslides, issues that are drivers of many direct and indirect public health concerns. Figure 3 provides a synthesis of BC abatement priority areas from a public health and climate geography perspective. It is helpful to note the overlap in priorities within the climate and the health camps. BC emission abatement activities and policies should align themselves with both sets of priorities in order to achieve the maximal benefits and share resources from both sets of funding sources.

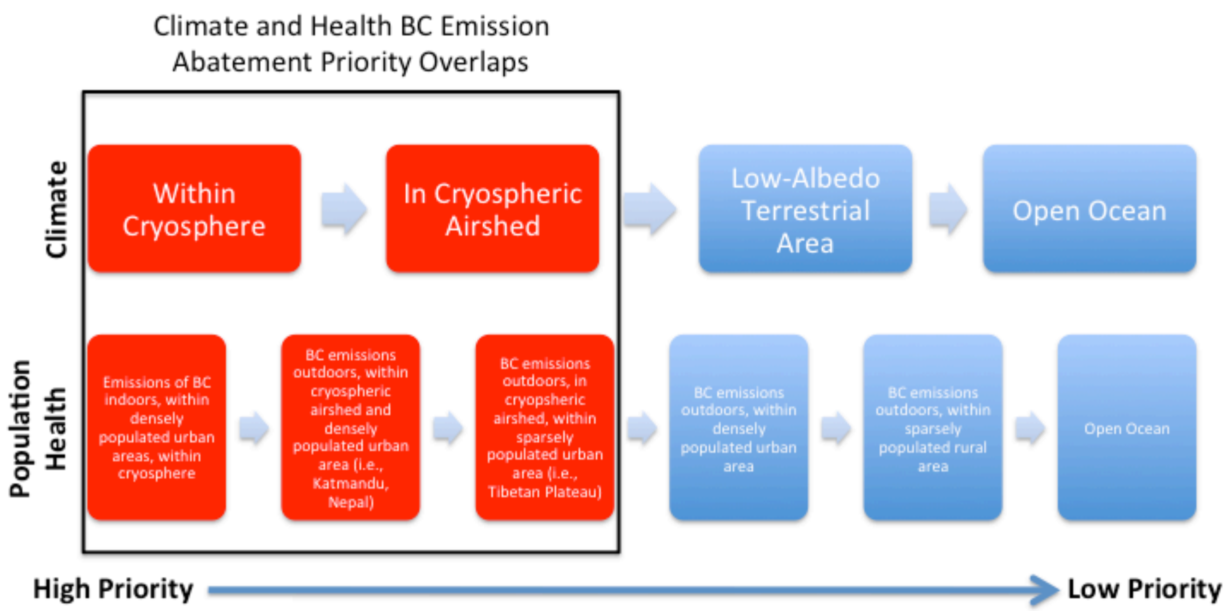


Figure 3. Hierarchy of Reduction Priorities for BC Emission from Climate and Population Health Perspective

As seen in Figure 3, from a climate perspective, priorities for BC control should focus on the abatement of emissions proximate to and within the airshed of glaciers. From a health perspective, abatement priorities should focus on the control of BC in indoor environments and urban areas. There are specific economic sectors that are more effective abatement targets than others given the technologies and abatement policies currently developed.

The control of BC in households that use solid fuels to meet their energy needs is difficult because it is not yet possible to control BC emissions without controlling emission of OC, even with improved cookstoves (Berkeley Air Monitoring Group 2011). The transport sector is a good “win” in this area, because BC:OC ratios are relatively high in diesel emissions and emission reductions have already been demonstrated through policy (Bahadur, Feng et al. 2011). For instance, Bahadur et al. (2011) found that there was a 50% reduction in BC emission in CA between 1989-2009, attributed to outdoor air pollution regulations. An analysis has not been conducted on the averted health burden attributable to these reductions, but it is likely that there was an effect.

Another viable regulatory option is to control open agricultural burning in glacial airsheds (this would lead to a decrease in outdoor air pollution and therefore decrease BC deposition on glaciers. Agricultural burning in areas that are densely populated would be a health co-benefit plus. However, the alternatives employed to not burn agricultural refuse on site is important to interrogate as well. For example, life cycle analyses should evaluate the energy input and emission differentials of open burning compared with industrial agricultural refuse incinerators.

7. Conclusion

In order to develop the most effective emissions reduction strategies for BC and other pollutants aimed to protect climate and human health, the atmospheric science and climate and environmental policy communities must reach consensus on measurements, inventory building, and treatment of co-emitted pollutants based on the best scientific knowledge available from multiple disciplines.

Additionally, climate change mitigation efforts focused on BC that aim to most effectively realize the associated health co-benefits should be ideally be most focused in geographic areas with the closest proximity to cryospheric environments and dense human populations.

Transition to Chapter 4: Cookstove, Human Health, Anthropogenic Climate Change and Carbon Offsets

Approximately one-third of the human population depends on solid fuels for their household energy needs, predominantly in the global south (Pope, Mishra et al. 2010). This includes biomass represented predominantly by wood, dung, and agricultural residues as well as solid fossil fuels such as coal (Fullerton, Bruce et al. 2008; Wilkinson, Smith et al. 2009). These solid fuels, mostly used for cooking and heating, are often combusted on open fires or traditional stoves and result in elevated levels of indoor air pollution. Biomass smoke emitted indoors contains a host of climate forcing (i.e., carbon dioxide, methane, and black carbon) and health-damaging (i.e., particulate matter, carbon monoxide, formaldehyde) pollutants (Smith, Jerrett et al. 2009; Tang, Bai et al. 2009). For example, exposure to air pollution has been associated with health impacts including: pneumonia (Smith, McCracken et al. 2011), respiratory tract infections (Smith, Samet et al. 2000), exacerbations of inflammatory lung conditions (Smith, Samet et al. 2000), cardiac events (Brook, Franklin et al. 2004), stroke (Hong, Lee et al. 2002), eye disease (Pokhrel, Smith et al. 2005), tuberculosis (Mishra, Retherford et al. 1999; Perez-Padilla, Perez-Guzman et al. 2001; Pokhrel, Bates et al. 2009), and cancer (Behera and Balamugesh 2005). On the whole, indoor air pollution results in approximately 1.6 million premature mortalities annually and according to the World Health Report 2002 indoor air pollution is responsible for 2.7% of the global burden of disease (WHO 2002). The majority of this disease burden falls on women and children because women tend to prepare the food over indoor fires, while the men tend to work elsewhere.

Household energy in the form of solid fuel combustion also contributes to large fractions of outdoor air pollution that contribute to the burden of health outcomes listed above as well as to emissions of climate active pollutants (CAPs). For instance, it is estimated that 30% of primary anthropogenic $PM_{2.5}$ measured outdoors in China and up to 50% of it in India is due to household combustion of solid fuels predominantly for cooking and space heating (Chafe, Mehta et al. Under Review), Moreover, household cooking and heating with solid biomass fuels is responsible for a significant fraction of global methane (a strong CAP) emissions, which further atmospherically transforms to tropospheric ozone, another CAP with health consequences.

Cleaner burning and more fuel-efficient biomass cookstoves have gained traction in environmental and public health communities as health and climate intervention technologies over a long history[a]. Confidence in cookstoves as viable health intervention technologies is sourced from much research (Fullerton, Bruce et al. 2008), including randomized trials (Smith, McCracken et al. 2009; Smith-Sivertsen, Diaz et al. 2009; Smith, McCracken et al. 2011), increased funding from the public and private sectors, and growing voluntary and compulsory carbon markets. A number of examples of large-scaled cookstove interventions have recently been announced. These include public-private collaborations such as the Global Alliance for

[a] There is a long history of the cookstove as an environmental performance and health promoting technology that is beyond the scope of this paper. For an excellent review please refer to (Booker, 2011)

Clean Cookstoves (Global Alliance for Clean Cookstoves 2011), The Indian Cookstove Initiative; and initiatives by the *Shell Foundation*, which collectively aim to sell hundreds of millions of advanced cookstoves by 2020 (Shell Foundation 2010).

Many plans for the dissemination of cookstove technologies to households include market-based components, several of which use carbon offsets to finance their operations (Global Alliance for Clean Cookstoves 2011). The rationale for a cookstove project developer to enter the carbon market is that if their stove reduces non-renewable biomass (NRB) fuel use below the levels consumed before the introduction of their stove, then they can claim a reduction in emissions of carbon and carbon equivalents. NRB differs from the broad category of total "biomass" in that it is the fraction of the total biomass – such as wood and charcoal – that is harvested more rapidly than woodstocks can be replenished. If carbon emission reductions are verified by a carbon offset certification process – namely the Clean Development Mechanism (CDM) under the Kyoto Protocol and the Gold Standard Foundation (GSF) (Gold Standard Foundation 2011) on the voluntary market – then a project developer can sell these credits on either the compulsory or the voluntary markets in order to help to finance and scale the project, to cash the credits in as profit, or sell the credits to other firms that need to offset their emissions, but would rather not invest in reducing them on site.

The CDM, under the Kyoto Protocol – set to expire in 2012 with talk about a treaty renewal – allows emitters to offset their emissions of CAPs by investing in offset projects or purchasing carbon credits from these projects in less developed nations. Although offsets face many political hurdles and are contested for their effectiveness in CAP reductions, the projects aim to bring efficient and renewable technologies that emit fewer CAPs than existing technologies to developing nations, which cannot afford to invest in these modern technologies and practices themselves while simultaneously contributing to sustainable development. By purchasing these credits, emitters can more easily, albeit with a price tag, meet their emission reduction requirements under Kyoto. Alternatively, the voluntary carbon market, with carbon offset credits verified predominantly by the GSF, is not associated with any agreements, treaties, or regulations and is thus not considered part of the compulsory market. Instead consumers of voluntary carbon credits are predominantly firms and industries that view corporate social responsibility (CSR) in areas of environment, climate, and sustainable development as important dimensions of their business images or business portfolios. Cookstove projects are touted as a relatively sound carbon offset opportunity in relation to other carbon projects because of the large amount of energy consumed globally through the combustion of solid fuels and because of the links to development issues and the Millennium Development Goals including maternal and child health, energy access, and ecological sustainability (United Nations 2008; Wilkinson, Smith et al. 2009).

Central to a robust process of CAP reduction verification is the ability of monitoring methodology requirements to produce robust estimates of these emissions and to hold the evaluators of these projects accountable to consumers of carbon credits, the target communities that host the carbon offset project, and to the international treaties that trust that verified carbon offsets are true reductions in CAPs (Lohmann 2006). Both of these parameters – robust emission estimates and accountable behavior of evaluators – contribute to the value and longevity of the entire offset process and its effectiveness at achieving climate and sustainable development goals.

Although the CDM has more public oversight, the GSF produces more valuable and accountable credits (Sterk, Ahrens et al. 2009). What can explains this? In this paper, I contend that differences between the value and perceived veracity of the two types of carbon credits is attributable to the fact that the GSF has developed metrics in its monitoring requirements that can more effectively discipline evaluators and project developers into responsible and accountable behavior. This in turn produces M&E results with a higher standard of veracity to be reported to the certifying institutions and other stakeholders. Nonetheless, the GSM still has flaws that leave open opportunities for project evaluators and developers to exploit to obtain results that cannot be empirically justified. These methodological flaws can be rectified through the identification and improvement of the M&E metrics in the required carbon-offset methodology. These improvements will further strengthen the authoritativeness of the GSF, make the accountability system more influential, and hopefully lead to more trusted carbon credits, more effective emission reductions, and greater sustainable development gains.

Chapter 4: Don't Hate the Player, Hate the Game[6]: How to make Cookstove Carbon Offset Methodologies More Accountable

"The only way these sky high numbers aren't impressive, is if you compare them to something."
- Stephen Colbert, The Colbert Report, August 2010

1. Introduction

The Clean Development Mechanism (CDM) under the Kyoto Protocol was set up to allow emitters from Annex 1 countries – including the European Union (EU), Japan, and Canada – that are bounded by this agreement to reduce their emissions of climate active pollutants (CAPs) through either investing in carbon offset projects or by purchasing carbon credits from these projects in less developed nations. The rationale of the CDM is that regulated emitters should be able to reduce their CAP emissions wherever it is most cost effective and it is best to do so while simultaneously contributing to sustainable development through the transfer of resources from the global north to the global south. In addition to this "compulsory" carbon market, the *voluntary* carbon market has entered the scene, with carbon offset credits verified predominantly by the Gold Standard Foundation (GSF). The primary difference between these two markets is that unlike the voluntary carbon market, the compulsory market is associated with governmental agreements, treaties, public regulations, and diverse institutional and governmental oversight, while the voluntary market is predominantly overseen by the GSF alone. Consumers of voluntary carbon credits are predominantly firms and industries that view corporate social responsibility (CSR) in areas of environment, climate, and sustainable development as important dimensions of their public image and to the bottom line of their business portfolios.

Despite the enthusiasm of proponents for carbon offsets, a number of critical scholars argue that this type of climate change mitigation mechanism is ineffective. For instance it is argued that carbon offsets are not verifiable due to the scale at which the offsets are deployed, which limits the generalizability of the monitoring data across different geographic locations (Lohmann 2006). It is also argued that these projects can suffer from problems with the verification that the project is "additional" in that the carbon offset project would not have been able to occur without the aid of carbon credit finance (Haya 2010). Some analysts criticize carbon offset projects because of what they refer to as intrinsic flaws in monitoring requirements (Michaelowa A and Purohit P 2007; Haya 2009). Still others argue that carbon offsets are unethical due to the abilities that they offer to industry in developed countries to continue to pollute while paying for others to reduce pollution in developing countries (Sovacool 2011).

Nonetheless, carbon offsets in general continue to be integral components of most large-scale climate change mitigation portfolios. For instance, any possible replacement for the Kyoto Protocol – which is set to expire in 2012 – as well as the California Global Warming Solutions Act of 2006 (AB 32) are both expected to use offsets to achieve their goals of CAP reductions. The use of offsets is politically attractive because it allows firms and other emitters to meet their CAP emission reduction goals in the most inexpensive fashions without the need to invest in

[6] Do not fault the successful participant in a flawed system; try instead to discern and rebuke that aspect of its organization which allows or encourages the behavior (Urban Dictionary 2011).

retrofitting their own facilities (Ellerman and Buchner 2007). Moreover, some proponents posit that given the political environment, excluding offsets from climate policies would produce a scenario in which there would be no climate change mitigation policy at all, because industrial countries and firms under regulation would not take action without access to offsets. Thus, I argue that offsets, including those from cookstove projects, are not *fatally* flawed, but rather that improvements must be made to their monitoring requirements before they can function effectively.

One specific criticism of all carbon offsets is the lack of robust accountability systems among actors and institutions charged with the estimation and verification of emission reductions (Lohmann 2006). Accountability systems help to ensure the correct behavior of those that hold power over others. Thus, a central component of accountability is the institutions that provide information to those who attempt to hold power-wielders accountable through sanctions if their actions fail to match their stated goals (Grant and Keohane 2005). However, one major difference between accountability mechanisms set up among human and institutional relationships and embedded in metric requirements is that humans are under constant performance scrutiny, while metrics are often more free of critical analysis and are, mistakenly, treated as quasi laws that people 'obey' because of their alignment with narratives of scientific objectivity, quantitative truth, and apolitical assessment (Porter 1995). Thus, while modifying human and institutional relationships and implementing sanctions when people behave outside of required standards is highly understood and accepted, how information on effectiveness is generated through metric requirements as a site of discipline to ensure standardized behavior has received less attention.

In the case of cookstove carbon offset projects, metric requirements that "discipline" means that there is a system that requires evaluators to follow specific data collection protocols and to employ specific metrics when analyzing CAP emission reductions of cookstove offset projects. Additionally, disciplinary metric requirements would ensure that evaluators report these data back without adjusting or tampering with the data in self-serving fashions. Central to the maintenance of an effective accountability system in cookstove carbon offset projects are the suites of monitoring and evaluation (M&E) requirements that project evaluators must adhere to in order to determine whether the offset is a true empirical reduction in CAPs, a true increase in sustainable development, etc. or not. In Table 1 I briefly summarize the central M&E components necessary to generate the information needed to adequately hold carbon offset projects accountable. The categories of representative sampling and the control of household behavior during fuel-use tests contain metric requirements that are, simultaneously, particularly central to robust estimates of fuel consumption estimates and are notably weak in their ability to discipline project evaluators into accountable behavior. Additionally, the requirements for which metrics, data inputs, and analytical processes are used to calculate the fraction of non-renewable biomass consumed in the project area is a point of particular weakness in the methodology and leads to wildly varied estimates, most often in the positive direction (Ghilardi, Guerrero et al. 2009). Lastly, the category of indicators of sustainable development, although not central to project fuel consumption are a particularly ill-defined category in carbon offsets yet are imperative to understand both the sustainable development benefits and the negative impacts of an offset project (Liverman 2010). Strengthening of these requirements could help to safeguard the offset methodologically from manipulation, gaming, and mistakes in the calculation of emissions that can produce effectively empty, or not trustworthy carbon credits. In the current version of the GSM, there are many opportunities for evaluators to take short cuts, either intentionally for corruption or project developer financial benefit, or inadvertently through cognitive and social biases that ignore local variation.

Table 1. M&E Components and their Corresponding Importance to Accountability

M&E Component	Importance to Accountability
Representative Sampling	Disciplines the evaluator into collecting data on households that are representative of all of the households and not biased sub-populations that ensure allocation of carbon credits
Controlling Household Behavior during Fuel Consumption Tests	The extent to which evaluators are allowed to control the behavior of households or institutions (cooking, stove use, etc.) partially determines the results. The higher the control of behavior the less reflective the data is of the fuel use and sustainable development of the communities in which the project is being implemented.
Estimation of the Fraction of Biomass Derived from a Non-Renewable Source	Cookstove carbon project developers only generate carbon credits for reducing the consumption of non-renewable biomass. Therefore, calculations of "renewability" are central to the M&E of cookstove carbon offset projects.
Indicators of Sustainable Development	The extent to which evaluators are required to measure indicators of sustainable development determines the understanding of the effect of the project on these social and economic benefits or detriments.

For example, in a cookstove carbon offset project, fuel consumption (the main indicator of CAP emissions) estimates can be greatly influenced by the metrics chosen to analyze the M&E data. A larger household may consume more fuel to cook than a smaller household so choosing to analyze fuel consumption at the household level, as opposed to at the individual meal level, can increase the average fuel consumption and give a false impression of the resulting emissions. As such, evaluators can manipulate reported reductions in fuel consumption in order to support the claim that a cookstove carbon offset project reduces fuel consumption above the pre-existing fuel consumption baseline before the introduction of the cookstove project if they have access to whichever method of data analysis suits their needs best. A more rigorous M&E system is needed to strengthen accountability in generating carbon credits for a properly functioning carbon market.

Accountability mechanisms are found throughout the carbon offset generation process. For instance, although some disagree, Backstrand (2008) found that carbon credits generated on the compulsory market through the CDM have relatively high levels of transparency, robust information gathering requirements, and the monitoring mechanisms that are clearly stated and heavily required compared with other climate mitigation partnerships (Backstrand 2008). However, Backstrand (2008) also indicated that the CDM process lacks accountability because the level of oversight by public officials of countries that have ratified this treaty is insufficient to keep the voting public informed of the processes, developments, and veracity of CDM carbon offset projects.

Yet with all of the oversight by and the points of transparency in public agencies (i.e., federal environmental protection departments), international treaties (i.e., the Kyoto Protocol) and private markets, CDM carbon credits fail to be viewed as veraciously and are consistently valued monetarily lower than Gold Standard Foundation (GSF)-certified carbon credits, which are not publically affiliated and thus lack many of these same points of oversight from a regulatory perspective. Why is this the case? All else being equal, the answer lies in the relative strength of the M&E methodology of the Gold Standard, which acts as an accountability system that "disciplines" evaluators through data collection rules, restricted uses of metrics, and data analysis requirements into more responsible and accountable behavior, producing results with a higher standard of veracity to be reported to the certifying institutions and other stakeholders.

Some authors have made specific suggestions on how to improve the scientific estimation of individual aspects of cookstove carbon M&E protocols. These suggestions have included improvement of fuel use estimation (Johnson, Edwards et al. 2009) and more robust calculations of the "non-renewable" proportion of the biomass used by households included in cookstove projects (Ghilardi, Guerrero et al. 2009). However, no studies have focused on how metric requirements can play integral roles in managing the perverse incentives of project developers to act in ways that distort the true emission reduction impact of a project for financial gain.

Thus I explore whether enhanced M&E metrics can better assure the accountability of cookstove carbon offset projects for target communities, international treaties, and businesses that rely on the veracity of the information on their emission reduction and sustainable development outcomes to reduce their environmental footprints and socioeconomic impacts. To establish this claim, I interrogate the metric requirements in the Gold Standard cookstove offset methodology (GSM) with the goal to improve the disciplinary dimensions of the metric requirements to help to ensure the production of stronger, more accountable information to inform the cookstove carbon offset crediting process. I focus on the GSM because of the pre-existing emphasis on the methodology to ensure more veracious carbon crediting.

2. Theorizing Accountability

Thinking about how to create and sustain accountability in environmental performance improvement efforts is important because the demand for accountability is central to democratic governance in contemporary societies from the local to the global level (Schedler 1999; Weber 1999). Policies, markets, and transactions all benefit from accountability in terms of the trust they evoke, and through this, to varying degrees, the sustainability and longevity that they enjoy (Schedler 1999).

Accountability is defined in a variety of ways. In general accountability is conceived of as actions that adhere to the following formula: "A is accountable to B when A is obliged to inform B about A's (past or future) actions and decisions, to justify them, and to suffer punishment in the case of eventual misconduct" (Schedler 1999). Other researchers discuss accountability in more specific terms. For example, Dykstra (1939) defines accountability as synonymous with responsibility (Dykstra 1939) and Fox and Brown (1998) define accountability as "the process of holding actors responsible for actions" (Fox and Brown 1998). Alternatively, Edwards and Hulme (1996) assert that accountability is defined as "the means by which individuals and organizations report to a recognized authority (or authorities) and are held responsible for their actions" (Edwards and Hulme 1996). Similarly, with a wider, more inclusive definition, Cornwall, Lucas, and Pasteur (2000) assert that accountability necessarily connotes components of both holding individuals responsible by others and taking responsibility for oneself in relationships of differential power holding (Cornwall, Lucas et al. 2000). O'Rourke, in his discussion of *community-driven regulation*, finds that the community is responsible for upholding accountability by determining its own set of priorities and inspection needs and by acting as an inspector and a monitor of progress, thus increasing the accountability of state-firm negotiations (O'Rourke 2000). Woven throughout these definitions, are two primary requirements: 1) that accountability requires *external* dimensions to generate an obligation among the power-wielding body to meet pre-determined standards of behavior (Chisolm 1995); and 2) An *internal* dimension of felt responsibility on the part of the power-wielding body based on individual action and organizational mission (Fry 1995; Ebrahim 2003)

In contrast, Weber (2003) defines accountability as a system, or set of mechanisms, designed to ensure that promises are kept, duties are performed, and compliance is forthcoming. In other words, the power-wielding actor or institution is "disciplined" to carry out the obligation. This model of accountability is more relevant to the cookstove carbon offset case than the other definitions because of how the measurement components are distributed as a system dependent on metrics between humans, technologies, organizations, and M&E requirements (Scott 1998). Cookstove carbon project evaluators have traditionally had considerable latitude in the field to design and carry out measurements, but as mentioned above, this latitude has increasingly become embedded in a process of compliance with standardized protocols and sets of metrics to report to certifying institutions.

2.1 Elements of Accountability in Cookstove Carbon Offset Projects

Under the Gold Standard Foundation (GSF) – the voluntary cookstove carbon offset certification scheme – the project evaluator, determined by the project developer, who collects M&E data to determine the effect of the project on CAP emissions, is accountable to five primary entities: 1) the project developer in order to make sure the project supplies carbon credits; 2) the credit certification or market for the validation of real emission reductions; 3) any external investment entity that provides up-front finance to the project prior to carbon credit issuance; 4) the Designated Operational Entity (DOE) assigned by the certifying institution to cross-check the M&E findings; and 5) the local communities for ensuring social, developmental, health, and other developmental benefits beyond carbon finance (Figure 1).

Figure 1. Accountability Relationships of Carbon Finance Evaluators

Nonetheless, certification-based accountability has not been fully achieved. For example, some have reported the conflicting incentive structures of the DOEs who crosscheck evaluation of offset project performance in order to determine access to finance generated from carbon credits. DOEs value robust project monitoring on the one hand and expeditious validation of carbon offsets to meet their commission on the other (Lohmann 2006), creating conflicting interests that could compromise accountability. Others criticize the perverse incentive structures of carbon offsets that place an emphasis on project developer profit over climate and socioeconomic outcomes (Sovacool 2011).

Whether the project evaluator is held accountable for and by these entities that he or she is accountable to depends upon the creation of an accountability system that addresses these concerns. However, since everything hinges on the information generated by the evaluation, the primary mechanism of accountability in these projects are the metric requirements that discipline the evaluators to collect a standardized quality of data and to analyze them in systematic fashions that ensure that those data are reflective of the effect of the project on the target communities, the climate, and the finances of participants in the carbon market.

3. Metrics as a Fulcrum of Accountability

An *indicator* is something expressed in numerical terms that provides useful information about a physical, social, or economic system (Farrell and Hart 1998) and *metrics* are mathematical formulas that organize and commensurate indicators and observations in order to assess a system. Metrics and indicators are used in combination to show progress and performance in activities, such as environmental restoration, public health interventions, education and social services, etc. (Metzenbaum 2001). M&E is a process that employs metrics to provide information on the performance of activities that individuals, workplaces, governmental agencies, etc. undertake in order to assess the extent to which their performance functions according to their goals.

M&E is often touted as an integral component of generating knowledge relevant to networks and relationships on the performance of relevant actors (i.e., regulatory branches, voting citizens, bureaucrats, etc.). However, what is less discussed is that metrics, the units that aggregate to form M&E requirements, can encourage or discourage accountable behavior amongst evaluators and data analysts.

One of the primary accountability concerns in the field of carbon offsets is how project developers are constrained from applying "biased" or "self-serving" metrics to measure the success and failures of their activities. These constraints are grounded in defining the M&E methodology requirements on which types of data are to be collected and which tools are required to be employed. The process through which specific metrics are chosen and the requirements for the conditions under which they are wielded to measure is critical to the understanding of how these metrics are used and why. For example, without disciplining standards of data collection and analysis, one could easily imagine a project developer arbitrarily intervening to select metrics for use by evaluators that will bias evaluation results towards effective carbon emission reductions and sustainable development goals even in the case that this is not empirically justifiable. For instance, M&E requirements that allow evaluators of cookstove carbon offset projects to use laboratory data in place of field data to assess fuel use differences between households that have a project stove and those households that do not, can produce results that are more favorable to the financial outcome of the project developer than they are a realistic indicator of true emission reductions. This is because the correlation between laboratory and field measurements is consistently weak and high control of combustion and fuel variables often can increase efficiency (Roden, Bond et al. 2009).

The design of more foolproof and 'sturdy' metrics is needed to protect against these project developer and evaluator proclivities and to avoid spurious interpretation of M&E data. Loose requirements without strict prescribed metric standards allow project developers to exercise their own choice of metrics that suit their financial needs. This may lead to inappropriate interpretation in favor of projects that endanger the accountability mechanisms of the carbon offset generation process. This in turn holds implications for the amount of carbon credits the project will generate, which affects the future of the project and its impact on the climate, the target community, and the public's trust in carbon offsets as a viable climate change mitigation mechanism. In this way, metric requirements hold consequences for the atmospheric, social, economic and ecological systems within which they function.

Metrics are needed to discipline actors to follow the desired measurement behavior and metrics should be designed with attention to what they are disciplining for (Please see Section 3.5). This requires not only the development of metrics that move estimates towards higher measurement accuracy, but also those that stabilize requirements in order to better control the inevitably subjective nature of metric choices. Therefore, to evaluate whether metric requirements actually ensure a fair assessment of the system they set out to describe it is important to critically examine what metrics render visible and invisible.

3.1 Blinding versus Illuminating Metrics

The choice of metrics used to evaluate a project or program partially determines what is seen and what is rendered invisible. Metrics act as a partial determinant of both the research findings and the subsequent policy decisions guided and bolstered by those findings. Thus, metrics can be divided into two broad categories in terms of their effects on results: 1) *Blinding metrics* construe representations of a system that blinds the viewer to specific factors of importance; and 2) *Illuminating metrics* construct representations of a system that make previously invisible factors and issues under investigation visible.

As an example of a *blinding* metric, if the M&E focuses exclusively on CAP reductions, issues of socioeconomic equity, health and other social and economic development factors will be rendered invisible in the final results and subsequently in future project and policy decisions. Examples of this are projects that focus on the replacement of CAPs with very high global warming potentials (GWP) that are used in industrial processes. Projects that focus on the destruction of HFC-23 in HCFC-22 facilities and the destruction of N_2O from adipic or nitric acid production are examples of these types of offset projects. They are popular because their CAP abatement costs are relatively low, often only around 1 US$/t$CO_2$e because of the amount of offsets generated per unit of the pollutant due to their high GWP (Schneider 2007). These projects are predominantly rolled out in China because it is a more simplified landscape to implement these projects compared to poorer developing countries. As such, these carbon offset projects arguably create wins for climate (and profits project developer profits) yet offer few gains in social, economic, health and other developmental areas. For these reasons, these projects are said to be cases of "C" (for clean), but a lack of "D" (for "development") in CDM (Wittman and Caron 2009).

Similarly, if controlled laboratory results are used to estimate some aspect of fuel consumption of a cookstove, there is an *a priori* evasion of visibility of relevant behavioral factors that influence household fuel consumption such as use of other appliances, difference in fuels, and of course, if the stove is being used at all. Indeed the presence of a cookstove in a household does not necessarily indicate that the stove is being used, or that it has replaced the use of other traditional cooking technologies (Ruiz-Mercado, Masera et al. 2011). *Illuminating* metrics have the opposite effect of *blinding* metrics. For example, an inclusion of requirements to measure differences in household socioeconomics before and after a cookstove carbon offset project is launched illuminates these factors and allows the information to weigh in on conclusions of the effect of the project with implications for future project and policy decisions. Mere assumptions, based on literature reviews or opinion, will keep the results blind to what is actually occurring on the ground. It is therefore crucial to critically unpack the methodologies and metrics required to be used in the M&E of carbon offsets in order to understand the impacts and benefits accrued by the project, as well as to assess the equity implications of their distribution.

4. The Gold Standard Carbon Offset Generation Process

Based in Geneva, Switzerland, the Gold Standard Foundation (GSF) offers certifications for carbon emission offset projects. The GSF is a non-governmental organization (NGO) founded by the World Wildlife Fund (WWF) in 2003. In terms of its governance structure, the GSF "consists of, and is supported by, a Secretariat of 30 people based in 10 different countries, a Foundation Board, a Technical Advisory Committee (TAC), more than 80 NGO supporters, a roster of industry experts, UN accredited auditors and registry platforms such as APX and Markit" (Gold Standard Foundation 2012). It promotes itself, in many ways justifiably so, as a certifier of lower reputational risk and more robust carbon offset credits than other certification programs such as the CDM. Moreover, the Gold Standard Foundation asserts that its carbon credits are guaranteed to represent not only real reductions in GHG emissions, but also that these credits represent gains for the economies, health, welfare and environment of the local community hosting the project (Gold Standard Foundation 2011).

A full explanation of the carbon credit generation process associated with cookstove projects under the GSM is beyond the scope of this chapter and so I lay out only the basic steps that are relevant to the Gold Standard carbon project process[7]. I list and explain these steps in Table 2.

---

[7] For a full explanation of the process from registration to carbon credit validation, please see the Gold Standard Foundation methodology (GSM), *Technologies and Practices to Displace Decentralized Thermal Energy Consumption*, the methodology used to monitor and evaluate cookstove projects for carbon offsets (Gold Standard Foundation 2012).

Table 2. Steps of the Gold Standard Foundation Certification Process

Project Pre-Evaluation: Is the proposal appropriate for a carbon offset project? Will it reduce emissions with energy efficiency or renewable energy?
Open a Registry Account: Register with the Gold Standard Foundation and upload documents.
Conduct Local Stakeholder Consultation (LSC): Discuss the impacts of the project with the "host" community. At the meeting there should be sufficient diversity of stakeholders (skills, gender, ethnicity, etc.). After the meeting the LSC report, or a synopsis of the proposed impacts – both positive and negative – will be uploaded to the Gold Standard Foundation website. After this is done, the project is considered a "Gold Standard Project Applicant" and becomes public on the Gold Standard website. Note: there are no specified opportunities for community members to weigh in on how data is collected or analyzed to evaluate the project. In most cases, these meetings are simply a way for project developers to work on buy-in and support from community stakeholders.
Finalize project design documentation (PDD): The PDD report includes the findings from the M&E of the project in the field. The M&E process investigates whether the project indeed reduces fuel consumption and emissions of CAPs below the determined baseline level of fuel consumption in the project area before the initiation of the project and whether the project improves sustainable development. This fuel consumption and demographic baseline is determined through two activities: 1) a social survey to measure behavior relevant to fuel consumption (i.e., the number of meals cooked per day, the number of people cooked for, etc.); and 2) an empirical kitchen performance test (KPT), which consists of measuring fuel (wood, charcoal, liquid petroleum gas, kerosene, etc.) both in households that have a project stove and in households that do not. This work is carried out by project affiliates or fieldworkers hired by the project with no specific training or performance requirements and no oversight to ensure that they are collecting or analyzing data correctly or responsibly. A "Sustainability Assessment" is also required to be included in the PDD, yet there are no standards for the type of data to be collected or the metrics chosen to analyze these data.
Validation: The project developer must hire a United Nations Framework Convention on Climate Change (UNFCCC)-certified Designated Operational Entity (DOE) as a third party auditor to visit the project site and validate the M&E results that are in the PDD. DOEs are independent auditors accredited by the CDM executive board to validate project proposals or to verify whether implemented projects have achieved their planned CAP reductions (UNFCCC 2012).
Conduct Second Stakeholder Feedback Round: This is a follow-up from the LSC, however it is not required to be conducted with stakeholders on site. Instead it is a write-up of how account was taken of stakeholder comments during the LSC. This step can be conducted simultaneously with the validations phase.
Registration: After the project developer has uploaded the necessary documents (PDD, legal documents, validation certificates, etc.), the Gold Standard Foundation initiates an 8-week review period in which all documents are reviewed. The project developer must then address comments from the Gold Standard Foundation.
Verification: In order to ensure that the project is functioning according to the results in the PDD, a second third-party audit by a DOE is required at least once in the first three years of the project and then once every three years.
Issuance: Once the Gold Standard Foundation has verified that all documents are of acceptable quality and agreement, carbon credits in the quantity of tons of carbon offset as specified by the PDD will be issued to the project developer.

Source: (Gold Standard Foundation 2011)

Table 3 lists my analysis of the monitoring requirements of the GSM. A deeper analysis of the metrics and their respective strengths and weaknesses are discussed in detail in Section 3.4.

Table 3. Gold Standard Cookstove Carbon Offset Monitoring Methodology Requirements

Representative Sampling of Households	Field-Base Monitoring Requirement?	Control of Variables during the KPT	Indicators of Sustainable Development	Emission Factors (CO2 & CH4) Requirements	Non-Renewable Biomass (NRB) Assessment	Third-Party Monitoring Guidelines
Yes, but not specified when it is appropriate	Yes, for baseline and project monitoring	Yes, but poorly specified	Yes, but poorly specified	None directly specified and project proponent is free to use the fossil fuel emission factors	Based on local data (studies, statistics, surveys, etc.) - if data is not available, national-level data is allowed for if conservative.	None

Source: (Gold Standard Foundation 2011)

5. Toward Improved Accountability through Prescribed M&E Requirements in the GSM

In this section, I critique the GSM and make systematic recommendations to improve it by creating accountability according to Weber's (2003) definition – that metric requirements can be used to discipline evaluators to collect and analyze data in standardized fashions that protect against perverse financial incentives to claim more project emission reductions than is empirically justifiable. These recommendations focus on the four groups of metric requirements that are most important and feasible to apply disciplinary guidance to in order to maintain an effective accountability system: 1) Representative sampling and the use of adjustment factors; 2) Control of variables during fuel-use data collection activities in the field; 3) Calculation of the fraction of biomass consumed my communities in the project area that is derived from non-renewable resources; and 4) Indicators of sustainable development. Improvement to these groups of metric requirements would provide a substantive standard within which evaluators and project developers must perform their M&E activities, and on which they must report to communities, certification agencies, and the carbon market. I present the specific standard and metric problems and make technical recommendations of disciplining metrics and standards that may help to ensure more credible and accountable results.

5.1 Representative Sampling Requirements and Adjustment Factor Guidelines in the GSM

As the GSM is currently written, there is limited guidance on how to generate *representative samples of households* from the target population of technology users. Representative sampling is the only way to ensure that emission and sustainable development measurements are robust and construct an accurate understanding of the effect of the project across all households and institutions under question instead of only convenient sub-populations. Moreover, currently under the GSM, adjustment factors[8], standard multipliers used to estimate, but not directly measure different stove types, fuel types, stove sizes, and technologies, are currently allowed to be used in place of some direct field measurements with little guidance on when the use of such adjustment factors is appropriate. Adjustment factors can wildly influence estimates of fuel-use and other parameters relevant to GSM carbon crediting. For example, measuring the fuel consumption of a group of one stove size and then using an adjustment factor to *indirectly* measure a group of stoves of a larger size has embedded assumptions about efficiency that may not be empirically accurate. Even more to the point, if project developers have the latitude to be able to choose their own adjustment factors, perverse financial incentives to choose the adjustment factor that gives them the highest yield of carbon credits is quite likely.

Without metric requirements that require direct field monitoring, project proponents have a limited incentive structure to be accountable to stakeholders including target communities in which projects function (Figure 1). This is important in terms of representative sampling and the use of adjustment factors because local field conditions can differ enormously across geographic, ecological, and socio-cultural space, thus reducing generalizability and increasing the need for contextually bounded primary data collection. For example, even within small countries, such as Ghana, Mali, or Guatemala geographic and socio-cultural differences including ambient temperature (the need for warmed bath water, space heating, etc. or not), different foods that require more, less, or different fuel to prepare, and the relative accessibility of charcoal, wood, LPG, or dung contribute to differential fuel consumption scenarios. Thus, biases in household sampling can propagate sometimes severe biases in fuel use estimates, which in turn can lead to biased estimates of CAP emission reductions and subsequent distortions in carbon credit allocation to project developers. Without clear guidelines on how to conduct representative sampling, project developers and evaluators are free to choose to monitor sub-populations that help their bottom line – to maximize their carbon credit allocation.

The list of recommendations aims to better ensure that the metric requirements in the GSM adequately discipline evaluators to follow a procedure that encodes a more complete representation of the offset. Each recommendation is accompanied by guidelines on when adjustment factors are appropriate and under which conditions they may be inappropriate.

5.1.1 Recommendations: Representative Sampling

My overarching recommendation is that project developers and other affiliated parties choose which household energy technologies they will seek carbon crediting for and after this determination, data should be directly collected only on those attributes for the baseline and subsequent project monitoring investigations.

This recommendation aims to ensure that the M&E activities generate data derived from direct measurement of those attributes of a cookstove project that will be counted for carbon crediting and sustainable development acknowledgment. As explained above, the requirement to directly

[8] Although adjustment factors provide opportunities to conduct more cost-effective and simplified means of estimating fuel savings across different technologies, fuel types, and geographic areas, they should not be a replacement for direct representative sampling.

measure indicators of project impacts avoids the use of multipliers and adjustments that often fail to accurately measure the behavioral, social, technological, and environmental factors salient to reliable estimates. This requirement will discipline evaluators to collect data that are more empirically representative, and in turn, the information will be more accountable to the target population and public and private entities that offset their carbon emissions through the purchase of carbon credits. Below, I indicate specific data collection guidelines and adjustment factor applications in the areas of fuel types, stove technologies, stove sizes, and the application of the methodology to carbon offsets related to drinking water interventions aimed to replace boiling.

Recommendation: Different Fuel Types

Types of fuels used in the target population should be assessed independently from one another (i.e., measure wood and measure charcoal separately) and adjustment factors should not be used to estimate fuel use for different baseline or project fuels. This is because different fuels emit different proportions of CAPs per unit time or cooking event. For example, if a proportion of the customer population uses wood and another proportion of that same population uses charcoal, the M&E entity must measure each fuel type separately. It therefore should not be acceptable to measure wood consumption exclusively and then use an adjustment factor to determine charcoal consumption for cooking. It should be appropriate, however, to choose to include only the wood or only the charcoal users in the carbon offset project, leaving households and institutions that use different fuels out of the carbon offset project. Lastly, adjustment factors must not be used to estimate the unmeasured baseline fuel type(s). A lack of adherence to these recommendations could result in further ambiguity and spuriousness of carbon savings and leave open opportunities for project-associated evaluators to claim a greater offset than is empirically justifiable.

Recommendation: Different Stove Technologies

The stove technologies that a customer group uses at the *baseline* as well as the stove technologies that a project promotes to reduce CAP emissions during the *project implementation* should be specified and directly measured in a fashion that is representative of the user population. For example, if at baseline, half of a customer population uses a three stone fire and the other half of the customer population uses a locally-produced ceramic wood stove with an internal combustion chamber, then the project proponent has to choose one of two options: 1) Monitor one half of the customer population (defined by the type of wood stove used) and compare the intervention stove to that baseline; or 2) Choose to seek carbon finance for both of the baseline stove populations and then measure fuel use for both stove types, comparing each to the intervention cookstove separately. Adjustment factors should not be used to estimate fuel consumption of unmeasured baseline cooking technologies.

In the case of sampling the project stove technology in which a project developer seeks carbon finance from more than one type of cookstove technology, each type of cookstove must be *directly* monitored and evaluated separately for emission reductions. Adjustment factors should not be used to extrapolate from one cookstove technology that has been directly monitored to the other cookstove technology that has not been directly monitored. This helps to ensure accountability between the project proponent and the stove customer as well as between the project proponent and the international community that relies on real carbon emission reductions for setting and meeting emission targets.

One exception to direct monitoring requirements of stove technologies should be that project proponents should be able to treat multiple baseline stove technologies as well as multiple intervention stove technologies as singular categories if the technologies can be demonstrated to be similar in their fuel-consumption attributes (fuel type, fuel consumption rate per person, etc.). For example, if a community has two internal combustion ceramic cookstoves at their baseline (prior to intervention) and it can be shown that there is not a statistical difference in the fuel consumption between the two stoves, they can be monitored as one aggregated baseline category so long as commensuration of the categories results in a conservative aggregated category. Commensuration of different technologies into singular monitoring categories must be supported by robust data in the literature or from primary empirical data collected by an M&E entity.

Recommendation: Different Stove Sizes

Related to the recommendations above on inclusion of multiple cookstove technologies in a single project is how to methodologically deal with inclusion of multiple sizes of the same stove technology within a single project. There are many instances when project developers disseminate a variety of sizes of the same cookstove technology in order to meet the needs of their target population(s). For instance, cookstoves with smaller enclosed combustion chambers are targeted to households that cook for fewer people, while cookstoves with larger enclosed combustion chambers are targeted to those households that cook for more people.

I recommend that the use of adjustment factors in place of direct monitoring to generalize fuel consumption across different sizes of the same technological design should be permissible under the condition that the same fuel type is being used across all stove sizes. These adjustment factors can be implemented in the form of direct application of the fuel consumption rate of the less efficient intervention cookstove to the more efficient cookstove; or in the form of conversion metrics such as kg of fuel per person (or per person-meal), time per person-meal, etc. Of course it should remain a requirement that the estimates are adequately justified as conservative.

Recommendations: Boiling Drinking Water

If a project proponent seeks to document carbon emission reductions from the activity of boiling drinking water, they should have to monitor fuel consumption from water boiling activities directly. Adjustment factors should not be used to extrapolate fuel savings from one household energy application (such as cooking) to another (such as boiling drinking water).

Exception to Water Boiling Adjustment: The local choice of cookstove used to boil water often differs from those cookstoves used to cook food. If, however, it is shown via empirical survey data from the specific project area, that the same baseline technologies are used to cook food and boil water, adjustment factors may be used per the guidelines in the exception to stove technology adjustment (under the recommendations for different stove technologies, above) so long as the estimate is adequately justified as conservative.

Recommendations: Extreme Seasonal Weather Variation[9]

If a project proponent aims to reduce carbon emissions and to seek subsequent carbon finance from the activity of space heating, they should treat this as an activity that is different from cooking and directly monitor it during a representative period in the season when the stove is being used as a space-heating device (i.e., conduct monitoring in the cold season). Adjustment factors should not be allowed to be used to extrapolate cooking activities in the warm season to space heating in the cold season, as the time-activity, technologies, and fuel types involved may differ in ways that cannot be generalized across seasons.

5.2 Guidelines for Controlling Variables during the Fuel Consumption Tests

One of the strengths of the Gold Standard Methodology is that it requires empirical *field based* kitchen tests, such as kitchen performance tests (KPTs) to measure fuel use as opposed to tests that are performed under more controlled conditions (i.e., water boiling tests or controlled cooking tests)[10]. KPTs are "subsumed tests" that measure all fuel consumption at the *household* or *institutional* level – taking into account all energy consumption including all stoves, ironing, cooking, heating, etc. – as opposed to only testing the project stove in isolation. This is important because KPTs answer the salient climate-relevant question of what effect the stove has on household fuel consumption as opposed to the efficiency of the project stove alone, a situation that rarely occurs (Ruiz-Mercado et al. 2011). Put another way, KPTs test the project with the fuel-consumption factors defined by the population that interacts with it. With these locally nuanced factors, the KPT ultimately determines whether the project succeeds or not. Alternatively, more controlled cooking tests make the often erroneous assumption that a community will use the stove 100% of the time in the same manner and under the same conditions that a laboratory or a project developer dictates. Thus, the KPT departs from other more controlled tests by remaining sensitive to the socio-behavioral and other measured and unmeasured systems that it is rolled out in. High amounts of variable control during the cookstove kitchen test could result in significant over- or under-estimates of fuel savings from the cookstove technology (Bailis, Berrueta et al. 2007). This leaves room for evaluators to control the KPT conditions and does not adequately discipline evaluators into responsibly measuring fuel use. This contributes to a "blinding metric" issue because it hides what actually occurs on the ground.

Currently, the GSM does not clearly specify guidelines on the extent to which evaluators are able to control the conditions within which the KPTs take place. The benefit of using a field-based test is that it more accurately reflects real-world cooking and fuel consumption contexts. Too much external control of variables during the KPT threatens to decrease the real-world, everyday contexts that the kitchen test was developed to be sensitive to in the first place. Weak guidelines on these parameters leave a sizable amount of leeway for evaluators to control the conditions in a way that can maximize the appearance of CAP reductions, even if it is not empirically justifiable.

---

[9] In certain regions there are extreme seasonal weather variations due to topography, elevation, and/or latitude. These variations can change both the fuel types and/or the intensity of stove usage, often linked to the need for space heating.

5.2.1 Recommendations

In order to maintain adherence to their real world household energy practices households/institutions should not be influenced by any external parties regarding their choice of stoves, fuels, foods, or meals during the kitchen tests. Asking the household/institution to maintain a food diary, however, is acceptable.

5.3 Calculation of Non-Renewable Biomass (NRB) Fraction

According to the GSM, project developers are only allowed to claim carbon offsets when they reduce biomass derived from non-renewable sources. For instance, if a community uses wood to meet its household energy needs and the amount of wood extracted from forests is equal to or less than the amount of biomass that is re-generated (either through natural re-growth or through agroforestry) on an annual basis, forests are assumed to not being depleted from a carbon standpoint.

Despite its salience to carbon-offset calculation, the GSM provides surprisingly little guidance on how to appropriately and systematically calculate the fraction of NRB used in a given population. Currently, evaluators are asked to search for the most relevant data to the area within which the carbon project is being implemented and in the absence of local biomass and forest surveys, to use regional or national estimates – often sourced from the Food and Agriculture Organisation (FAO) – or "expert opinion" with little guidance on what constitutes and "expert". It is clear that NRB estimates vary greatly by location, even within the same county, as evidenced by a study by Ghilardi et al. (2009) that found biomass renewability in the Central Highlands region of Mexico alone ranged from 0% to 96% in different locations.

As another example, GSF PDD estimates of biomass renewability for the same project areas and years in the Greater Accra and the Eastern Region of Ghana range from 77% to 96% for cookstoves projects externally financed by E+Co and JP Morgan, respectively (Gold Standard Foundation 2012). While the E+Co estimates followed systematic and transparent methods, the JP Morgan calculation was non-systematic, difficult to understand, and scientifically questionable. Nonetheless, the GSF approved the 96% non-renewability estimate and from a carbon finance perspective this is far more important than scientific credibility because subsequent carbon projects can now cite this elevated figure. Of course, without clear guidelines, it is in the project developer's best financial interest to argue for and use the highest estimates of non-renewability, often inflating estimates above what is arguably justifiable from an empirical perspective.

5.3.1 Recommendations

It is the case that a primary issue in calculating "non-renewability" is that this arena is, in many parts of the developing world, extremely data poor. While crude national-level estimates exist in many nations, local and regional data is often not available. To fill these gaps, the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology was developed through a partnership between the Wood Energy Programme of the FAO Forest Products Service (FOIP) and the Ecosystem Research Center (CIECO) of the Institute of Ecology of the National University of Mexico (UNAM) (Masera, Ghilardi et al. 2006). WISDOM integrates geo-referenced socio-demographic and natural resource databases into layers that can be analyzed within a geographical information system (GIS) frame. Thus, WISDOM provides comprehensive estimates that integrate the amount of woodfuel available with the demand for that woodfuel within an adaptive framework. WISDOM is used to generate more sound national and regional/local (Ghilardi, Guerrero et al. 2009) estimates than relying on national-level data alone. For a detailed WISDOM methodology, please refer to Ghilardi et al. (2009) and it is my recommendation that it be required to be used in place of crude national estimates.

5.4 Indicators of Sustainable Development and Socioeconomic Implications of Cookstove Interventions

As the GSM currently exists, there is a requirement for periodic monitoring of sustainable development indicators such as time-savings for cooks, economic savings from decreased fuel consumption, and health status of women and children. There are, however, no requirements as to which social and socioeconomic criteria and indicators of sustainable development are to be included in the surveys and other monitoring instruments. The lack of required categories of metrics to include in monitoring does not adequately guide evaluators as to what is generally important to measure. This contributes to a *blinding metric* problem: what is not measured is simply not seen, leaving evaluations of projects with anemic datasets and the ability for evaluators to make opportunistic claims without empirical justification.

Another issue – more tied to institutional rules of the GSF and the carbon market more generally rather than the a metric or standards issue with the GSM – is that, despite the GSF framing their value as a certifier of carbon credits that simultaneously increase sustainable development, no mechanisms exist to commensurate sustainable development and socioeconomic measurements of stove projects with measurements of CAP reductions. Thus, if a project greatly improves indicators of sustainable development, its carbon credits will be priced the same as a project that reduces the same amount of CAPs but does little for sustainable development.

5.4.1 Recommendations

The following broad criteria should be included <u>as a minimum</u> in the survey instruments in order to track and <u>illuminate</u> the implications of cookstove interventions over time, and across projects and geographic space:

<u>Recommendations: Time-Savings</u>
Evaluators should have to gather data on the implications of the project cookstove for time-savings or otherwise for households due to cookstove adoption (Table 3). This is important because, theoretically, time-savings from these activities could free up the cook and fuel gatherers for increased economic opportunities that could translate to increases in household resources. It is important to note that this has not been empirically substantiated in the literature to date. Nonetheless, without these measurements, these issues are blinded from the results used to understand this important economic development effect of the cookstove carbon offset project.

Table 3. Examples of Metrics to Estimate Time-Savings

Categories of Time-Savings	Metric Example
Gathering Fuel	• Hours per day, week, month
Preparing Fuel (i.e., chopping)	• # Of times per day, week, month • Amount of time per day, week, month
Cooking Time	• Minutes per cooking event • Time per day

Note: These metrics should be employed for data collection and analysis both before and after the introduction of a new cookstove

Recommendations: Measurements of Household Socioeconomics

Indicators of household socioeconomics could include measures of economic status (Table 4). Without disciplined requirements to collect data on household socioeconomic changes before and after the project cookstove enters the household or institution, evaluators are free to make statements of benefit that may not be empirically founded.

Table 4. Examples of Metrics to Estimate Household Socioeconomics

Categories of Socioeconomics	Metric Example
Income	• Income per day, month, year
Assets	• Ownership of electronics, television, etc. • If locally relevant: number of heads of cattle, chickens, etc. • Land ownership (y/n), amount of land owned, etc. • Ownership of transportation (bicycles, cars, motorbike, etc.)

Note: These metrics should be employed for data collection and analysis both before and after the introduction of a new cookstove

Recommendations: Commensuration of Sustainable Development and Carbon

As mentioned, although the GSM can do little about the naiveté of the carbon market regarding the difference between a carbon credit that does or does not come from a project rooted in sustainable development, it is worth noting that the GSF could provide incentives to project developers to implement projects that not only reduce CAP emissions, but also contribute to sustainable development to try to change this. Thresholds for sustainable development gains could be linked with differential values of carbon credits on the carbon market. Put another way, projects that contribute to sustainable development could sell their carbon credits at a premium over projects that do not. Because these changes predominantly involve the structure of the *GSF* and not the *GSM*, the development of these thresholds is beyond the scope of this paper. Nonetheless, following the GSM sustainability recommendations in this section may help to build an understanding of what positive sustainable development thresholds might be in the future.

Another intersection of sustainable development and the carbon market is improved health, and in the case of cookstoves, the health of woman and children has the most to gain. Cookstoves built for fuel efficiency and reduction of CAPs do not necessarily reduce emissions of health-damaging pollutants and vice versa. Of course this is not a law of physics and it is likely that, given the proper incentives, cookstove engineers and project developers would develop cookstoves that could simultaneously reduce CAP emissions and health damaging pollutants. Again, incentives for "healthier" biomass cookstoves could be sourced from GSM metrics that require the evaluator to measure emissions during the KPT. Similarly to differential pricing of carbon credits upon meeting sustainable development thresholds as described above, if a stove is able to bring household emissions below a determined threshold, the GSF could perhaps deem these credits more financially valuable than carbon credits that are simply associated with decreased CAP emissions. Unfortunately there are no global standards for cookstove emissions yet, although the ISO has begun to convene to move this process forward.

Although there are no global standards for cookstove emissions, the World Health Organization (WHO) has air quality guidelines for indoor and outdoor environments for PM_{10} (20 ug/m^3) and $PM_{2.5}$ (10 ug/m^3) that could be adopted by the GSF as standards, which if met could secure a premium price for carbon credits over credits from projects that did not meet or measure these environmental health-oriented parameters. Alternatively, pricing of carbon could be applied in incremental steps as a stove reduces indoor air concentrations and is able to meet any of the three WHO *interim* targets (Table 5) (WHO 2006).

Table 5. WHO Annual Mean Air Quality Guidelines and Interim Targets for PM_{10} and $PM_{2.5}$

Annual Mean Level	PM_{10} (ug/m^3)	$PM_{2.5}$ (ug/m^3)	Basis for Selected Level
WHO Interim Target-1 (IT-1)	70	35	These levels are estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2-11%] compared to WHO IT-1 levels.
WHO interim target 3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risk by another approximately 6% [2-11%] compared to WHO-IT-2 levels
WHO Air Quality Guidelines (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary, and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM2.5 in the ACS study (Pope et al. 2002). The use of PM2.5 guideline is preferred.

Adapted From: (WHO 2006)

Of course, emissions are a function of, but not the same as indoor emissions. Some work has been done using Monte Carlo box modeling methods to estimate indoor air concentrations given a stove that achieves given emission factors (Johnson, Lam et al. 2011). More work should be done to ensure that these methods are reliable prior to being used to value carbon credits generated from carbon offset projects.

5.5 Independent Third-Party Monitoring

Although there is some debate around the effectiveness of external review, the engagement of independent third-parties, with no financial stake in the results of an evaluation is a well-understood way to minimize bias in data collection and data analysis (Ball, Owen et al. 2000). The current loose rules in the GSM that allow financially interested evaluators with financial interests in specific outcomes of the project evaluation to assess carbon offset projects allows and even incentivizes evaluators to use biased data collection and blinding metrics.

5.5.1 Recommendations

M&E activities in the GSM would benefit by being implemented or supported by expert third parties (i.e., M&E firms) that are familiar with the implementation of these types of protocols and data analyses, and have experience with the communities that host the projects. Further, third party monitoring may also help to decrease perverse incentives to skew data towards particular outcomes to shed more favorable light on projects than they deserve.

Requiring these third party M&E entities to be *independent* from the project developer would further ensure the fulfillment of the Gold Standard Foundation *Principles of Engagement* which stipulate that real emission reductions and sustainable development gains be achieved in order for the CAP reductions to be considered a certifiable carbon credit. Independent third party monitoring could help to fulfill the Gold Standard Foundation's goals to certify higher quality carbon credits and would enable a more robust commitment to true emission reductions and sustainable development outcomes with measureable outcomes.

6. Discussion

In Table 5, I summarize my recommended disciplining metrics and standards, their characteristics, and justifications for their inclusion for the metrics and standard recommendations that can be addressed by the GSM.

Table 5. Summary of Recommended Disciplining Metrics and Standards for the GSM

Recommended Metric or Standard	Characteristics	Justification
Representative Sampling		
Restrictions on the use of adjustment Factors		With few exceptions, prohibitions on adjustment factors confine evaluators to using empirical, field-based data, which is more representative of reality.
Do not control any behavior of households during kitchen performance tests	• Do not exert control over type of fuel or stove used. • Do not exert control over type or quantity of meals cooked • Do not exert control over other household energy consumption activities.	Controlling of household behavior during the KPT can result in non-representative sampling and subsequently skewed results, often in the direction of financial profit for the project developer.
In the absence of credible local or regional estimates, use the WISDOM model to generate NRB estimates	WISDOM is a GIS-based systematic process through which national and local natural resource and social access data is aggregated to understand the amount of NRB that a population actually has access to.	Without requirements for systematic methods to estimate the NRB fraction of fuel consumed in the project area, evaluators will continue to employ whichever method will provide them with the highest fraction that, in turn, will provide them with the highest numbers of carbon credits.
Sustainable Development		
Time-Savings: Gathering Fuel	• Hours per day, week, month	Time Savings is a major claim of cookstove projects with little to no empirical data to substantiate it.
Time-Savings: Preparing Fuel (i.e., chopping)	• # Of times per day, week, month Amount of time per day, week, month	Time Savings is a major claim of cookstove projects with little to no empirical data to substantiate it.
Time-Savings: Cooking Time	• Minutes per cooking event Time per day	Time Savings is a major claim of cookstove projects with little to no empirical data to substantiate it.
Income	• Income per day, month, year	A basic, but important indicator of socioeconomic status and an important indicator to track effects of a cookstove carbon offset project.
Assets	• Ownership of electronics, television, etc. • If locally relevant: number of heads of cattle, chickens, etc. • Land ownership (y/n), amount of land owned, etc. • Ownership of Transportation (bicycles, cars, motorbikes, etc.)	Oftentimes more locally-relevant indicator of socioeconomic status.

Cookstove carbon offset projects are a promising approach to reduce CAP emissions while simultaneously contributing to sustainable development outcomes. That said a primary obstacle to the generation of carbon credits that reflect true emission reductions and sustainable development gains is that accountability between the project proponent, the community, and consumers of carbon credits remains low. This paper demonstrates that accountability should not only be assessed among interactions between people, but should also be critically examined in the metric requirements used to evaluate the process.

In this way, prescribed metrics are not only mathematical tools to assess performance, but are also tools that can increase or decrease the visibility of factors relevant to the function of an accountability system. There is an old saying that "you don't get what you want, you get what you measure". My analysis suggests, however, that if project proponents are free to choose what and how they measure, there are few barriers from them finding what they want instead of what empirically exists. Strengthening the prescription of metric requirements in cookstove carbon offset methodologies from not only an accuracy perspective, but also from a disciplinary standpoint focused on keeping project developers accountable to those that rely on robust understandings of what does or does not reduce emissions of CAPs. This will help to ensure that the carbon-offset arena becomes stronger, more sustainable, and more accountable to target communities, investors, the climate, and to the human and ecological systems that depend on it.

The contribution of this study remains applicable beyond the cookstove carbon offset process. Of course the wielding of metrics to construct an image not reflected in reality is pertinent to other carbon offset methodologies that are being deployed to monitor and evaluate projects from household solar panel to large-scale wind-powered turbine projects. Moreover, the enhancement of accountability mechanisms in other environmental performance measurement processes such as the environmental impact report required under the National Environmental Protection Act (NEPA) and the California Environmental Quality Act (CEQA) could benefit from critical analyses of their metric requirements and standards with an eye towards the modes of accountability in the metric requirements that make important parameters visible and invisible.

As discussed, accountability exists in many forms of relationships throughout projects and processes and if these relationships are not properly formulated and regulated, systems of accountability will surely break down. For instance, in the case of carbon offset project accountability, how project proponents gain access to project sites, how they work with households and communities to test the effectiveness of the project, and how members of the target community are able to call back to the certification agency if there are questions about how the metrics are being applied to their community or activities are all important aspects of accountability that do not directly involve metrics. Nonetheless, robust accountability systems that discipline evaluators into accountable data collection, data analysis, and results reporting to the certifying institution and other stakeholders are needed. As demonstrated in this paper, in the case of carbon offset projects, the M&E of the carbon credit certification process could be an effective site for such discipline.

In conclusion, metrics and metric requirements are not objective quasi-laws that innocuously portray reality when used to evaluate projects, processes, and markets. Rather they are tools used to evaluate the legitimacy of flows of capital and networks of social and cultural groups. Therefore it is imperative to critically examine and retrofit metrics in the context of their use in order to uncover, expose, and rectify gaps in the accountability of processes. This paper demonstrates that, concerning accountability in the carbon offset sector, the devil is in the details. Perhaps though, with proper construction of disciplinary metric requirements, the saint might be in the details as well.

Chapter 5. Dissertation Discussion

My dissertation shows that environmental health, equity, and accountability are important to effective climate change mitigation strategies that are sensitive to environmental concerns and the social systems within which these strategies function. To more fully understand the process of climate change mitigation strategy development to maximize benefits to environmental, social, and economic systems, it is helpful to understand the process as a multi-faceted and iterative process. This process begins with the generation of knowledge including scientific, community, political, and policy information. Strategies to reach goals based on information that has been generated, compiled, and vetted are then manufactured and implemented. Lastly the monitoring and evaluation of the implemented strategies is enacted in order to track indicators that determine the success or failure of the strategy, and thus assure performance.

Each section of my dissertation explores a step (or a series of steps) through this iterative process towards sound climate change mitigation policy development aimed to maximize environmental, social, and economic co-benefits. The section on inconsistencies in scientific knowledge about BC highlights the importance of making sound science and robust systems for sharing that science across disciplines through consensus-building activities. The chapter on the Climate Gap in environmental health and equity co-benefits in and concerns over AB 32, explores the outcomes of a mitigation policy portfolio when mapped onto a diverse pre-existing social and economic system. Lastly, unpacking the accountability dimensions of the monitoring and evaluation processes of carbon offset projects in the cookstove arena critically examined how measurement matters in order to be able to see the implications of a mitigation policy at the ground level.

The iterative process of mitigation strategy development, from the source of knowledge to the outcomes of implementation and evaluation, is not always linear (Figure 6). For example, lessons learned from the M&E of a cookstove project can be used to fortify the knowledge used to manufacture subsequent project designs and technologies. Moreover, community knowledge of economic and health equity features of policies, as is the case in the implementation of AB 32 in California, has the potential to influence the focus of measurements and the metrics employed to evaluate the success and failures of a mitigation strategy. These non-linear interpenetrations throughout the mitigation strategy development process have helped to strengthen climate change mitigation strategies in the real world and develop them to fit local contexts.

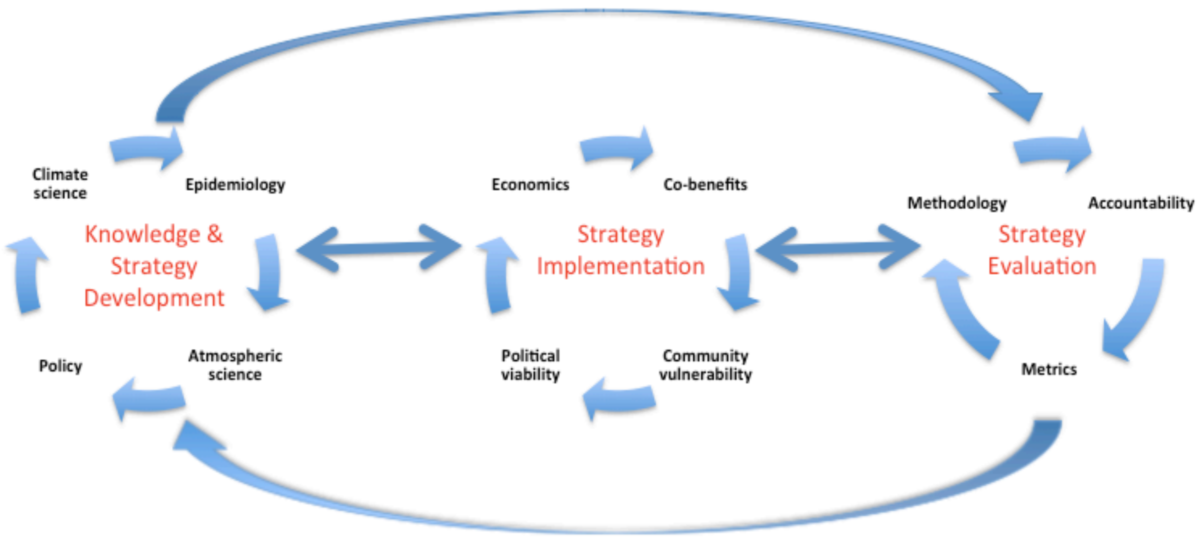


Figure 6. Interpenetration of Knowledge and Activities Along the Iterative Climate Change Mitigation Development Process

These knowledge interpenetrations and mutual learning processes are also not limited to crossovers *between* major links on the mitigation strategy development process (i.e., knowledge, development, implementation, evaluation), but can also be found *within* these linkages (Figure 6). For example, in the first link in the mitigation supply chain ("knowledge and strategy development") the inconsistencies in BC measurements and conceptions between the health, atmospheric science, and public policy communities reveals how the sharing of knowledge can heal the often-problematic tension between disciplinary depth and commensurability. More specifically, while the atmospheric science community often generates extraordinarily detailed knowledge, this information often lacks commensurability with processes necessary to inform public policy (i.e., commensuration of emission inventories with standards in the IPCC). The aim of my analysis of the inconsistencies in assumptions, data types, and conceptual understanding of BC as a climate forcing and health-damaging pollutant was an attempt to shed light on concrete bridges across communication silos that exist between three integral groups of information manufacturers: atmospheric scientists, health scientists, and policymakers. Building bridges between these cleaved disciplinary worlds could infuse the climate mitigation development process with important knowledge to fortify and inform the implementation and evaluation of subsequent mitigation strategies. Without this sharing of information, fundamentally flawed strategies such as using rocket or blower cookstoves to abate BC will fail (Berkeley Air Monitoring Group 2011).

As another example, in the chapter on AB 32, I explored the interconnections between literatures in environmental health, epidemiology, climate science, and economics. These individual fields and the relevant knowledge generated from them were overlaid on the vulnerability landscape across the California population in order to identify socioeconomic, geographic, and demographic sub-populations at increased risk of impacts from climate change climate change mitigation strategies. On the ground, the engagement of activists, economists, academics, the public health department, and NGOs during the planning and implementation held great ramifications for the ways in which this suite of policies are being laid out. Moreover, these ramifications have cross-penetrated all links of the mitigation strategy supply chain from basic knowledge of climate, environmental, community, and place-based systems to implications for socioeconomic and demographic sub-groups. The opening of the climate gap as an arena of research holds implications for the knowledge from which mitigation strategies will arise in the future.

Chapter 6. Dissertation Conclusion

Anthropogenic climate change and climate change mitigation policies do not only concern environmental systems, but they also hold implications for human and social systems. Without proactive policies and other strategies that address both environmental systems as well as social systems throughout their implementation processes and their outcomes, climate change mitigation policies could exacerbate existing health, economic, and power disparities from the local to the international level.

Climate change mitigation could be planned and implemented in a fashion amenable to policy development that addresses CAP emissions with simultaneous mechanisms to support and improve human health and to avoid economically regressive outcomes. Currently however, knowledge generation, strategy development, implementation, and evaluation of climate change mitigation operate within highly fractured silos that address these issues in a piecemeal fashion. To build effective climate change mitigation, the most rigorous, vetted, and highest quality data must be employed across disciplines and sectors and the resultant policies and projects must be supported by strict accountability standards.

Sources Cited

Ackerman, F. and E. Stanton (2008). The cost of climate change: what we'll pay if global warming continues unchecked. New York, NY, NRDC.

ACS. (2007). "2007 American community survey 1-year estimates." Retrieved July 10, 2010, from http://factfinder.census.gov/servlet/ADPTable?_bm=y&-geo_id=05000US06037&-qr_name=ACS_2007_1YR_G00_DP3&-context=adp&-ds_name=&-tree_id=307&-_lang=en&-redoLog=false&-format=.

Apte, J. S., T. W. Kirchstetter, et al. "Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India." Atmospheric Environment **45**(26): 4470-4480.

Backstrand, K. (2008). "Accountability of networked climate governance: The rise of transnational climate partnerships." Global Environmental Politics **8**(3): 74-102.

Bahadur, R., Y. Feng, et al. (2011). "Impact of California's air pollution laws on black carbon and their implications for direct radiative forcing." Atmos. Environ. **45**(5): 1162-1167.

Bailey, D., K. Knowlton, et al. (2008). Boosting the benefits: improving air quality and health by reducing global warming pollution in California. New York, NY, Natural Recources Defense Council.

Bailis, R., V. Berrueta, et al. (2007). "Performance Testing for Monitoring Improved Biomass Stove Interventions: Experiences of the Household Energy and Health Project." Energy for Sustainable Development **6**(2): 57-70.

Ball, A., D. Owen, et al. (2000). "External transparency or internal capture? The role of third-party statements in adding value to corporate environmental reports." Business Strategy and the Environment **9**: 1-23.

Ban-Weiss, G. A., M. M. Lunden, et al. (2008). "Measurement of Black Carbon and Particle Number Emission Factors from Individual Heavy-Duty Trucks." Environmental Science & Technology **43**(5): 1419-1424.

Basu, R., W. Y. Feng, et al. (2008). "Characterizing temperature and mortality in nine California counties." Epidemiology **19**(1): 138-45.

Basu, R. and B. D. Ostro (2008). "A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California." Am J Epidemiol **168**(6): 632-637.

Behera, D. and T. Balamugesh (2005). "Indoor air pollution as a risk factor for lung cancer in women." J Assoc Physicians India **53**: 190-2.

Berkeley Air Monitoring Group (2011). In-home emissions of greenhouse pollutants from rocket and traditional biomass cooking stoves in Uganda. Washington, DC.

Blaikie, P., T. Cannon, et al. (1994). At risk: natural hazards, people's vulnerability, and disasters. Routledge, New York.

BLS (2002). Consumer expenditure survey. Washington DC, Bureau of Labor Statistics.

Bolin, R. and P. Bolton (1986). Race, religion, and ethnicity in disaster recovery, program on environment and behavior. Boulder, CO, University of Colorado, Institute of Behavioral Science, Natural Hazards Research and Applications Information Center.

Bond, T. C. (2009). "Black Carbon Emissions Inventory, Version 7.1.1, 14 Feb 2009." Retrieved Jul 9, 2009.

Bond, T. C., D. G. Streets, et al. (2004). "A technology-based global inventory of black and organic carbon emissions from combustion." Journal of Geophysical Research-Atmospheres **109**(D14).

Bond, T. C. and H. L. Sun (2005). "Can reducing black carbon emissions counteract global warming?" Environmental Science & Technology **39**(16): 5921-5926.
Brook, R. D., B. Franklin, et al. (2004). "Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association." Circulation **109**(21): 2655-71.
CARB (2006a). Assembly Bill No. 32: California Global Warming Solutions Act of 2006.
CARB (2006c). Emission reduction plan for ports and goods movement in California. Sacramento, CA.
CARB (2008a). Methodology for estimating premature deaths associated with long-term exposures to fine airborne particulate matter in California. Sacramento, CA, California Air Resources Board.
CARB (2008b). Climate change draft scoping plan: a framework for change. June 2008 discussion draft. Pursuant to AB32. The California Global Warming Solutions Act of 2006. Sacramento, CA, California Air Resources Board.
CARB (2008c). Diesel particulate matter health risk assessment for the West Oakland community: Preliminary summary of results. Sacramento, CA, California Environmental Protection Agency, Air Resources Board.
CARB (2008d). Climate change proposed scoping plan: a framework for change. Sacramento, CA, California Air Resources Board.
CASS (2002). California agriculture statistical review. Sacramento, CA, California Agriculture Statistics Service.
CBO (2007). Trade-offs in allocating allowances for CO2 emissions. A series of issue summaries from the Congressional Budget Office. Washington, DC, Congressional Budget Office.
Chafe, Z., S. Mehta, et al. (Under Review). "Estimating the Proportion of Fine Particulate Ambient Air Pollution (PM2.5) Attributable to Household Fuel Use for Cooking in Asia."
Chisolm, L. (1995). "Accountability of nonprofit organizations and those who control them: the legal framework." Nonprofit Management and Leadership **6**(2): 141-156.
Cooke, W. F., C. Liousse, et al. (1999). "Construction of a 1 degrees x 1 degrees fossil fuel emission data set for carbonaceous aerosol and implementation and radiative impact in the ECHAM4 model." Journal of Geophysical Research-Atmospheres **104**(D18): 22137-22162.
Cooke, W. F. and J. J. N. Wilson (1996). "A global black carbon aerosol model." Journal of Geophysical Research-Atmospheres **101**(D14): 19395-19409.
Corburn, J. (2005). Street science: community knowledge and environmental health justice. Cambridge, MA, MIT Press.
Corburn, J. (2009). "Cities, Climate Change and Urban Heat Island Mitigation: Localising Global Environmental Science." Urban Studies **46**(2): 413–427.
Cordova, R., M. Gelobter, et al. (2006). Climate change in California: health, economic and equity impacts. Oakland, CA, Redefining Progress.
Cornwall, A., H. Lucas, et al. (2000). "Introduction: accountability through participation: developing workable partnership models in the health sector." IDS Bulletin **31**(1): 1-13.
Costello, C., O. Deschênes, et al. (2009). Economic impacts of climate change on California agriculture. Climate Action Team Report. Sacramento, CA, California Energy Commission; California Air Resources Board**:** 53.

CRAG (2002). Preparing for a changing climate: the potential consequences of climate variability and change for California. Washington, DC, California Regional Assessment Group, US Global Change Research Program.

Curriero, F. C., K. S. Heiner, et al. (2002). "Temperature and mortality in 11 cities of the eastern United States." Am J Epidemiol **155**(1): 80-7.

Donaldson, K., L. Tran, et al. (2005). "Combustion-derived nanoparticles: a review of their toxicology following inhalation exposure." Part Fibre.Toxicol. **2**: 10.

Drury, R., M. Belliveau, et al. (1999). "Pollution trading and environmental injustice: Los Angeles' failed experiment in air quality." Duke Environmental Law and Policy Forum **9**: 231-289.

Dykstra, C. (1939). "The Quest for Responsibility." American Political Science Review **33**(1): 1-25.

Ebrahim, A. (2003). "Accountability In Practice: Mechanisms for NGOs." World Development **31**(5): 813-829.

EDD. (2004). "Occupational employment (2002) and wage (2003) data, occupational employment statistics survey results." 2004, from (http://www.calmis.cahwnet.gov/file/occup$/oeswages/Cal$oes2003.htm.

EDGAR. (2009). "Emission Database for Global Atmospheric Research (EDGAR)." Retrieved August 10, 2009, from http://www.mnp.nl/edgar/contact/index.jsp.

Edwards, M. and D. E. Hulme (1996). Beyond the magic bullet: NGO performance and accountability in the post-Cold War World. West Hartford, CT, Kumarian Press.

Ellerman, A. and B. Buchner (2007). "The European Union Emissions Trading Scheme: origins, allocation, and early results." Review of Environmental Economics and Policy **1**(1): 66-87.

English, P., K. Fitzsimmons, et al. (2007). Public health impacts of climate change in California: community vulnerability assessments and adaptation strategies. Richmond, CA, Climate Change Public Health Impacts Assessment and Response Collaborative, California Department of Public Health Institute.

EPA (2005). Toxics release inventory (TRI) basis of OSHA carcinogens. Washington, DC, United States Environemental Protection Agency.

Farrell, A. and M. Hart (1998). "What does sustainabity really mean? The search for useful indicators." Environment **40**(9): 4.

Forster, P., Ramaswamy, et al. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Forster, P., V. Ramaswamy, et al. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, and T. K. B., M., and Miller, H. L. Cambridge and New York, Intergovernmental Panel on Climate Change.

Fothergill, A. and L. Peek (2004). "Poverty and disasters in the United States: A review of recent sociological findings." Natural Hazards Journal **32**(1): 89-110.

Fox, J. A. and L. D. E. Brown (1998). The struggle for accountability: The World Bank, NGOs, and grassroots movements. Cambridge, MA, The MIT Press.

Fry, R. (1995). "Accountability in organizational life: problem or opportunity for nonprofits? ." Nonprofit Management and Leadership **6**(2): 181-195.

Fullerton, D. G., N. Bruce, et al. (2008). "Indoor air pollution from biomass fuel smoke is a major health concern in the developing world." Trans R Soc Trop Med Hyg **102**(9): 843-51.
Gage, K. L., T. R. Burkot, et al. (2008). "Climate and vectorborne diseases." Am J Prev Med **35**(5): 436-50.
GEA (2011). Global Energy Assessment, IIASA.
Ghilardi, A., G. Guerrero, et al. (2009). "A GIS-based methodology for highlighting fuelwood supply/demand imbalances at the local level: A case study for Central Mexico." Biomass & Bioenergy **33**(6-7): 957-972.
Global Alliance for Clean Cookstoves. (2011). "Global Alliance for Clean Cookstoves." Retrieved July 5, 2011, from http://cleancookstoves.org/the-alliance/partners/.
Gold Standard Foundation (2011). Technologies and Practices to Displace Decentralized Thermal Energy Consumption. Geneva-Cointrin The Gold Standard Foundation. Available at: http://www.cdmgoldstandard.org/wp-content/uploads/2011/10/GS_110411_TPDDTEC_Methodology.pdf.
Gold Standard Foundation. (2011). "The Gold Standard: Premium Carbon Credits." Retrieved November 1, 2011, from http://www.cdmgoldstandard.org/about-us/who-we-are.
Grant, R. and R. Keohane (2005). "Accountability and Abuses of Power in World Politics." American Political Science Review **99**(1): 29-43.
Greenberg, J. H., J. Bromberg, et al. (1983). "The epidemiology of heat-related deaths, Texas--1950, 1970-79, and 1980." Am J Public Health **73**(7): 805-7.
Greenough, G., M. McGeehin, et al. (2001). "The potential impacts of climate variability and change on health impacts of extreme weather events in the United States." Environ Health Perspect **109 Suppl 2**: 191-8.
Greenough, P. G. and T. D. Kirsch (2005). "Hurricane Katrina. Public health response--assessing needs." N Engl J Med **353**(15): 1544-1546.
Harlan, S., A. Brazel, et al. (2008). "In the shade of affluence: the inequitable distribution of the heat island. equity and the environment." Research in Social Problems and Public Policy **15**(173-202).
Hassett, K., A. Mathur, et al. (2008). The incidence of a U.S. carbon tax: a lifetime and regional analysis. Cambridge, MA, American Enterprise Institute for Public Policy Research.
Haya, B. (2009). Measuring Emissions Against an Alternative Future: Fundamental Flaws in the Structure of the Kyoto Protocol's Clean Development Mechanism. Berkeley, CA, USA, Energy and Resources Group, University of California, Berkeley**:** 30.
Hayhoe, K., D. Cayan, et al. (2004). "Emissions pathways, climate change, and impacts on California." Proc Natl Acad Sci U S A **101**(34): 12422-7.
Hepburn, C., M. Grubb, et al. (2006). "Auctioning of EU ETS phase II allowances: how and why?" Climate Policy **6**(1): 137–160.
Hong, Y. C., J. T. Lee, et al. (2002). "Effects of air pollutants on acute stroke mortality." Environ Health Perspect **110**(2): 187-91.
Howitt, R., J. Medellín-Azuara, et al. (2009). Estimating the Economic Impact of Agricultural Yield Related Changes for California Climate Action Team Report. Sacramento, CA, California Energy Commission; California Air Resources Board.**:** 41.
IPCC (2007). Working Group I Report: "The Physical Science Basis", Intergovernmental Panel on Climate Change.

Jackson, L., F. Santos-Martin, et al. (2009). Potential for Adaptation to Climate Change in an Agricultural Landscape in the Central Valley of California Climate Action Team Report. Sacramento, CA, California Energy Commission; California Air Resources Board**:** 168.
Jacobson, M. (2008). "On the causal link between carbon dioxide and air pollution mortality." Geophys Res. Let. **35**(L03809).
Jacobson, M. Z. (2007). "Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States." Environ Sci Technol **41**(11): 4150-7.
Jerrett, M., R. T. Burnett, et al. (2009). "Long-term ozone exposure and mortality." N Engl J Med **360**(11): 1085-95.
Johnson, M., R. Edwards, et al. (2009). "Ouantification of carbon savings from improved biomass cookstove projects." Environ Sci Technol **43**(7): 2456-62.
Johnson, M., N. Lam, et al. (2011). "Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model." Atmospheric Environment **45**(19): 3237-3243.
Junker, C. and C. Liousse (2008). "A global emission inventory of carbonaceous aerosol from historic records of fossil fuel and biofuel consumption for the period 1860-1997." Atmospheric Chemistry and Physics **8**(5): 1195-1207.
Kaur, S. and M. J. Nieuwenhuijsen (2009). "Determinants of personal exposure to PM2.5, ultrafine particle counts, and CO in a transport microenvironment." Environ Sci Technol **43**(13): 4737-43.
Kilbourne, E. (1997). Heat waves and hot environments. The Public Health Consequences of Disasters. E. Noji. New York, NY, Oxford University Press.
Kirchstetter, T. W., J. Agular, et al. (2008). "Black carbon concentrations and diesel vehicle emission factors derived from coefficient of haze measurements in California: 1967-2003." Atmospheric Environment **42**(3): 480-491.
Klinenberg, E. (2002). Race, place, and vulnerability. Heat Wave.
Knowlton, K., M. Rotkin-Ellman, et al. (2008). "The 2006 California heat wave: impacts on hospitalizations and emergency department visits." Environ Health Perspect **117**(1): 61-67.
Kovats, R. S. and S. Hajat (2008). "Heat stress and public health: a critical review." Annu Rev Public Health **29**: 41-55.
Lamarque, J. F., T. C. Bond, et al. (2010). "Historical (1850-2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application." Atmospheric Chemistry and Physics **10**(15): 7017-7039.
Lejano, R. and R. Hirose (2005). "Testing the assumptions behind emissions trading in non-market goods: the RECLAIM program in Southern California." Environmental Science & Policy **8**: 367-377.
Liverman, D. (2010). Carbon Offsets, the CDM and Sustainable Development. Global Sustainability – A Nobel Cause. H. Schellnhuber, M. Molina, N. Stern, V. Huber and S. Kadner. Cambridge, United Kingdom and New York, USA, Cambridge University Press**:** 129-141.
Lohmann, L. (2006). Carbon trading, a critical conversation on climate change, privatization and power. Uppsala, Sweden, Dag Hammarskjöld Foundation.
Masera, O., A. Ghilardi, et al. (2006). "WISDOM: A GIS-based supply demand mapping tool for woodfuel management." Biomass & Bioenergy **30**(7): 618-637.

Meleux, F., F. Solmon, et al. (2007). "Increase in summer European ozone amounts due to climate change." Atmospheric Environment **41**(35): 7577-7587.
Metzenbaum, S. (2001). Measurements that matter: cleaning up the charles river. Environmental Governance: A Report on the Next Generation of Environmental Policy. D. e. Kettl, (forthcoming, 2001. New York, NY, Brookings Institution Press.
Michaelowa A and Purohit P (2007). Additionality determination of Indian CDM projects: Can Indian CDM project developers outwit the CDM Executive Board? Zurich, Switzerland, Climate Strategies.
Minkler, M. and N. Wallerstein (2003). Community-based participatory research for health. San Francisco, CA, Jossey-Bass.
Mishra, V. K., R. D. Retherford, et al. (1999). "Biomass cooking fuels and prevalence of tuberculosis in India." Int J Infect Dis **3**(3): 119-29.
MMWR (2008). "Heat-related deaths among crop workers - United States, 1992-2006." Mortality and Morbidity Weekly Report **57**(24): 649-653.
Moffet, R. and K. Prather (2009). "In-situ measurments of the mixing state and optical properties of soot with implications for radiative forcing estimates." Proc Natl Acad Sci U S A **Early Addition**(XX): XXXX-XXXX.
Moffet, R. and K. Prather (2009). "In-situ measurments of the mixing state and optical properties of soot with implications for radiative forcing estimates." Proc Natl Acad Sci U S A **106**(29): 11872–11877.
Morello-Frosch, R. and B. Jesdale (2006). "Separate and unequal: residential segregation and estimated cancer risks associated with ambient air toxics in U.S. metropolitan areas." Environ Health Perspect **114**(3): 386-93.
Morello-Frosch, R. and R. Lopez (2006). "The riskscape and the color line: examining the role of segregation in environmental health disparities." Environ Res **102**(2): 181-96.
Morello-Frosch, R., M. Pastor, Jr., et al. (2002). "Environmental justice and regional inequality in southern California: implications for future research." Environ Health Perspect **110 Suppl 2**: 149-54.
Morello-Frosch, R., M. Pastor, et al. (2009). The Climate Gap: Inequalities in How Climate Change Hurts Americans & How to Close the Gap, The Program for Environmental and Regional Equity (PERE), University of Southern California.
Novakov, T. and J. E. Hansen (2004). "Black carbon emissions in the United Kingdom during the past four decades: an empirical analysis." Atmospheric Environment **38**(25): 4155-4163.
O'Neill, C. (2004). "Mercury, risk and justice." ELR News and Analysis **34**: 11070-11115.
O'Neill, M. S., P. L. Kinney, et al. (2008). "Environmental equity in air quality management: local and international implications for human health and climate change." J Toxicol Environ Health A **71**(9-10): 570-7.
O'Neill, M. S., A. Zanobetti, et al. (2003). "Modifiers of the temperature and mortality association in seven US cities." Am J Epidemiol **157**(12): 1074-82.
O'Neill, M. S., A. Zanobetti, et al. (2005). "Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence." J Urban Health **82**(2): 191-7.
O'Rourke, D. (2000). Community-driven regulation: balancing development and the environment in Vietnam. Livable Cities: The Politics of Urban Livelihood and Sustainability. P. Evans. Berkeley, CA, University of California Press.

Oberdoerster, G., V. Stone, et al. (2007). "Toxicology of nanoparticles: A historical perspective." Nanotoxicology **1**: 2-25.
Ojerio, R., C. Moseley, et al. (2010). "The limited involvement of socially vulnerable populations in federal programs to mitigate wildfire risk in Arizona." Natural Hazards Review **Posted ahead of print 10 June 2010**
Oke, T. (1973). "City size and the urban heat island." Atmos. Environ. **7**: 769–79.
Pacific Institute (2009). The Impacts of Sea-Level Rise on the California Coast. Oakland, CA, The Pacific Institute**:** 101 pp.
Pastor, M., R. Morello-Frosch, et al. (2010). Air pollution and environmental justice: integrating indicators of cumulative impact and socio-economic vulnerability into regulatory decision-making, California Air Resources Board
Pastor, M., R. Morello-Frosch, et al. (2010). Minding the climate gap: what's at stake if California's climate law isn't done right and right away. Los Angeles, CA, Program for Environmental and Regional Equity, University of Southern California.
Patz, J., D. Campbell-Lendrum, et al. (2008). "Health impact assessment of global climate change: expanding on comparative risk assessment approaches for policy making." Annu Rev Public Health **29**: 27-39.
Penner, J. E., H. Eddleman, et al. (1993). "Towards the development of a global inventory for black carbon emissions." Atmospheric Environment Part a-General Topics **27**(8): 1277-1295.
Perez-Padilla, R., C. Perez-Guzman, et al. (2001). "Cooking with biomass stoves and tuberculosis: a case control study." Int J Tuberc Lung Dis **5**(5): 441-7.
Phelan, J. C., B. G. Link, et al. (2004). ""Fundamental causes" of social inequalities in mortality: a test of the theory." J Health Soc Behav **45**(3): 265-85.
Pittock, B., D. Wratt, et al. (2001). Climate change 2001: impacts, adaptation, and vulnerability. Cambridge, U.K., Cambridge Univ. Press.
Pokhrel, A., M. Bates, et al. (2009). "Tuberculosis and Indoor Biomass and Kerosene Use in Nepal: A Case-control Study." Environ Health Perspect.
Pokhrel, A. K., K. R. Smith, et al. (2005). "Case-control study of indoor cooking smoke exposure and cataract in Nepal and India." Int J Epidemiol **34**(3): 702-8.
Pope, D. P., V. Mishra, et al. (2010). "Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries." Epidemiol Rev **32**(1): 70-81.
Porter, T. (1995). Trust in Numbers: The Pursuit of Objectivity in Science and Public Life. Princeton, NJ, Princeton University Press.
Poumadere, M., C. Mays, et al. (2005). "The 2003 heat wave in France: dangerous climate change here and now." Risk Anal **25**(6): 1483-94.
Ramanathan, V. and G. Carmichael (2008). "Global and regional climate changes due to black carbon." Nature Geoscience **1**(4): 221-227.
Reid, J. S., P. V. Hobbs, et al. (1998). "Comparisons of techniques for measuring shortwave absorption and black carbon content of aerosols from biomass burning in Brazil." Journal of Geophysical Research-Atmospheres **103**(D24): 32031-32040.
Roden, C. A., T. C. Bond, et al. (2009). "Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves." Atmospheric Environment **43**(6): 1170-1181.

Roebroeks, W. and P. Villa (2011). "Reply to Sandgathe et al.: Neandertal use of fire." Proceedings of the National Academy of Sciences of the United States of America **108**(29): E299-E299.
Rogot, E., P. D. Sorlie, et al. (1992). "Air-conditioning and mortality in hot weather." Am J Epidemiol **136**(1): 106-16.
Rosen, H. and T. Novakov (1977). "Raman-scattering and characterization of atmospheric aerosol-particles." Nature **266**(5604): 708-710.
Ruddiman, W. (2006). Plows, Plagues, and Petroleum: How Humans Took Control of Climate. Princeton, NJ, Princeton University Press.
Ruiz-Mercado, I., O. Masera, et al. (2011). "Adoption and sustained use of improved cookstoves." Energy Policy **39**(12): 7557-7566.
Schedler, A. (1999). Conceptualizing Accountability. The Self-Restraining State: Power and Accountability in New Democracies. A. Schedler, L. Diamond and M. Plattner. London, Lynne Rienner Publishers**:** 13–28.
Schneider, L. (2007). Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of the CDM and options for improvement. Berlin, Germany, Oko-Institut e.V.
Schulz, A., D. Williams, et al. (2002). "Racial and spatial relations as fundamental determinants of health in Detroit." The Milbank Quarterly **80**(4): 677-707.
Schwarz, J. P., J. R. Spackman, et al. (2008). "Coatings and their enhancement of black carbon light absorption in the tropical atmosphere." Journal of Geophysical Research-Atmospheres **113**(D3): 10.
Scott, J. (1998). Seeing like a state: how certain schemes to improve the human condition have failed. New Haven, CT, Yale University Press.
Semenza, J. C., C. H. Rubin, et al. (1996). "Heat-related deaths during the July 1995 heat wave in Chicago." N Engl J Med **335**(2): 84-90.
Shell Foundation. (2010). "Breathing Space: tackling indoor air pollution from fires and stoves." Retrieved January 20, 2010, from http://www.shellfoundation.org/pages/core_lines.phpp=corelines_content&page=breathing.
Shindell, D. T., G. Faluvegi, et al. (2009). "Improved Attribution of Climate Forcing to Emissions." Science **326**(5953): 716-718.
Shonkoff, S., R. Morello-Frosch, et al. (2009). Environmental health and equity impacts from climate change and mitigation policies in California: a review of the literature. Climate Action Team Report. Sacramento, CA, CARB.
Shonkoff, S., R. Morello-Frosch, et al. (2009). Environmental health and equity impacts from climate change and mitigation policies in California: a review of the literature. Climate Action Team Report. Sacramento, CA, California Energy Commission; California Air Resources Board**:** 27.
Shonkoff, S., R. Morello-Frosch, et al. (2009). "Minding the climate gap: environmental health and equity implications of climate change mitigation policies in california." Environmental Justice **2**(4): 173-177.
Slowik, J. G., E. S. Cross, et al. (2007). "An inter-comparison of instruments measuring black carbon content of soot particles." Aerosol Science and Technology **41**(3): 295-314.

Smith, K., M. Jerrett, et al. (2009). "Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants." The Lancet **374**(9707): 2091-2103.

Smith, K., M. Jerrett, et al. (2009). "Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants." The Lancet **6736**(9): 56-69.

Smith, K., J. McCracken, et al. (2011). "Effect of reduction in household air pollution on childhood pneumonia in Guatemala(RESPIRE): a randomised controlled trial." The Lancet **Forthcoming**.

Smith, K. R., M. Jerrett, et al. (2009). "Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants." Lancet **374**(9707): 2091-2103.

Smith, K. R., J. P. McCracken, et al. (2009). "Personal child and mother carbon monoxide exposures and kitchen levels: Methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE)." J Expo Sci Environ Epidemiol.

Smith, K. R., J. M. Samet, et al. (2000). "Indoor air pollution in developing countries and acute lower respiratory infections in children." Thorax **55**(6): 518-32.

Smith-Sivertsen, T., E. Diaz, et al. (2009). "Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE Randomized Trial, Guatemala." Am J Epidemiol **170**(2): 211-20.

Solomon, S., D. Qin, et al. (2007). Working Group I Report: "The Physical Science Basis". Cambridge, United Kingdom and New York, NY, US, Intergovernmental Panel on Climate Change**:** 996.

Sovacool, B. K. (2011). "FOUR PROBLEMS WITH GLOBAL CARBON MARKETS: A CRITICAL REVIEW." Energy & Environment **22**(6): 681-694.

Stathopoulou, E., G. Mihalakakou, et al. (2008). "On the impact of temperature on tropospheric ozone concentration levels in urban environments." Journal of Earth System Science **117**(3): 227-236.

Sterk, W., C. Ahrens, et al. (2009). Further Development of the Project-Based Mechanisms in a Post-2012

Regime. Berlin, Final report of the project commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Available at: http://www.wupperinst.org/uploads/tx_wiprojekt/CDM_Post_2012_Study.pdf.

Su, J., R. Morello-Frosch, et al. (2009). "An index for assessing demographic inequalities in cumulative environmental hazards with application to Los Angeles, California." Environ Sci Technol **43**(20): 7626-34.

Su, J. G., M. Jerrett, et al. (2012). "Inequalities in cumulative environmental burdens among three urbanized counties in California." Environ Int **40**: 79-87.

Swiss Re (2006). Natural catastrophes and man-made disasters 2005: high earthquake casualties, new dimension in windstorm losses.

Tang, X., Y. Bai, et al. (2009). "Formaldehyde in China: production, consumption, exposure levels, and health effects." Environ Int **35**(8): 1210-24.

Tenenbaum, D. (2008). "Food vs. fuel: diversion of crops could cause more hunger." Environ Health Perspect **116**(6): A254-A257.

Thomalla, F., Downing T, et al. (2006). "Reducing hazard vulnerability: Towards a common approach between disaster risk reduction and climate adaptation." Disasters **30**(1): 39–48.

Tierney, K. (1988). "The Whittier Narrows, California earthquake of October 1, 1987 – Social aspects." Earthquake Spectra **4**(1): 11-23.
Unger, N., T. Bond, et al. (2010). "Attribution of climate forcing to economic sectors." Proc Natl Acad Sci **PNAS Early Edition**.
Unger, N., T. C. Bond, et al. (2010). "Attribution of climate forcing to economic sectors." Proceedings of the National Academy of Sciences of the United States of America **107**(8): 3382-3387.
Unger, N., D. T. Shindell, et al. (2008). "Air pollution radiative forcing from specific emissions sectors at 2030." Journal of Geophysical Research-Atmospheres **113**(D2): 1-12.
United Nations. (2008). "Millenium Development Goals." from http://www.un.org/millenniumgoals/.
Urban Dictionary. (2011). "Don't Hate the Playa, Hate the Game." Retrieved July 5, 2011, from http://www.urbandictionary.com/define.php?term=don%27t+hate+the+playa+hate+the+game.
US EPA. (2010). "Air trends." from http://www.epa.gov/air/airtrends/values.html.
USCB (2004). Current housing reports, American Housing Survey for the Los Angeles-Long Beach Metropolitan Area: 2003, U.S. Census Bureau.
USCB. (2005). "California -- County. Percent of people below poverty level in the past 12 months (for whom poverty status is determined): 2005." United States Census Bureau Retrieved July 2008, 2008, from http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=04000US06&-_box_head_nbr=GCT1701&-ds_name=ACS_2005_EST_G00_&-_lang=en&-mt_name=ACS_2005_EST_G00_GCT1701_ST2&-format=ST-2.
Walls, M. and J. Hanson (1996). Distributional impacts of an environmental tax shift: The case of motor vehicle emissions taxes. Washington, DC, Resources for the Future.
Watson, J. G., J. C. Chow, et al. (2005). "Summary of organic and elemental carbon/black carbon analysis methods and intercomparisons." Aerosol Air Qual. Res. **5**(1): 65-102.
Weber, E. P. (1999). "The question of accountability in historical perspective: From Jackson to contemporary grassroots ecosystem management." Administration & Society **31**(4): 451-494.
Whitman, S., G. Good, et al. (1997). "Mortality in Chicago attributed to the July 1995 heat wave." Am J Public Health **87**(9): 1515-8.
WHO (2002). The world health report 2002. Geneva, World Health Organization.
WHO (2006). Air quality guidelines: global update 2005, particulate matter, ozone, nitrogen dioxide and sulphur dioxide. Copenhagen, World Health Organisation Regional Office for Europe.
Wilkinson, P., K. R. Smith, et al. (2009). "Public health benefits of strategies to reduce greenhouse-gas emissions: household energy." Lancet **374**(9705): 1917-29.
Williams, D. and C. Collins (2001). "Racial residential segregation: a fundamental cause of racial disparities in health." Public Health Reports **116**: 404-416.
Wittman, H. K. and C. Caron (2009). "Carbon Offsets and Inequality: Social Costs and Co-Benefits in Guatemala and Sri Lanka." Society & Natural Resources **22**(8): 710-726.
Yasa, Z., N. M. Amer, et al. (1979). "Photoacoustic investigation of urban aerosol-particles." Applied Optics **18**(15): 2528-2530.