# HEALTH, CLIMATE, AND TIME-USE IMPACTS FROM A CARBON-FINANCED COOKSTOVE INTERVENTION IN RURAL INDIA

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## Abstract

Efforts to introduce efficient stoves and cleaner fuels increasingly leverage carbon-finance to scale up dissemination, highlighting climate, health, and livelihood co-benefits. However, actualization of co-benefits has not been evaluated. Two studies were implemented in Karnataka, India where a local organization initiated a Clean Development Mechanism-approved cookstove intervention.

A one-year randomized intervention study assigned 187 households in a village to either receive the intervention or continue using traditional stoves, and evaluated fuelwood usage, indoor fine particle mass ($PM_{2.5}$) and absorbance (Abs) levels, and blood pressure (BP) in women $\geq$ 25 years old (N=222). Forty percent of intervention homes continued using traditional stoves in combination with the intervention stove ("mixed stove"). There were minor and overlapping differences (post- minus pre-intervention change) between control and intervention groups for median (95% CI) fuel use [-0.60 (-1.02, -0.22) vs. -0.52 (-1.07, 0.00) kg $day^{-1}$], and 24-hr absorbance [35 (18, 60) vs. 36 (22, 50) x $10^{-6}$ $m^{-1}$]. For 24-hr $PM_{2.5}$ difference, there was a higher increase in control compared to intervention homes [139 (61,229) vs. 73(-6, 156) $\mu g\ m^{-3}$] between the two seasons. The intervention cookstoves partially mitigated the seasonal increase in $PM_{2.5}$ concentrations but resulted in measurements with a higher ratio of absorbance to $PM_{2.5}$ mass compared to traditional stoves.

Exclusive use of intervention stove was not associated with significant changes in systolic or diastolic BP. Mixed stove homes were associated with higher SBP in both within-group (post-pre: 4.1 [(95% confidence interval), 0.4, 7.8] mm Hg) and between-group (9.5 [3.7, 15.3]) mm Hg analyses.

In a cross-sectional, mixed-method study of households (N=50) in another village, time spent cooking and collecting fuelwood was similar between intervention and traditional stove homes. Women reported using saved time for farm work, household work, and leisure (e.g. rest, spend time with family). Self-reported time spent cooking and collecting fuelwood was overestimated compared to the observed measured time.

Absent rigorous evaluations, stove interventions may be pursued that fail to realize expected carbon reductions or anticipated co-benefits. Carbon financing can help move populations in low-income countries towards cleaner cookstoves by supporting field-proven technologies, and aligning with emerging health and climate guidelines.

## Preface

This doctoral dissertation includes three original research chapters (Chapter 2-4) written as stand-alone manuscripts intended for publication in peer-reviewed journals. Chapter 2 has been published and Chapter 3 and 4 are planned to be submitted to relevant journals. The titles, list of co-authors and their contributions are provided below.

Chapter 2 has been published: [Aung, T.; Jain, G.; Sethuraman, K.; Baumgartner, J.; Reynolds, C.; Grieshop, A. P.; Marshall, J. D.; Brauer, M. Health and Climate-Relevant Pollutant Concentrations from a Carbon-Finance Approved Cookstove Intervention in Rural India. *Environ. Sci. Technol.* 2016, *50* (13), 7228–7238]. JM and JB conceptualized the study and initiated contacts with the non-governmental organization (NGO) partner in India to evaluate its cookstove intervention program. JB and JM, who at the time were at the University of Minnesota (UMN), co-wrote the proposal and received funding from the Institute for Environment at UMN. JM, JB, CR, AG, and MB developed the study design, research questions, and sampling methods for the research project. JB, CR, AG, and TA developed field sampling protocols, and trained field sampling team on air pollution and blood pressure monitoring. GJ and KS supervised the field sampling team, collected data, and conducted first-pass quality control/quality assessment of data. TA conducted laboratory analyses of filters for particulate matter mass and absorbance, developed and managed a data storage system to compile and aggregate data, conducted statistical analyses, and led the writing of the manuscript. MB provided guidance as TA's thesis supervisor including detailed revision of the manuscript. All coauthors assisted in the revision of the manuscript.

Chapter 3 will be submitted to a health relevant and peer-reviewed journal, [Aung, T.; Baumgartner, J.; Jain, G.; Sethuraman, K.; Reynolds, C.; Marshall, J. D.; Brauer, M. Blood Pressure and Eye Health Outcomes from a Randomized Cookstove Intervention in Rural India]. As chapter 3 is derived from the same study as Chapter 2, contribution and roles of the co-authors are similar to what has been described above. JB is second author for this chapter on health outcomes owing to a more significant role she played in development of health related sampling methods, and detailed review of the manuscript. All coauthors assisted in the revision of the manuscript.

Chapter 4 will be submitted to a peer-reviewed journal with a social science focus on energy and development issues, [Aung, T.; Zerriffi, H.; Pradeep, T.; Narayana S.; Marshall, J. D.; Brauer, M. Evaluating time-use measurements and livelihood assumptions from a cookstove intervention in rural India]. TA conceptualized the study, developed research design and methods, and wrote a proposal to receive funding from the International Development Research Centre (IDRC), trained field sampling team, collected data, conducted statistical analyses and led the writing of the manuscript. HZ provided guidance on development of research design and methods, and served as the primary reviewer of the IDRC funding proposal and the manuscript. TP and NS assisted in review of the IDRC funding proposal, and provided logistical support in the field. JM and MB assisted in revising of the manuscript.

The study protocol for the first study (Chapter 2 and 3) was approved by institutional review boards at the University of Minnesota (IRB code #1104S97992), St. John's Medical College (IERB Study Ref No. 103/2011) in India, and the University of British Columbia (CREB #H14-03012). Ethics approval for the second study (Chapter 4) was obtained from the University of British Columbia's Behavioral Research Ethics Board (ID# H14-00648).

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## List of Abbreviations

| | |
|---|---|
| Abs | Absorbance |
| Alliance | Global Alliance for Clean Cookstoves |
| BC | Black carbon |
| CDM | Clean Development Mechanism |
| CI | Confidence interval |
| $CO_2$ | Carbon dioxide |
| COPD | Chronic obstructive pulmonary disease |
| DALY | Disability-adjusted life years |
| DBP | Diastolic blood pressure |
| FW | Fuelwood |
| GHG | Greenhouse gases |
| HAP | Household air pollution |
| IHD | Ischemic heart disease |
| LPG | Liquefied petroleum gas |
| NGO | Non-governmental organization |
| $PM_{2.5}$ | Particulate matter less than 2.5 micrometers in aerodynamic diameter |
| SBP | Systolic blood pressure |
| $W/m^2$ | Watts per meter squared |

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*To my parents whose sacrifices made this journey possible.*

# Chapter 1: Introduction

## 1.1 Global biomass fuel use

An estimated three billion people in the world rely on traditional and inefficient devices for burning solid fuels (wood, coal, dung, and agricultural crop residues) for cooking and heating purposes (International Energy Agency, 2015). This represents approximately 40% of the world's population, most of whom reside in low and middle-income countries (Pachauri *et al.*, 2012). Biomass fuel use (wood, dung, and crop residues) make up the majority of the solid fuel use population (2.7 billion) with the remaining relying on coal, mostly in China. Regionally, developing Asia has the highest number of people using biomass fuels (1.9 billion), followed by Sub-Saharan Africa (753 million), and Latin America (65 million) (International Energy Agency, 2015). India is home to the largest population in the world using biomass fuels (841 million) (International Energy Agency, 2015), where 87% of its rural households use biomass fuel as their primary source of fuel for cooking (Government of India, 2011).

The past three decades saw significant gains made in increasing access to modern fuels (gas, electricity) globally, increasing the proportion of the world's population using these fuels (Bonjour *et al.*, 2013). However, as a result of population growth and slow pace of access to modern fuels, the absolute population dependent on biomass fuels is not likely to decline significantly in the future (Rehfuess, Mehta and Prüss-Üstün, 2006; International Energy Agency, 2011). This presents a major concern because traditional use of solid fuels is associated with multiple adverse impacts on global and local environment, health and socio-economic development.

## 1.2 Impacts

### 1.2.1 Forest resources

Traditional biomass cookstoves burn fuelwood inefficiently, which contributes to forest degradation and deforestation (Bailis, Chatellier and Ghilardi, 2012). In the 1970s, household biomass use was seen as the major cause of deforestation in developing regions of the world (Bailis *et al.*, 2007). More recent evidence suggested that the impact from household biomass use was small relative to other land use practices, such as industrial agriculture, demand for timber and other infrastructure uses that were the main causes of deforestation (Arnold *et al.*, 2003). However, Bailis et al. (2015) estimated that in 2009, approximately a third of the fuelwood harvested was done so unsustainably, with higher rates in South Asia and East Africa (Bailis *et al.*, 2015).

Harvesting of fuelwood from unsustainable sources presents a major concern from both local forest resource and global $CO_2$ cycle aspects. Degradation of natural forests can lead to biodiversity loss, and impact ecosystem services, and livelihood. Burning of non-renewable fuelwood is believed to contribute to net $CO_2$ emissions whereas fuelwood harvested from sustainable sources is seen as carbon neutral because of re-uptake of $CO_2$ in the vegetation regrowth process (Johnson, Edwards and Masera, 2010). This concern is the basis of current carbon trading schemes, such as the Clean Development Mechanism (CDM) established under the UN Framework Convention on Climate Change. In order to reduce net greenhouse gas (GHG) emissions and climate change, the CDM allows investment in projects, such as more efficient cookstoves, that reduce the use of non-renewable fuelwood to avoid net $CO_2$ emissions (United Nations Framework Convention on Climate Change, 2015). However, emissions of non-$CO_2$ climate forcing agents from traditional biomass cookstoves may negate any carbon reductions (Smith *et al.*, 2000), as discussed below.

### 1.2.2 Climate

In addition to $CO_2$ from unsustainable biomass harvesting, burning of solid fuels in inefficient devices emit other greenhouse-gases (GHGs), such as carbon monoxide (CO), methane ($CH_4$), non-methane hydrocarbons, and nitrous oxide ($N_2O$). Though large uncertainties remain (Smith *et al.*, 2000; Zhang *et al.*, 2000; Johnson *et al.*, 2008), it has been estimated that biomass combustion, of which household cookstoves make up a major fraction, contributes to 20 - 50% of global greenhouse gas (GHG) emissions (Crutzen and Andreae, 1990; Zhang *et al.*, 2000; Bond, Venkataraman and Masera, 2004).

In addition to gaseous components, aerosol particles or particulate matter (PM) with climate-forcing effects are also emitted from residential biomass fuel use (MacCarty, Ogle, *et al.*, 2008). In particular, carbonaceous components, black carbon[1] (BC) and organic carbon (OC), play important climate-relevant roles. BC is the dark component of the particles produced during flaming fires, and is the dominant aerosol component that absorbs solar radiation (Ramanathan *et al.*, 2011). OC consists of light-scattering particles produced from smoldering fires, and can be white to brown in color, which has a cooling effect because it reflects sunlight back into space (MacCarty, Ogle, *et al.*, 2008). Formation of BC and OC and their ratio varies on how material is burned including its burn rate, air-fuel ratio, flame turbulence, and combustion temperature; vigorous flaming may emit more BC (black smoke) and other flames (e.g., smoldering

[1] *The term black carbon lacks a consistent definition, and several terms are used including light absorbing carbon (LAC), elemental carbon (EC), and soot. While they are used to describe the same pollutant, the names (BC, LAC, and EC) are operationally defined by how they are measured in the laboratory.*

conditions) more OC (white smoke) (Bond, Venkataraman and Masera, 2004; Venkataraman *et al.*, 2005).

BC can impact climate via direct and indirect mechanisms. BC directly warms the atmosphere because of its dark color and strong visible light absorption properties (Bond *et al.*, 2013). Indirectly, BC modifies cloud properties to influence their lifetime and behaviour through cloud formation and reduction, and shifting of cloud distribution and cover, contributing to either warming or cooling effects. In addition, BC contributes to cryosphere melting, where deposition of BC on snow and ice reduces their surface albedo, increases absorption of solar radiation, and contributes to their accelerated melting. BC's effect on the cryosphere has created concerns for the Himalaya and Tibetan Plateau regions owing to their large seasonal snow cover and glaciers and their proximity to high BC emitting sources. Faster melting of snow and ice in the region could have major impacts on seasonal trends in water supplies with implications for food and water security in South Asia (Rehman *et al.*, 2011).

Recent research suggests BC is the second most important climate warming agent after $CO_2$ (Bond *et al.*, 2013). Radiative forcing (RF) of BC, a term used for quantitative comparisons of the strength of different agents in causing climate change (Forster et al. 2007), is estimated to be +1.1 $W/m^2$, whereas the RFs of $CO_2$ and $CH_4$ are +1.56 $W/m^2$ and +0.86 $W/m^2$, respectively (Bond *et al.*, 2013). BC has a relatively short atmospheric residence time ranging from days to weeks and hence it is considered a short-lived climate pollutant (SLCP) compared to $CO_2$ which has a life-time of which may extend as long as 100-200 years (Ramanathan and Carmichael, 2008). The RF of BC from direct atmospheric warming effect is estimated to be as high as +10 $W/m^2$ at the local level in East and South Asia regions (Bond *et al.*, 2013). Because of the strong RF and BC's short atmospheric lifetime, targeting major BC sources has been proposed as a near-term climate mitigation strategy to provide immediate benefits and delay climate change effects (Grieshop *et al.*, 2009; Jackson, 2009).

Four major sources of BC emissions are open burning of biomass (40% of global emissions), residential solid fuel use for cooking and heating (25%), diesel engines (20%), and industrial coal combustion (9%) (Bond *et al.*, 2013). Though open burning of biomass is the largest source of global BC emissions, its net warming effect is the lowest because of high co-emission of organic aerosols that has cooling effect on climate (Bond *et al.*, 2013). Regionally, residential combustion of coal and biomass contributes to ~60% - 80% of BC emissions in Africa and Asia (Bond *et al.*, 2013). In India, residential biomass use is the largest contributor of BC, responsible for 42% of its emissions, followed by open agricultural burning (33%) and fossil fuel use (25%) (Venkataraman *et al.*, 2005).

### 1.2.3 Health

#### 1.2.3.1 Air pollutants and indoor concentration

Emissions from residential biomass combustion are referred to as household air pollution (HAP), which include the products of incomplete combustion (PIC) mentioned above, as well as other compounds such as benzene, and polycyclic aromatic hydrocarbons (PAHs) (Naeher *et al.*, 2007). Particulate matter less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) and CO are two of the most commonly measured household air pollutants; their association with health outcomes have been well characterized and health guidelines have been developed for these two pollutants (World Health Organization, 2014; Northcross *et al.*, 2015). The WHO's Global Household Air Pollution Database compiled from 154 studies in developing countries showed households burning biomass can have 24-hour mean concentrations of $PM_{2.5}$ over 500 $\mu g/m^3$ and can exceed 2,000 μg/m$^3$ (Balakrishnan *et al.*, 2011). These levels are significantly higher than the World Health Organization (WHO) air quality guidelines; the WHO has set interim targets goals with the first target not to exceed annual mean concentrations of 35 μg/m$^3$ for $PM_{2.5}$ (World Health Organization, 2014). Women and young children have the highest exposures because of women's traditional role of cooking, and children who spend much of their time with their mothers (World Health Organization, 2006a; Smith *et al.*, 2014).

Residential biomass combustion is also a major contributor to outdoor air pollution (Chafe *et al.*, 2014; Liu *et al.*, 2016). The proportion of ambient $PM_{2.5}$ pollution attributable to residential solid fuel use was estimated to be over 10% in low-income countries, with higher levels in southern Sub-Saharan Africa (37%), and South Asia (26%) (Chafe *et al.*, 2014).

#### 1.2.3.2 Health impacts

Exposures to $PM_{2.5}$ and CO from biomass cookstoves is associated with childhood pneumonia (acute lower respiratory infections), chronic obstructive pulmonary disease (COPD) in women, low birth weights, lung cancer, cataracts, and tuberculosis (Smith, Mehta and Maeusezahl-Feuz, 2004; Dherani *et al.*, 2008; Fullerton, Bruce and Gordon, 2008; Lin *et al.*, 2008; Salvi and Barnes, 2009; Hosgood, H Dean *et al.*, 2010; Pope *et al.*, 2010). Several cross-sectional epidemiologic studies have found associations between biomass-derived air pollution and cardiovascular related outcomes, such as blood pressure (Baumgartner *et al.*, 2011a; Clark *et al.*, 2011; Burroughs Peña *et al.*, 2015; Neupane *et al.*, 2015; Norris *et al.*, 2016), and biomarkers (Commodore *et al.*, 2013; Dutta *et al.*, 2013; Painschab *et al.*, 2013; Shan *et al.*, 2014; Ruiz-Vera *et al.*, 2015). Based on integrated exposure-response models which derive evidence of health risks from exposures to tobacco smoking, secondhand smoke, and ambient air pollution, combustion-derived $PM_{2.5}$ is associated with ischemic heart disease (IHD) and stroke (Newby *et al.*, 2014; Smith *et al.*, 2014).

Exposure to indoor HAP and outdoor air are ranked as the fourth highest risk factor for mortality (Forouzanfar *et al.*, 2015). The most recent (2013) burden of disease estimated that HAP exposures were responsible for 2.8 million premature deaths and 85.6 million disability-adjusted life year (DALY) in 2015 (Forouzanfar *et al.*, 2015). In India, where a third of the world's population using biomass fuels reside, HAP was estimated to contribute to over 950,000 premature deaths in 2013, and 27.3 million DALYs, representing 5.4% of the country's national burden of disease (Forouzanfar *et al.*, 2015).

### 1.2.4 Socio-economic impacts

Traditional stoves or open fires are associated with poor heat transfer capacity where energy and heat is wasted to the surroundings instead of directed at the pot, which can lead to high fuel consumption, and prolong cooking duration (MacCarty, Still and Ogle, 2010; Zube, 2010; Still, Bentson and Li, 2015). This translates to increased time and energy burden for rural women who are often responsible for cooking and collecting fuelwood. A survey in Zimbabwe, Ethiopia and India found women spent on average 40 minutes to over 2.5 hours a day cooking (Horrell, Johnson and Mosley, 2008). In India, the World Bank survey of 5,000 rural women from 180 villages across six states found that on a daily basis, women spent around 3 hours cooking, 40 minutes collecting fuelwood (World Bank, 2004). Other surveys found rural women may spend up to 5 hours a day cooking and collecting fuelwood (Cecelski, 1987; Parikh and Laxmi, 2000).

It is believed that the long hours and energy spent cooking and fuelwood collection may take time away from engaging in activities that build skills or generate income to improve their livelihoods (World Health Organization, 2006a). The World Bank survey in India found that over 9 hours spent on household production activities (cooking, collecting fuelwood, food processing, cleaning dishes and house, child care, and fetching water) daily leave just 2 hours for pursuing income-earning activities (World Bank, 2004). Rural women desire to reduce the burden of cooking and fuel collection; interviews with women in Nepal, India, and Bangladesh revealed their motivation for adopting improved stoves was because they believed it would reduce fuel wood use and cooking time (Pandey and Yadama, 1992; Barnes *et al.*, 1994; Chowdhury *et al.*, 2011).

### 1.3 Cookstove interventions

Cookstove interventions have been implemented for the past several decades but motivations and stove technologies have changed dramatically since then. Earlier interventions were implemented in the 1970's and 80's, and were primarily motivated by a desire to reduce fuelwood consumption and deforestation (Barnes *et al.*, 1994; Bailis *et al.*, 2007). As a result, many of the cookstoves distributed were focused on energy efficiency and were considered "improved" with a simple change in design by primarily enclosing an open fire (F. R. Manibog, 1984). These stoves fell into portable or built-in stoves; portable stoves were made of metal and ceramic; and built-in stoves inside homes were made of mud, bricks, concrete, clay, and sand, which may be installed with chimneys (F. R. Manibog, 1984).

In the late 1980s and 90s, increased awareness of health impacts led to interventions that were focused on reducing exposure to air pollutants (Akbar *et al.*, 2011). One of the first health focused randomized controlled trials was in Guatemala where chimney mud stoves (plancha) that vented smoke outdoor were distributed to assess the effect on personal exposures and health outcomes (Smith-Sivertsen *et al.*, 2004). Other large-scale interventions in China under the

National Improved Stove Program also focused on energy (fuel) efficiency and indoor smoke removal through chimneys (Edwards *et al.*, 2007; Smith and Keyun, 2010).

More recently, increased awareness of the scale of health, climate and socio-developmental impacts has led to initiatives that emphasize co-benefit aspirations. For example, the government of India launched the National Biomass Cookstove Initiative in 2009 with aims to provide energy services from biomass cookstoves equivalent to that of liquefied petroleum gas (LPG), and these efforts are expected to yield significant gains for health and welfare, and reduce emissions of GHG and black carbon (Venkataraman *et al.*, 2010; Ministry of New and Renewable Energy, 2012). Internationally, the Global Alliance for Clean Cookstoves (Alliance) was established in 2010 under the leadership of the United Nations Foundation to coordinate the global efforts and has an explicit mission to save lives, improve livelihoods, empower women, and protect the environment (Global Alliance for Clean for Cookstoves, 2013)**.**

The most commonly distributed stove technologies in the rural developing regions are biomass stoves. The most basic "improved" biomass stoves are natural draft (ND) stoves made with basic structural modifications to enhance air flow. Rocket stoves that have an elbow-shape insulated combustion chamber are an example of a ND stove. More advanced biomass cookstoves include forced draft (FD) and gasifier stoves with additional modifications to provide for more complete combustion compared to ND stoves. A FD stove has a fan that actively draws air into the combustion chamber. A gasifier stove may contain a fan, but their distinctive feature is a two-stage combustion process where solid biomass is first converted to hot gas and then combusted in a separate chamber containing the supply air (Roth, 2014). Typically, the cleaner the biomass cookstove technologies, the more expensive they become. Modern fuel (LPG and electric) stoves which are prevalent in high-income, urban households have also been deployed in rural households (Chandar and Tandon, 2004) though on a much limited scale. Access to these modern fuels continue to be limited by high cost and physical access, particularly in rural remote parts of the world (Foell *et al.*, 2011). Hence, the majority of cookstove technologies distributed has been in more basic biomass cookstoves category (Akbar *et al.*, 2011; Global Alliance for Clean for Cookstoves and Ecosystem Marketplace, 2015).

Previous cookstove interventions were primarily financed by governments, or private bilateral and multi-lateral agencies (F. R. Manibog, 1984). Today, there are new financing mechanisms, such as carbon financing, that is posited to transform rural household energy sector. Carbon financing is a term applied to resources provided to a project or activities generating GHG (carbon) emission reductions, usually in developing countries, and allowing for trading of those emissions reductions (Kossoy and Ambrosi, 2010). A main rational for investing in developing countries is to reduce cost of abatement, since the GHG effect is global in nature and location of abatement is irrelevant to the goal of reducing overall atmospheric concentrations (The World Bank (Carbon Finance Unit), 2016a). Carbon financing is also seen as a way to transfer investment and cleaner technologies to promote sustainable development in developing countries (The World Bank (Carbon Finance Unit), 2016b).

Cookstove projects qualify for carbon financing; one of the major carbon financing programs is the Clean Development Mechanism (CDM) (Chiquet, 2015), a market mechanism established under the Kyoto Protocol. The CDM-issued carbon credits (each credit equals one tonne of $CO_2$) can be sold on the compliance market as part of Kyoto Protocol obligations; via that market, governments and regulated agencies in industrialized countries may purchase credits to offset GHG emission-reduction obligations.

In addition to the CDM, three other carbon financing programs accept emission reductions from cookstove projects: the Gold Standard, the Verified Carbon Standard, and the American Carbon Registry (Sanford and Burney, 2015). The majority of the cookstove interventions financed under carbon programs fall under the CDM program, followed by the Gold Standard (Lee *et al.*, 2013).

Many cookstove interventions are increasingly leveraging carbon financing to scale up interventions. India's National Biomass Cookstove Initiative plans to utilize carbon markets to expand their effort to distribute millions of improved biomass cookstoves over the next decade (Venkataraman *et al.*, 2010; Ministry of New and Renewable Energy, 2012). The Alliance also launched a Clean Cooking Loan Fund in 2014 to leverage carbon financing to scale up cookstove interventions globally (Kerr, 2014). In 2012, approximately 4 million distributed improved cookstoves were financed under carbon programs (Putti *et al.*, 2015). In 2013, carbon finance was the single largest financier (36% of funding) of cookstove projects, followed by governments (25%) (Ecosystem Marketplace and Global Alliance for Clean Cookstoves, 2014).

### 1.4 Anticipated co-benefits within a theory of change

In the field of public health intervention evaluation, theory of change can be described as a logical sequence of intermediate outcomes needed to bring about specific long-term outcomes (Breuer *et al.*, 2016). Burwen et al. (2012) first presented theory of change in the context of a cookstove intervention with ultimate goals of reducing deforestation, lowering GHG emissions and improving health (Burwen and Levine, 2012). The authors explained assumptions inherent in this chain of outcomes including: 1) field-based performance on fuelwood and emission efficiencies achieving similar levels to those measured in laboratory settings; and 2) that households completely dis-adopt traditional stoves and exclusively use intervention stoves

(Burwen and Levine, 2012). Figure 1-1 provides a theory of change for achieving anticipated co-benefits from cookstove interventions that expands further from the context in the Burwen et al. (2012) study with factors relevant to this thesis work.

For example, environmental benefits can be attained by increasing stoves' efficiency[2] to reduce fuelwood use (impact on forest), and emissions of climate-relevant pollutants (GHG, BC, OC). Whether the desired outcome is achieved will also depend on other influencing factors, such as suppressed demand (shown in green bubble in Figure 1-1), defined as unmet latent demand for basic services needed for social and economic development (Gavaldão *et al.*, 2012). Rural low-income households may have suppressed demand for energy because of high energy costs associated with inefficient stoves that consume high quantity of fuelwood and take long to cook. Intervention cookstoves that are more fuel and time efficient may allow households to meet their demand which may include increased use of the intervention stoves. In this case, the extent of fuelwood reduction benefits may be lower than expected.

For health benefits, increasing stove's combustion efficiency is important for reducing HAP emissions. However, actualization of health benefits will also depend on whether households stack stoves or fuels, a common phenomenon where households continue using traditional stoves or fuels (Masera, Saatkamp and Kammen, 2000; Ruiz-Mercado *et al.*, 2011; Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012; Johnson and Bryden, 2012; Hankey *et al.*, 2015). Households may stack stoves or fuels for many reasons including inability of the new stoves to cook certain types of food or fulfil socio-cultural needs (Ruiz-Mercado and Masera, 2015). Johnson and Chiang's evaluation of stove performance and usage scenarios on air

[2] *Efficiency includes the ability to turn energy in fuel into heat (combustion efficiency), and the ability to transfer the fire's heat into the food or the pot ("thermal efficiency" or "transfer efficiency").*

quality impacts suggested that even lower performing stove (i.e. Tier 2) can have equal or greater benefits than higher performing stoves if the lower performing stove has a significantly higher displacement of the traditional stoves (Johnson and Chiang, 2015). However, the study demonstrated that to reach the WHO annual interim Target 1 for achieving health benefits (World Health Organization, 2014), a complete displacement of traditional stoves with high performing (Tier 4) stoves or clean fuels would be needed (Johnson and Chiang, 2015).

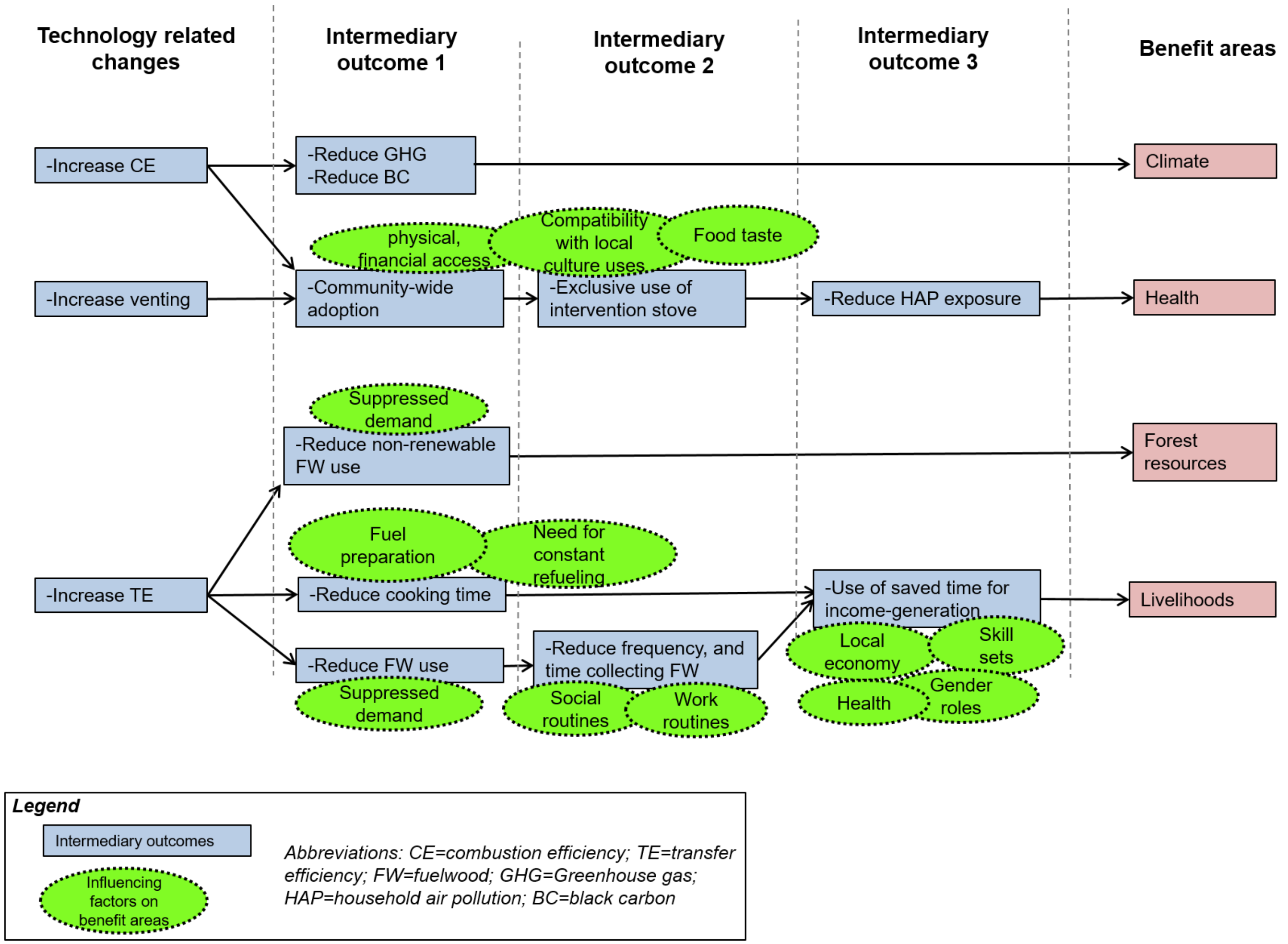
Further, in communities where residential biomass combustion is a major source of exposure, a community-wide or broader (i.e., regional) adoption of cleaner-burning cookstoves may be needed as an additional intermediary outcome. This is because indoor smoke can exfiltrate outdoors (directly via chimneys or indirectly through cracks and windows in homes) (Soneja *et al.*, 2015) and still impact exposure in the outdoor environment or when the emitted HAP infiltrates into homes (Zhou *et al.*, 2011; Balakrishnan, Cohen and Smith, 2014; Chafe *et al.*, 2014).

The theory of change for livelihood benefit outcome depends in part on increasing thermal efficiency of cookstoves to reduce time needed for cooking and fuelwood collection. However, some improved cookstove models showed time savings may be negated by the need to cut wood into smaller pieces, thus time saved may be redirected to fuel preparation (Sambandam *et al.*, 2015). Use of saved time for income generating activities will also depend on many factors such as local economy, skill sets, and gender roles that may influence whether women are able utilize time savings for livelihood improvement (Asian Development Bank, 2015).

The theory of change for achieving the co-benefits from cookstove intervention is not necessarily a linear path as shown in Figure 1-1. Trade-offs may occur within a cookstove technology where it may contribute to an outcome that is beneficial for one aspect but worse for the other. For example, certain improved cookstove models reduce fuelwood consumption but increase emissions of  HAP with higher climate warming impacts (Roden *et al.*, 2009; Just, Rogak and Kandlikar, 2013) or ultrafines (Just, Rogak and Kandlikar, 2013) defined as particles with size less than 0.1 μm in diameter (Oberdörster, Oberdörster and Oberdörster, 2005), which may have serious health implications (Pope III and Dockery, 2006).

A detailed analysis by Grieshop et al. (2011) showed how different cookstove technologies and fuels  provide variable benefits as well as drawbacks on different co-benefits (Grieshop, Marshall and Kandlikar, 2011). An example is a charcoal stove that can reduce HAP emissions and exposure in households at the point of contact with users, however the production of charcoal fuel is associated with high emissions of climate warming pollutants (Pennise *et al.*, 2001). As described earlier, previous health focused interventions have relied on use of chimney which can reduce  indoor concentrations (Naeher, Leaderer and Smith, 2000; Albalak *et al.*, 2001; Smith *et al.*, 2010), and improve health (McCracken *et al.*, 2007; Smith-Sivertsen *et al.*, 2009). However, venting smoke outside creates a trade-off for climate as it releases climate warming pollutants directly into the atmosphere, and could still pose exposures outdoor.

**Figure 1-1: Simplified theory of change for primary anticipated co-benefits with intermediary outcomes (blue boxes) and their influencing factors (green bubbles)**



## 1.5 Cookstove evaluations

Many of the earlier cookstove interventions were deemed as failures because of limited number of stoves that were built, distributed or numbers still in use (Kishore and Ramana, 2002; Putti *et al.*, 2015). The lack of sustained stove-use was attributed to several factors including lack of user acceptance, inability of the intervention stoves to reduce fuelwood use or smoke compared to traditional stoves (based on self-reported data), and durability (F. R. Manibog, 1984). It is important to note that evaluations of earlier interventions paid little attention to measurement of stove combustion efficiencies that were related to health and climate-relevant air pollutants. The evaluations did not include any systematic field-based monitoring of fuelwood use, or other benefits on health, time savings, or livelihoods (Gill, 1987). In fact, given the short "useful life" of the intervention stoves - estimated to range from six months to two years, with fuel performance declining as stoves deteriorate (Dechambre, 1983) - the extent of the fuelwood savings was likely to be much lower than expected.

Today, there are updated standards and protocols for evaluating cookstove technologies. Water Boiling Test (WBT) is one of the most frequently conducted tests that provides technical performance of a stove by completing a standard task in the lab that includes boiling a pot of water to measure specific fuel consumption and emissions (Global Alliance for Clean for Cookstoves, 2014b). While the WBT is quick and inexpensive to conduct, it does not reflect what it can achieve in real households. For tests in the field, Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT) are used. The CCT is performed using local fuels, pots, and cooking practices but under controlled conditions by a local cook who prepares a pre-determined local meal in a test kitchen. The KPT reflects more real-world settings through measurements done in actual households (Bailis, Smith and Edwards, 2007). As CCT and KPT are performed in either test or real kitchens, indoor HAP concentrations or cook's exposure can also be measured.

Even though CCT and KPT are performed in the field, they still provide a limited understanding of the stoves' true effects when they are used in households on a day-to-day basis. Tests conducted in controlled settings, such as the CCT, does not allow for variations in cooking styles of different cooks and their behaviour in the community, which may affect the operation of the stove and subsequent outcome on emissions. Once the new stoves are disseminated, households may stack stoves or fuels (continue use of traditional stoves in addition to the intervention stoves) or increase intensity and frequency of stove use as a result of suppressed demand, which can influence exposures and health outcomes (Baumgartner *et al.*, 2011b). In addition, stove-related measurements in households may also create a "demand effect" as users are more likely to keep using their new stoves during the measurement period and may bias intervention's effect (Burwen and Levine, 2012). Therefore, even KPT tests conducted in the field may miss out on capturing the true effect of stove intervention program if measurements are not conducted over sufficient time duration that reflects varying stove use and behavioral patterns (Edwards *et al.*, 2007).

Only a limited number of cookstove interventions have been rigorously evaluated in the field. They include three large-scale randomized controlled studies in Guatemala, India and Ghana[3] (Smith-Sivertsen *et al.*, 2004; Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012). These studies' findings on lab vs. field differences in performance, and other behavioral outcomes suggest importance of community-based evaluations. In all three studies, the

[3] *Results on changes in air pollution and health outcomes from another randomized controlled trial in Ghana (Ghana Randomized Air Pollution and Health Study (GRAPHS)) have not been published yet.*

interventions were chimney woodstoves that enclosed combustion chamber and vented smoke outdoor. The stoves were locally made in communities and showed reduced indoor concentrations or fuelwood use in the lab (Hanna, Duflo and Greenstone, 2012) or field (Smith-Sivertsen *et al.*, 2004; Burwen and Levine, 2012). In a study involving over 500 households, the Guatemala study distributed plancha stoves (constructed on site with bricks and concrete blocks, and a chimney), and found reduced indoor air concentrations and personal exposures, and improved certain health outcomes in homes using the intervention stoves (Díaz *et al.*, 2007; McCracken *et al.*, 2007; Smith-Sivertsen *et al.*, 2009; Smith *et al.*, 2011). However, the improved mud stoves without chimneys in India and Ghana did not find significant reductions in HAP exposure or fuelwood use compared to the control group despite laboratory results indicating increased fuelwood efficiency. The study in India followed the largest sample size (2,600 households) of all the RCT cookstove intervention evaluations; it found stoves usage declined over time and households did not make efforts to repair them. Stove stacking was also evident in all three studies (Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012; Ruiz-Mercado *et al.*, 2013). The results of these studies show limitations of laboratory-based assessment or even field tests conducted in controlled settings or over a short period of time as they will not be able to capture actual stove use behavior and conditions likely to vary over time.

## 1.6 Unresolved issues and knowledge gaps

Many cookstove technologies remain untested in the field (Burwen and Levine, 2012). Costs and logistical challenges associated with field-based monitoring have frequently limited evaluation of cookstoves to laboratory settings. Such controlled tests are unable to take into account variations in local food and fuel types and moisture, or behavioral patterns (Smith *et al.*, 2007; Berrueta, Edwards and Masera, 2008; Roden *et al.*, 2009; Carter *et al.*, 2014). As a result, large disparities have been reported between laboratory and field measurements on emissions and fuel use consumption (Bailis *et al.*, 2007; Roden *et al.*, 2009). A recently developed protocol, the International Standard Organization (ISO) International Workshop Agreement (IWA) on Clean and Efficient Cookstoves, provides an interim guideline for categorizing stove performance for both health and environmental benefits (ISO, 2012). The ISO/IWA guideline allows for necessary standardization of cookstove technologies that encourages cleaner burning stoves and fuels, however, they are based on laboratory tests.

There is also limited knowledge on what makes households adopt and use stoves over a long-term. A systematic review of enablers and barriers to adoption of cookstoves by households suggested a total of 31 factors across seven domains found to be influential in large-scale uptake of stoves (Rehfuess *et al.*, 2014). The domains spanned from fuel, technology, and household characteristics to knowledge, perceptions, and financial and market aspects as well as regulatory, program and policy mechanisms. The authors concluded that the nature of evidence currently available did not allow for prioritization of the factors, and that local context may be important to determine the most influential factors.

Further, the extent to which an intervention can provide co-benefits is unknown. The issue of rural household energy concerns multiple sectors, including energy, forestry, gender, health, and climate change (Akbar *et al.*, 2011). Previous cookstove interventions have been mostly single issue-based. For example, the large RCT trials in Guatemala, India and Ghana were primarily concerned with exposures and health outcomes with little attention paid to emissions or untended consequences from venting of smoke outdoor. As climate-financed cookstove interventions increase, it could potentially run the same risk of focusing too narrowly on $CO_2$ or other GHG at the cost of other outcomes on regional climate, health, and welfare of users.

Lastly, many cookstove interventions tout time savings and livelihood improvements but these outcomes are rarely evaluated with rigorous methods. Current methodology for assessing time savings from cookstove interventions are based on laboratory Water Boiling Tests (Hutton, Rehfuess and Tediosi, 2007), or self-reported time savings and HAP monitoring (García-Frapolli *et al.*, 2010; Malla *et al.*, 2011). The validity of self-reported time savings in a rural setting has not been tested. In addition, non-technology related factors, such as suppressed demand, may influence cooking and fuelwood collection time. A recent study found that time spent near stoves may be higher for advanced biomass combustion stoves compared to traditional stoves because of more time needed to chop and load fuel (Sambandam *et al.*, 2015). Further, the saved time from cooking and fuelwood collection is assumed to be used for income-generating activities to improve livelihoods of rural women. However, this assumption is yet to be backed by empirical evidence from cookstove intervention literature.

## 1.7 Rationale

An Indian community-based NGO was in the process of implementing a carbon financed cookstove program in rural Karnataka, India. The project planned to replace traditional cookstoves in 21,500 households with CDM-approved intervention rocket stoves. The CDM projects are approved based on meeting the eligibility criteria of additionality that the $CO_2$ emission reductions would not have occurred in the absence of carbon financing (Clean Development Mechanism, no date). For CDM approval, the additionality criteria is simply met when the targets of the intervention project are households and communities (Lee *et al.*, 2013).

On top of additionality, the implementing NGO aimed to provide co-benefits associated with improved cookstove technologies. These co-benefits included improved health from reduced air pollution, time savings, and local employment through production, dissemination, maintenance, and monitoring of the intervention stove project. Co-benefits can be a major motivation for carbon-financed project developers and investors. A market survey of carbon offset actors showed that co-benefits, such as poverty alleviation and empowerment of women, were the second most important criteria for investing in carbon credits after providing greenhouse gas emission reductions (Crowe, 2013). However, the extent of carbon financed projects to provide co-benefits have not been assessed. Measurements of health-relevant emissions or health outcomes are typically not conducted under current carbon financing programs, therefore, the ability of these programs to provide health co-benefits is unknown. Time savings are either assumed from Water Boiling Tests in the laboratory or from self-reported measures which have not be previously verified in rural developing country setting. Further, efficient cookstove technologies are promoted with the view to reduce black carbon emissions and provide near-term climate mitigation (Grieshop *et al.*, 2009). However, black carbon is currently not accounted for under any of the carbon financing schemes, and field-based measures have been limited.

Climate driven interventions are primarily concerned with reductions in non-sustainable harvested fuelwood use, which are converted into carbon credits using a formula (Appendix A.1) (Freeman and Zerriffi, 2014). The reduction in fuelwood use is determined from laboratory tests especially for the CDM-approved projects. The rocket stoves approved for this intervention program were shown to reduce fuelwood consumption by 67% relative to a traditional stove in the laboratory Water Boiling Tests (CDM Executive Board, 2006; *Gold Standard Local*

*Stakeholder Consultation Report*, 2009; Central Power Research Institute, 2010). Numerous studies have shown that laboratory tests do not reflect real-world performance (Berrueta, Edwards and Masera, 2008; MacCarty, Still, *et al.*, 2008; Roden *et al.*, 2009; Hanna, Duflo and Greenstone, 2012).

As carbon financing of cookstove interventions scale up in India and around the world, the extent to which a climate driven intervention can provide co-benefits for health, climate (beyond fuelwood or $CO_2$ savings), and welfare needs to be rigorously evaluated. Carbon financing can provide the financial and self-sustaining power to switch households towards cleaner stoves and fuels. However, their effectiveness in delivering co-benefits for climate, health and socio-economic benefits have not been previously evaluated. India provides an important setting for evaluating this intervention. A third of the world's population (841 million) using biomass fuels are in India. Health outcomes associated with HAP exposure, specifically IHD, COPD, and lower respiratory tract infections, were the three leading causes of DALYs in the country in 2013 (Forouzanfar *et al.*, 2015). Residential biomass combustion is the largest source of BC emissions, and cookstove intervention provides a potential key to mitigating short-term impacts of climate change. Finally, the study evaluates an intervention being implemented in the "real world" rather than one that is investigator-driven. Thus, it provides a realistic assessment that is highly relevant for developing evidence-based recommendations for future programs and policies.

## 1.8 Objectives

The purpose of the research was to evaluate a CDM-approved intervention that was implemented by a third party NGO to assess whether co-benefits for health, climate and livelihoods were achieved. The objectives were to investigate whether replacement of traditional U-shaped mud stoves (or chulhas) with intervention cookstoves affected the following:

1. Climate and health-relevant air pollutants, specifically $PM_{2.5}$ and absorbance (a measure of black carbon);
2. Cardiovascular health as measured by blood pressure, and self-reported eye irritation symptoms for women above 25-years old; and
3. Time spent on household production activities (cooking and collecting fuelwood), and livelihoods.

In addition, the correlations between observed and self-reported measures on the frequency and time spent cooking and collecting fuelwood was also assessed. The hypothesis was that households using intervention stoves based on either intent-to-treat or as per-protocol analysis would experience reduced kitchen concentrations of $PM_{2.5}$ and absorbance. The second hypothesis was that female participants living in households using the intervention stoves would experience post-intervention decreases in blood pressure and self-reported eye irritation symptoms. Thirdly, the intervention stove households would spend less time cooking and collecting fuelwood compared to traditional stove homes.

## 1.9 Dissertation structure

This dissertation follows the manuscript-based thesis guideline of the University of British Columbia, and consists of five chapters: an introduction chapter, three original research chapters, and a conclusion chapter.

Chapter 1 provides background on the scale of household biomass use; impacts associated with traditional use of household biomass combustion; complexities and trade-offs associated with cookstove interventions and co-benefits; and carbon finance programs.

Chapters 2 and 3 are derived from the same randomized control study conducted from 2011 to 2012 in a village in Koppal District, northern Karnataka, India. Chapter 2 investigates changes in fuelwood usage, and 24-hour kitchen level $PM_{2.5}$ and absorbance concentrations in households between baseline and post-intervention season, and differences between control and intervention groups. Chapter 3 reports health outcomes, blood pressure and self-reported eye irritation symptoms, from women participants from the control and intervention households.

Chapter 4 provides time use and livelihood assessment from a cross-sectional study conducted in a nearby village in Raichur District in northern Karnataka. It compares time spent cooking and collecting fuelwood between traditional and intervention stove homes, as well as investigates correlation between observed and self-reported measured time, and how actual or theoretical time saved was used by women.

# Chapter 2: Health and climate air pollutants

## 2.1 Introduction

Burning solid fuel (wood, dung, agricultural residues, and coal) in traditional stoves for cooking and heating negatively affects the health and welfare of nearly 3 billion people, mostly in low and middle-income countries (Pachauri *et al.*, 2012). Household air pollution (HAP) emitted from solid fuel combustion contributed to an estimated 2.9 million premature deaths and 81.1 million disability-adjusted life-years in 2013 (Forouzanfar *et al.*, 2015). It is also an important contributor to emissions of climate-forcing pollutants (Zhang *et al.*, 2000; Bond, Venkataraman and Masera, 2004; Grieshop, Marshall and Kandlikar, 2011; Bond *et al.*, 2013).

Traditional solid fuel cookstoves emit HAP associated with childhood pneumonia, chronic obstructive pulmonary disease in women, lung cancer, cataracts, and tuberculosis (Smith, Mehta and Maeusezahl-Feuz, 2004; World Health Organization, 2006b; Dherani *et al.*, 2008; Fullerton, Bruce and Gordon, 2008; Gordon *et al.*, 2014), and combustion-derived $PM_{2.5}$ more generally is associated with ischemic heart disease and stroke (Newby *et al.*, 2014). Inefficient combustion of biomass emits black carbon (BC) which has also been associated with cardiovascular and respiratory morbidity and mortality (Janssen *et al.*, 2012; Baumgartner *et al.*, 2014), and is thought to have the second largest radiative forcing after $CO_2$ (Rehman *et al.*, 2011; Bond *et al.*, 2013). Household biomass combustion is a major contributor of BC emissions; in Africa and Asia, the sector is thought to account for 70% of the region's BC emissions (Bond *et al.*, 2013). Efficient, low-polluting cookstoves and fuels have the potential to achieve co-benefits for health and climate. Cookstoves that reduce $PM_{2.5}$ and CO exposures may improve respiratory and cardiovascular health compared to use of traditional stoves (Díaz *et al.*, 2007; McCracken *et* *al.*, 2007; Romieu *et al.*, 2009; Smith-Sivertsen *et al.*, 2009; Smith *et al.*, 2011; Clark, Bachand, *et al.*, 2013; Schilmann *et al.*, 2015). More efficient stoves and fuels have been proposed as mitigation strategies to reduce BC emissions (Grieshop *et al.*, 2009). However, only a few studies have quantified BC from cookstove interventions, and they suggest that while some intervention cookstoves reduce BC emissions (Johnson *et al.*, 2008; Kar *et al.*, 2012), others may actually emit more BC than traditional stoves (Roden *et al.*, 2009; Just, Rogak and Kandlikar, 2013).

Major development efforts aim to replace traditional cooking devices with more efficient stoves and fuels (i.e., ‘improved’ cookstoves) (Ministry of New and Renewable Energy, 2012; Global Alliance for Clean for Cookstoves, 2013; ECOWAS Centre for Renewable Energy and Energy Efficiency, 2014). Many of these efforts are financed through carbon markets, in which greenhouse gas (GHG) emission reductions from “improved” cookstoves are sold as carbon credits to investors to offset existing GHG emissions (Lambe *et al.*, 2015). Of the 8.2 million improved cookstoves distributed in 2012 and tracked by the Global Alliance for Clean Cookstoves (Alliance), half received carbon financing (Putti *et al.*, 2015). Despite the instability of carbon markets since 2011, carbon finance was still the single largest financier (36% of funding) of cookstove projects in 2013, with governments being the second largest at 25% (Ecosystem Marketplace and Global Alliance for Clean Cookstoves, 2014).

Several national and international efforts are leveraging carbon financing loans to scale up stove interventions. India's National Biomass Cookstove Initiative, launched in 2009, plans to utilize carbon markets to expand their effort to distribute millions of improved biomass cookstoves over the next decade (Venkataraman *et al.*, 2010; Ministry of New and Renewable Energy, 2012). In 2014, the Alliance launched a Clean Cooking Loan Fund to leverage private sector finance, such as from carbon financing, to scale up cookstove interventions globally (Kerr, 2014).

Carbon financing has been posited to hold transformative potential for the household energy sector in part because it is seen as self-sustaining with potential for scale-up with the market, in comparison to traditional donor-based interventions that can terminate when funding ends (Global Alliance for Clean Cookstoves, no date a). Several carbon financing schemes incorporate improved cookstoves (Lee *et al.*, 2013), of which the largest is the Clean Development Mechanism (CDM), established under the UN Framework Convention on Climate Change (Chiquet, 2015). Only CDM-issued carbon credits can be sold on the compliance market as part of Kyoto Protocol obligations; via that market, governments and regulated agencies may purchase credits to offset GHG emission-reduction obligations. Separately (outside of the Kyoto Protocol), any carbon financing program can sell carbon credits on voluntary markets, to be purchased by individuals and organizations to offset carbon emission for social responsibility.

The extent to which health and climate co-benefits can be achieved through carbon-financed cookstove intervention programs has not been systematically evaluated. Carbon financing schemes have been primarily concerned with reduced fuelwood use and emissions of $CO_2$ and methane, two GHGs included in the Kyoto Protocol (Freeman and Zerriffi, 2014). Reductions of other HAP pollutants that are important for health and climate are desirable but not accounted for in the current carbon crediting programs because they are not part of the Kyoto Protocol. Under the CDM, $CO_2$ savings are obtained from reduction in non-renewably harvested fuelwood use (United Nations Framework Convention on Climate Change, no date). The $CO_2$ savings typically are converted into carbon credits using laboratory-based Water Boiling Tests results on stove efficiency and fuelwood usage. Default values for emission factors result in large uncertainties (Johnson, Edwards and Masera, 2010; Lee *et al.*, 2013). Laboratory results are rarely replicated in the field because of variations in food and fuel types, cooking and behavioral patterns (Smith *et al.*, 2007; Berrueta, Edwards and Masera, 2008; Roden *et al.*, 2009; Carter *et al.*, 2014). Several large-scale energy intervention programs failed to demonstrate benefits to users despite demonstrated improved laboratory efficiencies compared with traditional stoves (Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012). Finally, stove technology choices and their trade-offs (Grieshop, Marshall and Kandlikar, 2011) as well as behavioral (stove usage) patterns (Hankey *et al.*, 2015; Johnson and Chiang, 2015) will impact whether and how much climate and health co-benefits can be achieved. These results suggest a causal chain of conditions needed for a cookstove intervention to achieve climate and health co-benefits, specifically: 1) the intervention stove must significantly reduce fuel wood use, and climate- and health-relevant pollutants under actual use; 2) households must substitute intervention stoves for traditional stoves; and 3) interventions must be community-wide or air pollution exposure must be primarily determined by the household's own stove.

Within this context, we partnered with a local non-governmental organization (NGO) implementing a CDM-approved cookstove intervention program in rural India. Our goal was to evaluate an approved carbon financed program for its potential to provide climate and health co-benefits. The study investigated whether replacement of traditional stoves with intervention stoves under a carbon-finance approved program: 1) reduced fuelwood consumption (primary intent of the CDM program); 2) lowered 24-hour $PM_{2.5}$ and BC indoor concentrations (health and climate co-benefits); and 3) led to actual substitution of traditional stoves with intervention stoves. As carbon financing of stove interventions scale up globally, the study aims to contribute to the development of evidence-based policies to maximize benefits from stove interventions.

## 2.2 Methods

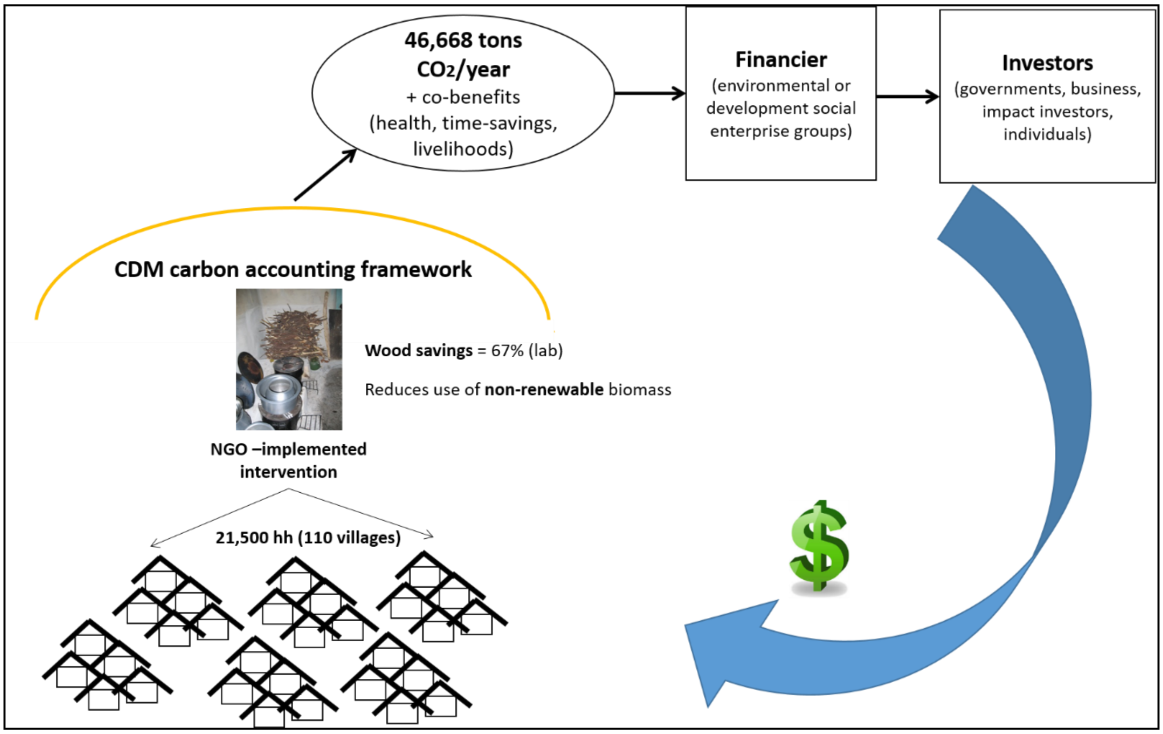
### Setting

The study site was in Koppal District of northern Karnataka, India. Most households (99%) in this region burn biomass fuels in three stone fires or traditional stoves made of mud or clay for cooking and heating of bath water (Fair Climate Network, 2012) (Appendix A: Figure A-1, A-2). The majority of households cook inside their main home, though some use outdoor cooking sheds with thatched walls extended from the main house structure.

In 2011, the partner NGO received the first cookstove-related CDM approval in India. They planned to distribute 40,000 fuel-efficient cookstoves to 21,500 households in rural Karnataka in exchange for carbon credits totaling 46,668 $tCO_2$/year over a period of 10 years (CDM – Executive Board, 2010). As illustrated in Figure 2-1, implementation of a carbon financed project works in such a way that a local implementing NGO and/or a foreign-based environmental or social development enterprise group typically finance the initial start-up cost of the intervention program (Global Alliance for Clean for Cookstoves, 2014a). The carbon credits generated from use of intervention stoves are then sold to investors looking to offset emissions for compliance or voluntary purposes. Anticipated co-benefits, such as improved health and time-savings, can fetch higher prices on the carbon credits, and also serve as additional incentives for socially minded investors. The income from sale of carbon credits can then help subsidize the rollout of intervention program including project operations, stove manufacturing, maintenance and monitoring (CDM Executive Board, 2006). In this pilot intervention village, participating households did not receive any direct financial incentives; households were informed through stakeholder consultations about benefits of intervention stoves including reduced fuel wood use and greenhouse gas emissions, and improved health and time-savings for women (*Gold Standard Local Stakeholder Consultation Report*, 2009).

The intervention stove approved by the CDM was a single-pot “rocket-style” biomass cookstove with an elbow-shape insulated combustion chamber made of lightweight ceramic (Appendix A: Figure A-3 to A-5). Rocket stoves fall under natural draft stove category where structural modifications are made to enhance air flow, and are considered the most basic of "improved" cookstoves types. They are cheaper compared to more advanced biomass stoves such as forced draft stoves, and gasifiers. The stove was manufactured in Karnataka and could be used with the same locally available fuelwood as used in traditional stoves. Laboratory tests of the intervention stove measured thermal efficiency of 30.8% (vs. 10% for a traditional stove) and an estimated 67% reduction in fuelwood consumption relative to a traditional stove (CDM Executive Board, 2006; *Gold Standard Local Stakeholder Consultation Report*, 2009; Central Power Research Institute, 2010). No emission tests were conducted in laboratory or field as these were not required for CDM approval. The carbon credit calculation for this project is provided in Appendix A.1. The market price of the intervention stove was 1,398 Rupees (approximately US$21). For the CDM program evaluated here, households paid a one-time registration fee of 200 Rupees (approximately equivalent to the cost of two traditional stoves) and received two new intervention stoves (*Gold Standard Local Stakeholder Consultation Report*, 2009).

**Figure 2-1: Implementation of CDM-approved cookstove intervention program**




Prior to launching the full CDM program, the partner NGO conducted a pilot intervention program in Hire Waddarkal (HW) Village in Koppal District in northern Karnataka (Appendix A: Figure A-6). Activities included removal of traditional stoves from homes receiving the intervention; constructing raised clay walls around the new stoves to make them look similar to the traditional set up; monitoring the use of new stoves; and assisting users with stove operation and maintenance. These activities were similar to those planned as part of the NGO's full CDM stove intervention program.

## Experimental Design

We implemented a one-year evaluation study from September 2011 to August 2012 in HW Village that coincided with the NGO's pilot intervention program; the study investigators were independent of this intervention program. A subset of households was randomly assigned to receive the intervention stove a year earlier than others, with the remainder serving as controls.

*Household Recruitment*

Households were initially recruited for the study by the partner NGO based on CDM program eligibility criteria that they: 1) did not use liquefied petroleum gas (LPG); 2) used traditional cookstoves that they were willing to remove from the home; 3) had a household of less than 11 occupants; 4) were not seasonal migrants; and 5) were willing to pay the registration fee. For our evaluation study, eligible households from the CDM intervention program were also required to: 1) have at least one female cook over 25 years old who was neither pregnant at enrolment nor a current or previous smoker; and 2) provide oral informed consent. Of the 300 households in the CDM pilot village, 202 were eligible to participate in the CDM program. Of these, 187 households met the additional eligibility criteria for the evaluation study (Appendix A: Figure A-7).

The study randomly assigned the households to either receive the intervention (n=96, or 32% of the 300 homes in the study village) or to continue cooking with their traditional stoves (n=91, 30%). Baseline (pre-intervention (pre)) measurements of household air pollution concentrations and fuelwood use were collected from September to December 2011. The intervention group received new stoves after baseline measurements were completed. Identical follow-up measurements (post-intervention (post)) were then conducted in control and intervention homes from March to August 2012, with a minimum of 124 days (average of 194 days) between pre- and post-intervention measurements. Control households were given the option to receive the intervention stoves at the end of the one year study period.

The study protocol was approved by institutional review boards at the University of Minnesota (IRB code #1104S97992), St. John's Medical College (IERB Study Ref No. 103/2011) in India, and the University of British Columbia (CREB #H14-03012).

The study included a range of air quality, health, fuelwood use, and time-use measurements: 1) 24-hr integrated gravimetric measurements of indoor and outdoor fine particle mass ($PM_{2.5}$) and absorbance (a measure of BC) (Quincey, 2007); 2) continuous measurement of in-plume emissions and indoor concentrations of carbon dioxide ($CO_2$), CO, BC, and $PM_{2.5}$ in a subset of samples; 3) blood pressure and health symptoms of adult women; 4) fuelwood usage, and 5) time spent cooking and collecting fuelwood. This paper reports on the integrated sampling air pollution measurements and fuelwood usage.

**Questionnaires**

Household questionnaires were administered to participants to collect socio-demographic information, including age, gender, education, caste, family size, income, and household assets (Falkingham and Namazie, 2002). Information on presence and number of smokers in the household, and physical characteristics of the house that could potentially impact indoor air quality was gathered, including presence of chimneys, windows and doors, gaps between wall and roof, and dwelling type (attached or shared wall with neighbor). In the post-intervention evaluation, we added questions on the type and number of stoves used during the indoor air pollution measurement and the frequency of intervention stove usage on most days and reasons for use or disuse in intervention households.

Questionnaires were modified from those used in other studies (Baumgartner *et al.*, 2011b) and from the Living Standard Measurement Study on household survey (The World

Bank, no date). The questions were first evaluated by local NGO staff for social and cultural appropriateness, translated and back-translated between English and Kannada, and pilot tested in a community near the study village.

**Fuelwood Weight and Moisture**

Households' fuelwood piles were weighed before and after a 24-hr period over two consecutive days to obtain a 24-hour average following the Kitchen Performance Test protocol (Bailis, Smith and Edwards, 2007). Pre- and post-intervention fuelwood weighing was completed in a total of 178 households. The water content of the weighed fuel was measured with a moisture meter (BD-2100, Delmhorst Instrument Co., Towaco, NJ, USA) by selecting three fuel logs from the weighed fuel pile and taking three measurements on each log, which were then averaged to estimate the wood moisture per fuelwood pile. Wood moisture readings were obtained from 164 households during both the pre- and post-intervention evaluations.

**Measurement of Household and Ambient Air Pollution**

Air pollution was measured over a 24-hour period at three locations: within cooking areas, at a fixed site in the center of the village, and a location 1-km in the predominant upwind direction of the village (Appendix A: Figure A-6). Cooking area measurements were conducted to assess 24-hour indoor air pollution concentrations in line with World Health Organization (WHO) HAP guidelines, a metric that is most relevant for health assessment (World Health Organization, 2014). In the study region, households typically cook two main meals per day (morning and evening). Air monitoring instruments were placed approximately 100 cm from the edge of the combustion zone and at least 150 cm away from doors and windows in accordance with the Standard Operating Procedure for Installing Indoor Air Pollution Instruments in a Home

(Indoor Air Pollution Team and Center for Entrepreneurship in International Health and Development (CEIHD) and University of California-Berkeley, 2005). PM mass samples were collected 60 cm above the floor to approximate a cook's breathing zone when squatting or sitting next to the stove. Post-intervention measurements took place in the same location as during the baseline assessment.

Fixed site monitors at the center and upwind of the village were used to assess ambient air quality. Paired (village center and upwind) ambient measurements were collected over a 4-week period in both the pre-and post-intervention phases, and consisted of 11 measurement-days (pre; September 2011) and 14 measurement-days (post; July to August 2012). Air quality measurements in the village center continued during days with indoor (cooking area) measurements.

$PM_{2.5}$ samples were collected on 37 mm Teflon filters (EMD Millipore, MA, USA) placed downstream of a cyclone (BGI Inc., Waltham, MA, USA) with a 2.5 µm aerodynamic-diameter cut point connected to a battery-operated pump (Apex Pro, Casella CEL, UK) (SI 2). Filters that sampled shorter than 24 hours but met a minimum sampling duration criteria of 16 hours were adjusted with correction factors drawn from distributions developed from co-located time-integrated and real-time $PM_{2.5}$ (DustTrak Aerosol Monitor 8520, TSI Incorporated, Shoreview, MN, USA) and BC (microAeth Model AE51, AethLabs, San Francisco, CA, USA) indoor measurements (Appendix A.3). To assess day-to-day variability, we conducted two additional 24-hour air pollution measurements (i.e., continuous 72 hours) in a random 10% sample of pre- and post-intervention homes.

Teflon filters were pre- and post-weighed in triplicate on a microbalance (Sartorius M3P) in temperature and humidity controlled environment. $PM_{2.5}$ mass concentration was obtained by dividing blank-corrected filter mass by sampled air volume (Appendix A.4). As in previous studies measuring BC from residential biomass combustion (Johnson *et al.*, 2008), absorbance was measured by filter reflectance analysis using a Smoke Stain Reflectometer (SSR) (Model 43D, Diffusion Systems Ltd., London, UK) in a room with minimal light (ISO 9835:1993) (ISO/TC 146/SC 3, 1993).

A weather station (model PWS 1000 TB, Zephyr Instruments, East Granby, CT, USA) was placed in the center of the village next to the community measurement location and recorded temperature, relative humidity, atmospheric pressure, wind speed, and wind direction every 30 minutes.

**Statistical Analysis**

Household physical and socio-demographic characteristics were compared between control and intervention groups using a chi-squared test for categorical variables and a *t*-test for continuous variables to assess whether randomization was successful. Day-to-day variability in air pollutant concentrations was assessed using the non-parametric Friedman test for repeated measures. We used the Wilcoxon rank-sum test for unpaired samples to compare ambient concentrations between upwind and village center sites and between pre- and post-intervention seasons. The Wilcoxon signed rank sum test for matched-subjects was used to assess changes in fuelwood use, fuelwood moisture, and indoor air concentrations of $PM_{2.5}$ and absorbance between pre- and post-intervention seasons. The Wilcoxon signed rank sum test was chosen because seasonal differences for the measured outcomes were not normally distributed. Though Wilcoxon tests have less power (i.e. less chance of detecting a true effect where one exists) compared to parametric methods, such as *t*-tests (Whitley and Ball, 2002), the Wilcoxon signed rank sum test is more robust for data with non-normal distribution, and more appropriate for hypothesis testing. The data met the assumptions of independence of paired differences, and the continuous and ordinal nature of the data.

In addition, we used mixed-effect models with random intercepts at household level to evaluate impact of stove use on log-transformed indoor HAP concentrations controlling for key covariates such as ambient conditions (temperature, humidity, and outdoor $PM_{2.5}$ or Abs concentrations), presence of chimney, and wood quantity and moisture. We calculated least-squares mean to assess percent change in HAP concentrations within and between stove use groups. Model assumptions were verified using normal quantile plots to inspect normality of random effect, and residuals of the mixed effect model.

Statistical comparisons were first conducted with households divided into assigned groups (control versus intervention, "intent-to-treat"); then intervention households were divided into those following / not following protocol ("per-protocol", i.e., did / did not exclusively use the intervention stove), and statistical analyses were repeated. Intent-to-treat evaluates the effectiveness of the overall intervention while per-protocol assesses stove efficacy. Analyses were conducted using R statistical software (R Core Team, 2014).

## 2.3 Results

Intervention and control groups were similar for key characteristics relevant to indoor PM concentrations, including socioeconomic status, the number of household tobacco smokers, chimney ventilation, or the number of windows in the home, indicating selection bias was unlikely and that randomization was successful (Table 2-1; Appendix A, Table A-5 with complete list of baseline characteristics). All households burned wood as their primary fuel in traditional cookstoves, with the exception of one household that reported using both fuelwood and LPG as primary fuels. The majority of homes (88%) reported cooking indoors on most days, with smaller numbers of households cooking outdoor (5%) or both (7%). Of the 187 households that initially participated in the study, 166 remained for post-intervention measurements, with drop-out rates in the control and intervention groups of 4% (n=4) and 18% (n=17), respectively (Appendix A, Figure A-7). Reasons for drop out were because either households were unavailable for follow-up (n=4 control; n=3 intervention), or no longer wanted the intervention (n=14 intervention). The households that dropped out of the study following baseline assessment were also similar to those that remained in the study (SI Table S5). Similarly, the control (n=87) and intervention (n=79) households that remained in the study were similar in key characteristics (Table 2-1).

Self-reported data suggested 60% of intervention homes that remained in the study followed the intervention protocol (exclusively using intervention stoves during household air pollution measurement); the remaining 40% used a combination of intervention and traditional stoves ("mixed stove"). Among the intervention homes that responded to questionnaires that elicited their views on the intervention stoves (N=71), 37% had no problems with the new stoves. The remainder reported difficulty making rotis (local bread) (54%), poor stove-quality (4%), needing to cut wood into smaller pieces (3%), food tasting different (1%), and taking longer to cook (1%).

The median 24-hour fuelwood use was slightly reduced during post versus pre (medians among all households: 3.6 kg $d^{-1}$ [post], 4.2 kg $d^{-1}$ [pre]). The median changes (post – pre) were -0.72 kg $d^{-1}$ for homes using intervention stoves only, -0.20 kg $d^{-1}$ for intervention homes using multiple stove-types, -0.60 kg $d^{-1}$ for non-intervention homes. Differences between control and intervention groups were not statistically significant based on ITT (p=0.74) or per-protocol analyses (p=0.95; Appendix A: Table A-6, Figure A-12). Fuelwood moisture was not significantly different (p>0.5) between the stove use groups (Appendix A.5).

**Table 2-1: Selected baseline characteristics of randomized households**

| Characteristics | Control (n=91) | Intervention (n=96) | p-value[a] | Control-after drop out (n=87) | Intervention-after drop out (n=79) | p-value[b] |
|---|---|---|---|---|---|---|
| Number of rooms in house | 2.0 ± 1.0 | 2.2 ± 1.1 | 0.19 | 2.0 ± 1.0 | 2.3 ± 1.2 | 0.14 |
| Family size | 6.1 ± 1.9 | 5.8 ± 2.0 | 0.35 | 6.1 ± 2.0 | 5.8 ± 2.0 | 0.30 |
| House type (shared wall with neighbor) (%) | 83 | 84 | 0.95 | 82 | 82 | 1.00 |
| Roof Material (*improved, i.e. corrugated iron, zinc, metal sheets, cement, concrete, tiles*) (%) | 53 | 52 | 1.00 | 52 | 52 | 1.00 |
| Floor Material (*finished floor, i.e. ceramic, marble tiles, cement/concrete, stone) (%)* | 67 | 75 | 0.30 | 68 | 75 | 0.42 |
| Area of irrigated land owned | 1.8 ± 2.8 | 1.6 ± 2.8 | 0.42 | 1.9 ± 2.8 | 1.5 ± 2.8 | 0.17 |
| TV (%) | 20 | 28 | 0.24 | 21 | 28 | 0.37 |
| Motorcycle (%) | 12 | 9 | 0.72 | 13 | 8 | 0.42 |
| Chimney above stove (%) | 36 | 39 | 0.79 | 37 | 38 | 1.00 |
| Smokers in home (%) | 36 | 36 | 1.00 | 35 | 37 | 0.93 |
| No windows (%) | 27 | 26 | 0.95 | 28 | 27 | 1.00 |

*Data are mean ± SD or number (%).Wilcox-test for continuous non-normal distributed data; chi-square tests for categorical variables.*
[a] *Between control and intervention groups as randomized.*[b] *Between control and intervention groups that remained until end of the study*

The mean outdoor temperature was lower and humidity was higher during the baseline season (September – December, post-monsoon/winter) than post-intervention (February – August, predominantly dry/summer) (Appendix A: Table A-7).

**Regional and Village-Level Ambient Concentrations**

The 24-hour background air pollution concentrations measured upwind of the village were low, with higher concentrations in the center of village (Appendix A: Table A-7). The differences in $PM_{2.5}$ concentrations between upwind and center of village were 13 $\mu g/m^3$ (95% CI: 8, 24) in pre-intervention season and 18 $\mu g/m^3$ (-1, 62) in the post-intervention season (Appendix A: Table A-7). For Abs levels, the upwind and village center differences were 2.7 x $10^{-6}$/m (1.4, 3.9) in pre-intervention season and 1.6 x $10^{-6}$/m (0.5, 2.9) in post-intervention season (Appendix A: Table A-7). Seasonally, the post-intervention season generally experienced slightly higher mean $PM_{2.5}$ and Abs concentrations compared to pre-intervention season; mean (SD) concentrations during pre- and post-intervention seasons were: $PM_{2.5}$ = 4 $\mu g/m^3$ (3.1) and 5 $\mu g/m^3$(0.5); Abs = 0.3 x $10^{-6}$/m(0.3) and 1.2 x $10^{-6}$/m(0.9) for upwind; and $PM_{2.5}$ = 23 $\mu g/m^3$ (15) and 29 $\mu g/m^3$(23); Abs = 3.3 x $10^{-6}$/m (2.1) and 3.2 x $10^{-6}$/m (2.2) for village center sites (Appendix A: Table A-7). Details on number of ambient samples analyzed are in Appendix A.6.

Analysis of real-time $PM_{2.5}$ concentration measurements in the center of the village revealed two peaks, one in the morning (5-10 am) and a second in the evening (6-8:30 pm), which correspond to cooking periods and illustrates the impact of household biomass combustion on village-level air pollution (Appendix A: Figure A-13). In addition to household biomass combustion, HW Village had a small, paved road with low traffic (~50 vehicles/day). No other major combustion sources, including agricultural burning, were observed by the field staff in or near the village during the study period.

**Indoor Concentrations**

In households that had repeated measurements to assess day-to-day variability, $PM_{2.5}$ correlation (mean absolute error) between one-day and multi-day averages was 0.84 (176 μg $m^{-3}$) for the two-day measures (N=13), and 0.92 (128 μg $m^{-3}$) for three-day measures (N=16) (SI Figures S14-S15). The Abs correlation (mean absolute error) between one-day and multi-day averages was 0.71 (18 x $10^{-6}$ $m^{-1}$) for the two-day measures, and 0.93 (54 x $10^{-6}$ $m^{-1}$) for three-day measures. This finding suggests that our 24-hour air pollution measurements were representative of longer duration measurements (i.e., 48-hour and 72-hour) (Appendix A.7).

A majority of homes in all groups experienced higher $PM_{2.5}$ concentrations and Abs in the post-intervention season (Table 2-2), with median change (post - pre) for both pollutants above zero (Figure 2-2 [as per-protocol]; Appendix A: Figure A-12 [ITT]). However, the magnitude of the $PM_{2.5}$ increase was smaller for the exclusive intervention stove users than for the control group (51 μg $m^{-3}$ [95% CI: -58, 161] versus 139 μg $m^{-3}$ [61, 229]), and this was corroborated by mixed effect model analysis (Appendix A: Table A-10). Post-intervention season was a marginally significant (p=0.07) modifier of the effect of stove use on indoor $PM_{2.5}$ concentrations (Appendix A: Table A-8). Specifically, the exclusive intervention stove homes had 26% lower [-53%, 18%]) indoor $PM_{2.5}$ compared to control in the post-intervention season (Appendix A: Table A-11).

All stove use groups experienced an increase in absorbance in the post-intervention season compared to pre-intervention (Table 2-2; Appendix A: Table A9 & A10). Absorbance:$PM_{2.5}$

ratios were higher in the post-intervention season in all stove use groups (Appendix A: Figure A-17), though the intervention stove users experienced twice the increase compared to control (exclusive intervention stove homes: 0.08 μg $m^{-3}$ [0.04, 0.13]; and mixed stove homes: 0.11 μg $m^{-3}$ [0.05, 0.19] versus 0.04 μg $m^{-3}$ [0.01, 0.06]) (Table 2-2). The increase in ratio was marginally larger (p =0.07) for the mixed stove group compared to the control.

Chimney homes were associated with 58% and 38% lower $PM_{2.5}$ and Abs concentrations, respectively, compared to non-chimney homes (Appendix A.8). HAP concentrations by chimney status are provided in Appendix A: Figure A-18, Figure A-19.

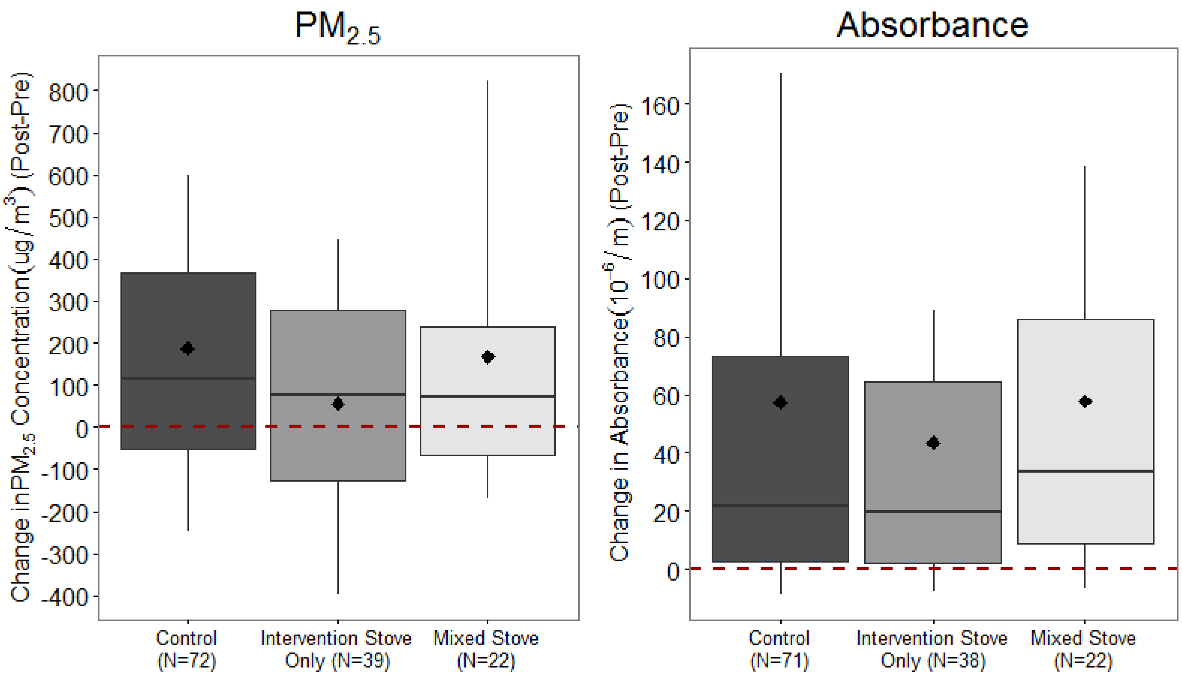
**Table 2-2: $PM_{2.5}$ concentrations and absorbance based on intent-to-treat and per-protocol analysis**

| **Treatment/Stove Use Groups** | Pre-Intervention | | Post-Intervention | | | Seasonal difference (post-pre) in paired households[4] **(95% CI)** |
|---|---|---|---|---|---|---|
| | N[1] | Median[2] (IQR: 1st Q-3rd Q) | N[1] | Median[2] (IQR:1st Q-3rd Q) | N[3] | |
| | | | **$PM_{2.5}$ (μg/$m^3$)** | | | |
| ***Intent-to-treat*** | | | | | | |
| Control | 78 | 246 (111-457) | 81 | 408 (217-700) | 72 | 139 (61, 229) |
| Intervention | 69 | 221 (121-491) | 70 | 299 (147-669) | 61 | 73 (-6, 156) |
| ***Per-protocol*** | | | | | | |
| Exclusive intervention stove | 41 | 208 (121-399) | 45 | 273 (144-605) | 39 | 51 (-58, 161) |
| Mixed stove | 28 | 229 (128-716) | 25 | 440 (208-900) | 22 | 92 (-18, 327) |

| Treatment/Stove Use Groups | Pre-Intervention | | Post-Intervention | | | Seasonal difference (post-pre) in paired households[4] **(95% CI)** |
|---|---|---|---|---|---|---|
| | N[1] | Median[2] (IQR: 1st Q-3rd Q) | N[1] | Median[2] (IQR:1st Q-3rd Q) | N[3] | |
| | | | **Absorbance ($10^{-6}$/m)** | | | |
| ***Intent-to-treat*** | | | | | | |
| Control | 78 | 31 (16-40) | 79 | 47 (28-110) | 71 | 35 (18, 60) |
| Intervention | 70 | 30 (16-40) | 69 | 52 (34-108) | 60 | 36 (22, 50) |
| ***Per-protocol*** | | | | | | |
| Exclusive intervention stove | 42 | 27 (15-39) | 44 | 50 (32-95) | 38 | 31 (16, 45) |
| Mixed stove | 28 | 31 (19-42) | 25 | 70 (41-136) | 22 | 48 (19, 85) |
| | | | **Absorbance/$PM_{2.5}$ mass ratio** | | | |
| ***Intent-to-treat*** | | | | | | |
| Control | 78 | 0.11 (0.08-0.15) | 79 | 0.15 (0.10-0.24) | 71 | 0.04 (0.01, 0.06) |
| Intervention | 69 | 0.12 (0.07-0.15) | 68 | 0.19 (0.14-0.31) | 59 | 0.09 (0.06, 0.13) |
| ***Per-protocol*** | | | | | | |
| Exclusive intervention stove | 41 | 0.12 (0.07-0.15) | 44 | 0.20 (0.14-0.31) | 38 | 0.08 (0.04, 0.13) |
| Mixed stove | 28 | 0.12 (0.07-0.15) | 24 | 0.18 (0.13-0.31) | 21 | 0.11 (0.05, 0.19) |

*N=sample size; IQR=interquartile range; CI=confidence interval*
*[1] Exclude drop outs*
*[2] Concentrations from unpaired data*
*[3] Sample size of paired households (those with both pre- and post-intervention measurements), excluding dropouts*
*[4] Wilcoxon signed-rank test of median difference and 95% CI for before and after intervention for paired households*

**Figure 2-2: Change in air pollutant concentrations by stove use groups**




*Note: lower and upper hinges represents the 25th and 75th percentiles, respectively; black line inside the box represents the 50th percentile; lower and upper whiskers represent the 10th and 90th percentiles, respectively; and diamond represents the mean. "Control" households did not receive the intervention. "Intervention" households received the new stoves and followed protocol. "Mixed Stove" households received the new stoves but decided to also use the pre-intervention stoves.*

## 2.4 Discussion

To our knowledge, this is the first study to independently and rigorously evaluate a cookstove intervention program approved for carbon financing in a real world setting. The primary goal of the CDM, and other carbon markets is to lower emissions of climate warming pollutants through reduction in non-renewable fuelwood use. The results of our study suggest that the intervention stove approved by CDM program did not significantly reduce fuel wood consumption compared to traditional stoves. Exclusive intervention stove use homes had slightly lower $PM_{2.5}$ concentrations compared to control, however abs:$PM_{2.5}$ ratio was higher in that group.

Our fuelwood use results are important because the CDM approval process assumed, based on laboratory testing of stove efficiency, that in-field non-renewable fuelwood use - a key variable in carbon credit calculations and therefore a primary financial driver of the intervention - would be lower with the intervention, compared to the traditional stove. Some field-based tests suggest natural draft cookstoves consume the same or higher fuel wood compared to traditional stoves (Kar *et al.*, 2012; Muralidharan *et al.*, 2015). It is also possible that in our study lack of fuelwood savings may be attributable to intervention households cooking larger sized meals or more dishes than they had previously done because of initial "suppressed demand" (The United Nations Framework Convention on Climate Change, no date; Michaelowa *et al.*, 2014). Households may have "suppressed demand" as a result of high energy costs associated with traditional stoves that consume large quantities of fuelwood. More efficient stoves that reduce fuelwood have lower energy costs in the form of reduced time spent collecting fuelwood or its purchasing costs. Therefore, it is possible that the energy demand of intervention households in the study were partially met by the intervention stove, thus improving their welfare, but without providing measurable fuelwood (and carbon) savings. Per-protocol analysis provides insight into mixed stove homes where suppressed demand may be at play. Mixed stove homes had the lowest reduction in fuelwood use (post-pre) of all groups despite having statistically significantly lower fuelwood moisture compared to the baseline, suggesting that these homes used more fuelwood compared to other groups. In fact, some mixed stove homes used three stoves (two intervention stoves and one traditional stove).

While reductions in health and climate relevant pollutants from cookstove interventions are desirable, this study demonstrates that they may not be occurring in practice. All groups experienced an increase in $PM_{2.5}$ concentrations and Abs levels in the post-intervention season though the $PM_{2.5}$ increase was lower for the intervention group compared to the control. The increase in $PM_{2.5}$ concentrations could be related to seasonal changes unrelated to the intervention. Stove use behavior, such as how users start or tend fires, may also be a factor (Roden *et al.*, 2009). In the mixed stove group, the increase in PM concentrations could also be from households using multiple stove types (or more than two stoves) as a result of "suppressed demand".

Whereas previous field-based studies have shown natural draft (ND) stoves can significantly reduce PM concentrations compared to traditional stoves, these have been based on tests in a limited number of households (Pennise *et al.*, 2009) or from controlled cooking tasks (Muralidharan *et al.*, 2015). On the other hand, larger-scale randomized interventions with controlled populations, similar to our study, have shown ND stoves do not consistently reduce HAP (Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012).

Though there was no significant difference in median indoor $PM_{2.5}$ concentrations between the stove use groups, it should be noted that the intervention stoves were associated with lower *mean* $PM_{2.5}$ concentrations in the post-intervention season compared to the control group. Larger reductions in mean $PM_{2.5}$ concentrations were seen in the post-intervention season in the exclusive intervention stove group. This outcome is relevant to, and potentially important from, the perspective of emissions and overall climate impact.

However, the slight reduction in mean $PM_{2.5}$ concentrations and potential climate benefit may be negated by the fact that the intervention households had twice the absorbance:$PM_{2.5}$ ratio compared to control households. This suggests that emissions from the intervention stoves produced a greater proportion of absorbing particles compared to traditional stoves. A laboratory investigation of improved biomass stoves, including the intervention stove used in this study, found significant reductions in PM concentrations and emissions factors, however, emission factors for BC and the elemental carbon (thermal-optical method for measuring BC) fraction of PM were three to seven times higher than that of three-stone fire tests (Just, Rogak and Kandlikar, 2013). Previous studies also suggest that when compared to traditional stoves, some rocket or ND cookstoves had higher BC emission factors (Preble *et al.*, 2014) or emitted higher BC concentrations when mixed fuels (wood, agricultural crop residue, and cow dung) are used (Kar *et al.*, 2012). Currently, no carbon market accounts for BC in their offset calculation methodology (Lee *et al.*, 2013; Freeman and Zerriffi, 2014; Sanford and Burney, 2015). The Gold Standard, a carbon finance program in the voluntary sector, is in the process of developing a methodology to account for BC in their financing approach (The Gold Standard, no date). These efforts can promote quantification of particle composition from cookstoves to emphasize technologies that generate verifiable reductions in climate warming pollutants beyond $CO_2$. However, it should be noted that climate impact of aerosols depends not only on black carbon but also co-emitted particles, such as organic carbon, which have cooling effects on climate. Therefore, to have a better understanding of the overall climate impact from stoves, detailed characterization of aerosols from different cookstove technologies is needed.

Chimneys significantly reduced HAP concentrations by as much as 58% for $PM_{2.5}$ compared to non-chimney homes. This is lower but not drastically different from estimates from several studies, including interventions, that found 70% of PM emissions can be vented outdoor (Grieshop, Marshall and Kandlikar, 2011). Unlike other chimney stove interventions where chimneys were part of the stove structure designed to directly vent smoke from stove to outdoor, chimneys in our study homes were not attached to the intervention stove directly.

Therefore, less smoke may be directed through the chimney. While natural draft mud stoves with chimneys have been shown to significantly reduce indoor HAP concentrations compared to traditional stoves (Chengappa *et al.*, 2007; Dutta *et al.*, 2007; Clark *et al.*, 2009; Fitzgerald *et al.*, 2012), venting indoor HAP to outdoor is not beneficial for climate particularly when BC and other climate warming pollutants are released into the atmosphere. High ambient air pollution levels in a community can also impact personal exposure levels and contribute to adverse health outcomes. However in our study, average indoor concentrations are still an order of magnitude higher than outdoor levels (370 versus 23 μg/m$^3$); even at peak cooking times, ambient PM concentrations only ranged from 25-75 μg/m$^3$ (Appendix A; Figure A-13). The population exposure in our study is dominated by indoor exposure where it accounted for 96% of the total time-weighted average exposure (Appendix A9), and suggests the importance of a person's own cookstove as the main source of exposure.

Adoption of the intervention stove was not complete in our study; 40% of intervention households used a mixture of traditional and intervention stoves. Stove or fuel stacking (Ruiz-Mercado *et al.*, 2011) where households use old and new stoves and fuels is prevalent in many settings, including interventions (Masera, Saatkamp and Kammen, 2000; Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012; Johnson and Bryden, 2012; Hankey *et al.*, 2015). It is possible that if the intervention stoves were more efficient and were able to significantly reduce fuelwood use and HAP concentrations, greater substitution of traditional with intervention stoves might have occurred. However, in our study population, the major reason for continuing to use traditional stoves were their ease and ability to make rotis (traditional bread) properly compared to the intervention stoves. Stove stacking can also influence HAP exposure both within and outside a household environment. Per-protocol analysis in our study revealed that stove stacking in mixed stove homes had a higher seasonal increase (post-pre) in $PM_{2.5}$ and Abs levels compared to homes that strictly used intervention stoves.

Based on our findings we provide recommendations for future climate-financed cookstove intervention programs, including a need to align with emerging standards and guidelines. For example, the recently developed International Standard Organization (ISO) International Workshop Agreement (IWA) on Clean and Efficient Cookstoves, provides for the first time an interim guideline for categorizing stove performance for both health and environmental benefits (ISO, 2012). The IWA uses a five-tiered ranking system for each of the following performance indicators: fuel use/efficiency, total emission, indoor emission, and safety. Traditional solid fuel stoves typically occupy the lowest rank (Tier 0) for all indicators, rocket stoves tend to be in Tier 1 & 2, more advanced biomass stoves in Tier 3, and modern fuel (liquid or gas) stoves in Tier 4 (Berkeley Air Monitoring Group, 2012). Though modern fuel stoves are ideal for achieving "ambitious health and environmental goals" of the IWA Tier 4 (Still, Bentson and Li, 2015), the CDM program does not support Tier 4 stoves because they use fossil fuels, which are not considered renewable. Cost and access to modern fuels also remain substantial barriers for the majority of the rural and poor households (Zerriffi, 2011). As such, biomass cookstoves are seen as interim solutions because a large part of the world's rural population will continue to depend on biomass fuels in the near future (International Energy Agency, 2002). An increasing number of more advanced biomass cookstoves, such as fan stoves and gasifiers, are becoming available but they are more costly and their field testing remains limited (Berkeley Air Monitoring Group, 2012). Limited field testing show advanced biomass cookstoves and modern fuels can significantly reduce HAP concentrations (Pennise *et al.*, 2009;

Kar *et al.*, 2012; Muralidharan *et al.*, 2015), though no solid-fuel stove intervention programs to date have reduced exposures to below the WHO guidelines (Clark, Peel, *et al.*, 2013).

Though an increasing number of centers are available that provide stove performance testing against the IWA/ISO standards in standardized laboratory settings (Global Alliance for Clean Cookstoves, no date b), field-testing at the community level remains critical. Laboratory studies cannot capture variability observed in the field, including types of foods cooked, fuelwood types and moisture, and user practices (Roden *et al.*, 2009; Johnson and Bryden, 2012). Implementing randomized controlled evaluations is feasible in rural developing country settings with "modest-cost methods" (Burwen and Levine, 2012). If large-scale trials are not feasible, pilot community-based studies would be beneficial prior to scaling-up interventions.

Although there is growing evidence that natural draft/rocket stoves are unlikely to significantly reduce HAP concentrations, the significance of our study lies beyond stove technology assessment. Specifically, this study illustrates the opportunities and challenges of implementing a large-scale climate-financed cookstove intervention. The NGO leading the intervention was a community-based organization with substantial cultural and social capital in the region, a factor that was essential in encouraging households to participate in the stove exchange program. In addition, during the intervention period, the NGO took great care (through daily visits to the village) to ensure that the intervention stoves were locally acceptable, and that stove related issues were promptly addressed. This included, for example, lowering the height of the intervention stoves to fit the ergonomic needs of women. Despite these on-the-ground intensive efforts, adoption and use of the intervention stoves as per the CDM protocol was only seen in 60% of intervention households. When interventions are expanded, even lower compliance may result if stove use monitoring and motivation efforts are not as intensive.

Though this particular project was not scaled up in Koppal District because of the 2012 carbon market crash, similar projects are proceeding through carbon markets in other locations. As of August 2015, the partner NGO had distributed a total of 36,102 intervention stoves out of the planned CDM-approved 40,000-stove distribution project, producing carbon credits primarily for the voluntary market.

This evaluation was a unique opportunity afforded by collaboration with a local NGO implementing a carbon-finance approved program, but as a result our study was limited by a relatively small sample size of households that were exclusively using the new intervention stoves. This aspect was a result of the high prevalence (~40%) of intervention households that elected to use both intervention stoves and traditional stoves (“mixed stove” / “stove stacking”). Hence, the sample size in the intervention group exclusively using the intervention stoves was smaller than originally intended. However, as the study's purpose was to evaluate the effectiveness of an intervention, the assessment of effectiveness in intention-to-treat analysis (thus accounting for the limited adoption of the intervention) is still highly relevant.

The study could have benefited from a longer follow-up period. In this study, seasonal effects were apparent, such as changes in fuelwood moisture. Although the study had a comparable group which controlled for biases, fuelwood moisture or other unmeasured seasonal effects may have influenced emissions from traditional and intervention stoves differently. A follow-up period over one year would have allowed the study to compare stoves’ emission and fuelwood efficiencies within similar seasons, thus controlling for seasonal effects. Further, a longer follow-up period would have allowed for assessment of air pollutant concentrations and fuelwood consumption over time that is reflective of real-world stove usage and changes in stoves’ conditions. Carbon financing of rural energy intervention programs has great potential to change the landscape of household energy in the developing world, while providing various benefits for health and climate. However, this potential needs to be more rigorously assessed. While co-benefits from cookstove interventions are theoretically plentiful, achieving them can be complex in reality. The recent guidelines for cookstoves under the ISO standards and the development of methods to account for BC by the Gold Standard can assist in helping to align future carbon financed stove interventions with health and climate goals but there is a need for careful and thorough population-based evaluations to ensure that these benefits are achieved.

# Chapter 3: Blood pressure and eye irritation symptoms

## 3.1 Introduction

High blood pressure (BP) is a leading risk factor for deaths and disability-adjusted-life-years (DALY) in both developed and developing countries (Forouzanfar *et al.*, 2015). High BP is a recognized risk factor for renal (Jha *et al.*, 2013) and cardiovascular diseases including stroke and ischemic heart disease (Sesso et al. 2003, Glynn et al. 2002), which are leading causes of death and DALYs worldwide (Feigin *et al.*, 2015; Roth *et al.*, 2015).

High BP has many contributing risk factors, including diet, tobacco use, physical activity, weight, genetics, family history, stress, and alcohol (P. Whelton *et al.*, 2002; Chobanian *et al.*, 2003; Shanthirani *et al.*, 2003). A 2010 review concluded that there was moderate epidemiological evidence of an effect of short-term (~days) exposure to ambient fine particulate matter ($PM_{2.5}$) and BP (Brook *et al.*, 2010). Both short- and long-term exposure to ambient $PM_{2.5}$ is associated with adverse cardiovascular events (Miller *et al.*, 2007; Mustafic *et al.*, 2012; Shah *et al.*, 2013, 2015).

Whereas associations between air pollution and cardiovascular events are well-established, the majority of this evidence comes from outdoor exposures in urban areas. A substantial segment of the world's population (2.7 billion) is exposed to household biomass combustion from burning of wood, cow dung, and crop residues in inefficient traditional stoves; a majority of this population resides in rural areas (International Energy Agency, 2011; World Energy Outlook/International Energy Agency, 2015). Exposures in these indoor settings are typically substantially higher (Smith and Peel, 2010) and differing in particle chemical composition (Naeher *et al.*, 2007) compared with the exposures to outdoor air pollution in urban areas.

Recently, several cross-sectional epidemiologic studies suggest associations between biomass derived air pollution and BP (Baumgartner *et al.*, 2011a; Clark *et al.*, 2011; Painschab *et al.*, 2013; Burroughs Peña *et al.*, 2015; Neupane *et al.*, 2015), and CVD related biomarkers (Clark *et al.*, 2009; Ruiz-Vera *et al.*, 2015; Quinn *et al.*, 2016). Only limited longitudinal experimental studies have examined effect of cookstove intervention on BP (McCracken *et al.*, 2007; Hanna, Duflo and Greenstone, 2012; Clark, Bachand, *et al.*, 2013; Alexander *et al.*, 2015).

Systematic reviews indicate an association between HAP exposure and cataracts (Smith *et al.*, 2014); links to other measures of eye health have also been suggested (West *et al.*, 2013). Few studies have assessed the effectiveness of cookstove interventions on eye irritation symptoms, although they have indicated improved conditions (Khushk *et al.*, 2005; Siddiqui *et al.*, 2005; Díaz *et al.*, 2007).

In this study, we evaluated whether a carbon financed rocket stove intervention implemented by a local non-governmental organization (NGO) in rural India resulted in blood pressure and eye health benefits for women. Our aim was to evaluate potential health benefits resulting from an intervention that was not primarily motivated by health considerations and which was already underway (Aung *et al.*, 2016). Climate motivated cookstove interventions are increasing worldwide (Ecosystem Marketplace and Global Alliance for Clean Cookstoves, 2014; Lambe *et al.*, 2015; Putti *et al.*, 2015), and while their overarching aim is to reduce carbon emissions, they have the potential to provide public health benefits. However, the extent of the health benefits from such climate financed cookstove interventions has not been previously investigated.

India is an important setting to evaluate the potential for health co-benefits because it has the largest number of population in the world using biomass fuels (841 million) (International Energy Agency, 2015). High blood pressure and HAP are top health risk factors in the country (Forouzanfar *et al.*, 2015). Results of the study could guide intervention programs to maximize public health benefits.

## 3.2 Methods

### *Setting*

An Indian NGO initiated a carbon-financed cookstove intervention in northern Karnataka, India as part of an approved United Nations' Clean Development Mechanism (CDM) cookstove program, described in detail elsewhere (Aung *et al.*, 2016). Briefly, the NGO planned to distribute 40,000 biomass cookstoves across 110 rural villages (21,500 households). As a CDM-approved program, the intervention was intended to sell carbon credits attributed to carbon emission reductions; the calculated quantity of carbon emission reduction attributed to stove use is derived from laboratory-based fuel consumption measurements (where the intervention cookstoves must demonstrate reduced fuelwood use) and available estimates of the proportion of biomass burned that would have been harvested non-renewably. Sale of the carbon credits subsidized the roll out of the intervention stoves.

Prior to the launch of the full CDM program across Karnataka, the partner NGO planned a pilot intervention in Hire Waddarkal (HW) Village in Koppal District, Karnataka. Of the 300 households in the HW Village, 202 met CDM eligibility criteria (Aung *et al.*, 2016) to participate in the intervention program.

***Study design***

We partnered with the local NGO prior to the start of the pilot intervention in HW Village. This allowed us to randomize distribution of the intervention cookstoves to the CDM eligible households. Of the 202 CDM eligible households, 187 homes were eligible to participate in the study (Aung *et al.*, 2016) and were randomly assigned to either the control (n=91) or intervention (n=96) groups.

Baseline (pre-intervention) measurements were collected from September to December 2011. Then, intervention rocket stoves were distributed to the intervention group. Identical follow-up measurements were conducted in control and intervention groups from March to August 2012 with a minimum of 124 days (average of 194 days) between pre- and post-intervention measurements. Control households were given the option to receive the intervention stoves at the end of the one year study period.

***Study Population***

Participation of eligible participants was restricted to women above the age of 25 years who were not pregnant at time of enrollment nor current tobacco or pipe smokers. From the 187 households, total of 247 women were eligible to participate. Upon obtaining oral informed consent, we recruited 222 women into the study who were randomized to control (n=111) and intervention (n=111) groups.

The study protocol was approved by institutional review boards at the University of Minnesota (IRB code #1104S97992), St. John's Medical College (IERB Study Ref No. 103/2011) in India, and the University of British Columbia (CREB #H14-03012).

***Intervention***

Each of two intervention stoves were single-pot "rocket-style" biomass cookstoves, with an elbow-shape insulated combustion chamber made of lightweight ceramic. The stoves used the same locally available fuelwood as traditional cookstoves. Laboratory tests indicated that the intervention stoves had thermal efficiency of 30.8% – three times more than a traditional stove – and reduced fuelwood consumption by 67% relative to a traditional stove (CDM Executive Board, 2006; *Gold Standard Local Stakeholder Consultation Report*, 2009; Central Power Research Institute, 2010). Each household received two intervention stoves in exchange for a participation registration fee equal to the cost of constructing two traditional stoves.

To improve users' acceptance of the intervention cookstoves, the NGO conducted extensive prototyping and in-village testing and used the stoves in its local field office where type of fuel and food cooked were similar to intervention communities. Before and during the intervention in HW Village and elsewhere, the NGO obtained community feedback on the cookstove design, ease of use, and quality issues, which were incorporated into the development of the final stove model. The NGO also made daily visits to intervention homes to ensure proper use of the stoves and to address users' concerns.

***Blood Pressure***

Systolic and diastolic blood pressure (SBP/DBP, respectively) readings were taken at participants' homes prior to cooking events using an oscillometric device (Omron 705 IT, Omron

Healthcare Europe BV, Hoofddorp, The Netherlands) that was maintained and calibrated within the last 6 months. The device has been validated against reference mercury sphygmomanometers in adults and is recommended for professional and home-use in adult populations (Coleman *et al.*, 2006). Recent guidelines recommend home (rather than in-clinic) BP measurements as a convenient method that avoids spurious increases in BP caused by measurement in a clinical setting (Pickering *et al.*, 2005).

Prior to taking a BP measurement, participants were encouraged to relax, and following at least 5 min of rest in a quiet room, SBP and DBP was measured in the supported right arm (at heart level) of a seated participant following the American Heart Association's recommendations (Pickering *et al.*, 2005). Three repeat measures were taken at intervals of at least 1 minute during a total period of 10 minutes of continued rest for each study participant. Only the second and third BP reading measurements were used for analysis as the first measurement tends to be elevated (Pickering *et al.*, 2005). BP measurement was repeated over the next two consecutive days to allow for averaging of readings over a 3-day period similar to protocol used in a previous cookstove intervention study (McCracken *et al.*, 2007). Field staff recorded day of the week and time of day during each BP measurement visit, and whether any caffeine beverages or betel nut were consumed prior to BP reading. Betel nut is a seed of the areca palm that has been associated with various adverse health effects, including hypertension (Tseng, 2008; Javed *et al.*, 2010; Heck *et al.*, 2012).

***Eye Health Symptoms***

Self-reported eye-health symptoms were collected via survey questionnaires on the same female participants in the BP monitoring group. The questions asked whether participants felt the following symptoms: 1) burning sensation in the eyes before, after, during cooking or at times other than cooking; 2) discharge on eye lids in the mornings; 3) eyes look red often; and 4) watering of the eyes often. Whereas previous studies (Saha *et al.*, 2005; Siddiqui *et al.*, 2005; Díaz *et al.*, 2007) obtained self-reported symptoms on broad eye health outcomes, such as "eye irritation", "eye congestion", "sore eyes", and "eye symptoms", our study probed specific symptoms by asking about burning sensation, discharge, and redness. We are not aware of any studies that have validated self-reported questionnaires on eye irritation symptoms from household biomass combustion exposures. One prior study found that self-reported symptoms such as "Tears while Cooking" provided a simple and immediate indicator for assessing effects of cookstove interventions (Ellegård, 1997).

### *Covariates*

Each subject's weight (kilogram), height (centimeters), and waist circumference (centimeters) was measured with a weighing scale and tape measure at baseline and post-intervention home visits. Weight and height was used to calculate body-mass index (BMI: weight (kilogram) divided by height squared (meter2)). We estimated 24-hr salt use for cooking by asking cooks to collect the same amount of salt they would use for the next 24-hour period into a plastic container, and to only use the salt from the container. The container was weighed before and after a 24-hr period with the difference indicating household salt consumption. To calculate salt consumption per person, we employed age- and gender-specific adult equivalence factors used for normalizing fuelwood consumption (Bailis, Smith and Edwards, 2007). Similar to fuelwood use per household, larger families are likely to cook larger meals and use more salt. Other demographics, previous health conditions and exposures were obtained from survey questionnaires administered to each subject about previous diabetes and high BP diagnoses and medications taken, coffee and betel consumed, and presence of smokers in the household, age, occupation, monthly income, education, caste, housing conditions, and household assets. Household assets were converted into asset scores representing the sum of binary indicators for owning the following assets: chair, mobile, radio, television, bicycle, motorcycle, mixer, land (irrigated and dry), livestock, and roof, floor and wall materials (natural/unimproved versus finished/improved quality). Questionnaires were translated (and, as part of pilot-testing, back-translated) between English and Kannada and pilot tested in a nearby village. Questions that did not pilot test well were modified or removed in order to ensure that they were appropriate to the local social and cultural context.

***Indoor air measurements***

Household air pollution was assessed in the cooking area using integrated gravimetric measurement of fine particulate matter ($PM_{2.5}$) and absorbance (an optical measure of black carbon) as described in detail elsewhere (Aung *et al.*, 2016). Post-intervention measurements took place in the same location as during the baseline assessment based on kitchen layout diagrams drawn by field staff in data collection forms and as verified by participating household members. $PM_{2.5}$ samples were collected on 37 mm Teflon filters placed downstream of a cyclone with a 2.5 µm aerodynamic-diameter cut point connected to a battery-operated pump. Details on pump flow rates, corrections on filters with shortened air sampling times because of pump failures, and number of analyzed filters for $PM_{2.5}$ mass and absorbance are reported elsewhere (Aung *et al.*, 2016). Teflon filters were pre- and post-weighed and blank-corrected by subtracting the seasonal mean mass of field blanks from the mass of the $PM_{2.5}$ filter samples. Absorbance was measured by filter reflectance analysis using a Smoke Stain Reflectometer (ISO/TC 146/SC 3, 1993).

***Statistical analysis***

Baseline characteristics of intervention and control households were compared to assess differences between the two groups using either the *t*-test (for normally-distributed data) or the Mann-Whitney-Wilcoxon Test (for skewed distribution data) for continuous variables; the chi-square test was used for categorical variables. Mixed-effect models with random intercepts at the individual and household level were used to evaluate the impact of stove use on BP and eye symptoms. Variables that were significantly different between the two groups at baseline, as well as potential risk factors (age, BMI, ambient temperature, education, family size, caste, socio-economic indicators (house type, room number, asset score, land ownership, time spent near stove), rating of one's health compared to others of same age, occupation, cooking years, self-reported time spent near stove during cooking events, betel use, salt consumption, presence of smokers, chimney and windows, previous diagnosis of hypertension and diabetes) were evaluated separately in univariate analyses for BP and eye symptom outcomes. Variables found to be significant at or below $p=0.10$, and which were not collinear (variance inflation factor $<2$) were included in regression analyses.

Following the approach used by McCracken et al. (2007) in a randomized controlled trial, two types of BP analyses were conducted: between-group and within-group analyses. The between-group analysis evaluates differences in BP between groups in the post-intervention season using the model:

$$BP_{ik} \sim \beta_0 + \beta_1 \text{ Stove Group}_{ik} + \beta_2 \text{ Age}_i + \beta_3 \text{ BMI}_i + \beta_4 \text{ Temperature} \ldots + \varepsilon_{ik}$$

where $i$ denotes individual and $k$ denotes household. $\beta_1$ is the effect estimate for the stove group as either the randomized "intent-to-treat" (ITT) (control versus intervention), or the actual use “per-protocol” (PP) where intervention households were divided into those following / not following the protocol (i.e., exclusive use of the intervention stove versus mixed use of intervention plus traditional stove). We adjusted for covariates that were known predictors of BP, such as BMI (Tesfaye *et al.*, 2006), age (Baumgartner *et al.*, 2011a), and ambient temperature (Barnett *et al.*, 2007), which were fitted as linear terms. Other covariates in the regression models included categorical variables: betel user (current, past, never), self-rating of health (excellent, good, fair, poor, don’t know); and continuous variable: ownership of irrigated land. Separate regression analyses were run for SBP and DBP.

Within-group analysis follows the model:

$$BP_{ijk} \sim \beta_0 + \beta_1 \text{ Stove Group}_{ijk} * \text{Season} + \beta_2 \text{ Age}_{ik} + \beta_3 \text{ BMI}_{ij} \ldots + \varepsilon_{ijk}$$

where *i* denotes individual, *j* denotes repeated measures within subjects, and *k* denotes household. An interaction term between stove group and season was included to reflect an intervention in the post-intervention season. As in the above model, we adjusted for age, BMI, ambient temperature, betel use, self-rating of health, and ownership of land. We performed sensitivity analysis by including individuals who reported undergoing hypertension and diabetes treatment or medication (N=9) to test robustness of the findings.

Additional BP analysis was performed with log-transformed indoor HAP concentration as a predictor variable adjusting for the variables as above (age, BMI, ambient temperature, betel use, self-rating of health, and ownership of land). This analysis was motivated by initial results suggesting significant changes in BP between groups. Previous analyses (Aung *et al.*, 2016) indicated the exclusive intervention stove homes had 26% lower [-53%, 18%]) indoor $PM_{2.5}$ compared to control in the post-intervention season. Because of higher absorption properties of particles emitted from intervention stoves, we also included Abs/$PM_{2.5}$ ratio in the regression analyses.

Stratified analyses were conducted for subgroups to assess effect modification by age and BMI as the effect of intervention on stove groups may differ based on these characteristics (Clark, Bachand, *et al.*, 2013). An interaction term was included between these variables and the randomized groups or actual stove groups in both between-group and within-group analyses. Age and BMI were first entered as linear terms and then dichotomized into groups. Age was dichotomized at below or above the median age of study's population, 40 years, following the approach of Clark et al. (2013) (Clark, Bachand, *et al.*, 2013). BMI was categorized as < 18.5 kg/m2 (underweight); 18.5 kg/m2 ≥ BMI < 23 kg/m2 (normal); and BMI ≥ 23 kg/m2 (overweight). The BMI cut off for overweight was in accordance with Indian guidelines which have a lower threshold than WHO standards (BMI ≥ 25 kg/m2) (Misra *et al.*, 2009).

Model assumptions were verified using normal quantile plots to inspect normality of random effect, and residuals of the mixed effect model. We conducted visual inspection of graphs by plotting residuals of the regression model against the fitted model to check for homogeneity of variance.

Self-reported eye health symptoms were analyzed using multivariate binomial logistic regression for having specific eye symptoms. The generalized linear model (glmer) function in R software (R Core Team, 2014) was used to model the odds of reporting an eye irritation symptoms:

$$\text{Eye symptom}_{ijk} \sim \beta_0 + \beta_1 \text{ Stove Group* Season}_{ijk} + \beta_2 \text{ Age} + \beta_3 \text{ Chimney} + \beta_4 \text{ Smokers} + \beta_5 \text{ Asset score} + \varepsilon_{ijk}$$

where *i* denotes individual, *j* denotes repeated measures within subjects, *k* denotes household. $\beta_1$ is effect estimate for stove group as either randomized (ITT) or actual use (PP), i.e. exclusive intervention stove users or mixed stove users. We controlled for age, presence of chimney and smokers in household, and asset score. Separate analyses were run for the four eye irritation symptoms: burning sensation in the eyes, discharge on eyelids in the mornings, red eye, and watering of the eye.

## 3.3 Results

Of the 222 female participants from 187 households that initially consented to participate in the study, 23 participants from 21 households dropped out of the study, with 199 remaining for post-intervention measurements. Participant drop out was related to households either unavailable for follow-up (n=4 control households; n=3 intervention households), or no longer wanted the intervention (n=14 intervention households). Participant drop-out rates in the control and intervention groups were 3.6% (n=4 individuals) and 17% (n=17 individuals), respectively.

Household characteristics (asset score, presence of smokers, windows) were not statistically significantly different between intervention and control groups, suggesting randomization was successful at the household level (Table 3-1). Other household characteristics (house type, number of rooms, family size) and assets were not significantly different between control and intervention groups (Aung *et al.*, 2016). However, households that dropped out from the study were 3.5 times more likely to be from caste group, Other Backward Class (OBC) (i.e., to have a comparatively lower socioeconomic status). As a result caste was included in the BP regression models.

Little more than half of women participants in the study were underweight (52%). A little over a third (36%) were of normal BMI, and a smaller percentage (12%) were overweight. Participants in the intervention group had marginally higher BMI (p=0.06) compared to the control group; we therefore adjusted for this difference in BP regression models.

At baseline, mean (SD) of SBP and DBP were higher in the intervention group compared to the control (SBP: 107.3 (17.7) vs. 111.8 (17.2) mg Hg; DBP: 70.2 (10.2) vs. 73.7 (10.3) mg Hg). Prevalence of symptoms of watering of the eyes was higher in the control group (61%) than in the intervention group (46%). We controlled for these differences by including random effects for subject and household in the mixed effect models.

**Table 3-1: Baseline characteristics of households and female participants**

| Characteristics | Control | Intervention | p-value | Drop-out | p-value |
|---|---|---|---|---|---|
| Number of households | 91 | 96 | - | 21 | - |
| Caste (%) | | | 0.89 | | **0.10** |
| Scheduled Castes and Tribes | 41 | 39 | - | 22 | - |
| Other Backward Class (I, II, III) | 59 | 61 | - | 78 | - |
| Asset Score | 6.8 (2.7) | 6.8 (2.4) | 0.93 | 6.8 (2.7) | 0.93 |
| Smokers present in home (%) | 36 | 36 | 1.0 | 35 | 1.0 |
| $PM_{2.5}$ (µg/m3)<br>*(79 control, 83 intervention)* | 357 ±379 | 396 ±434 | 0.62 | 447 ±581 | 0.81 |
| Absorbance (x $10^{-6}$/m)<br>*(79 control, 84 intervention)* | 29 ±16 | 31 ±22 | 0.95 | 33 ±38 | 0.28 |
| **Personal Characteristics** | **Control** | **Intervention** | **p-value** | **Drop-outs** | **p-value** |
| Number of women | 111 | 111 | - | 23 | - |
| Education (years) | 0.78 ± 2.2 | 0.56 ± 1.7 | 0.66 | 0.09 ± 0.42 | 0.16 |
| Age (years) | 43.1 ± 13.0 | 43.9 ± 11.9 | 0.42 | 41.9 ± 10.3 | 0.72 |
| BMI ($kg/m^2$) | 18.5 ± 3.3 | 19.3 ± 3.4 | **0.06** | 18.2 ± 3.6 | 0.21 |
| Waist circumference (cm) | 72.3 ± 8.4 | 72.5 ± 12.9 | 0.36 | 69.2 ± 12.7 | 0.20 |
| Salt intake (g/day/person) | 17.3 ± 10.4 | 18.3 ± 10.2 | 0.39 | 18.2 ± 10.2 | 0.77 |
| Betel nut use (%) | | | 0.18 | | 0.64 |
| Current | 67 | 56 | - | 67 | - |
| Never | 29 | 41 | - | 33 | - |
| Overall Health | | | | | |
| Self-rate of health compared to others of similar age (%) | | | 0.57 | | 0.49 |
| Excellent/Good | 55 | 58 | - | 48 | |
| Fair | 43 | 41 | - | 52 | |
| Poor | 3 | 1 | - | 0 | |

| Characteristics | Control | Intervention | p-value | Drop-out | p-value |
|---|---|---|---|---|---|
| Difficulty carrying out work/daily activities due to illness in past 3 months (%) | 48 | 56 | 0.42 | 61 | 0.58 |
| Blood Pressure (baseline) | | | | | |
| Systolic BP (mm Hg) | 107.3 (17.7) | 111.8 (17.2) | **0.01** | 108.8 (17.4) | 0.86 |
| Diastolic BP (mm Hg) | 70.2 (10.2) | 73.7 (10.3) | **0.003** | 72.5 (10.5) | 0.82 |
| Eye Health (baseline) | | | | | |
| Burning sensation in eye often (%) | 61 | 56 | 0.51 | 70 | 0.35 |
| During cooking | 85 | 93 | 0.22 | 78 | 0.45 |
| Discharge on eyelids in morning (%) | 22 | 22 | 1 | 30 | 0.44 |
| Eyes look red often (%) | 44 | 41 | 0.83 | 57 | 0.22 |
| Watering of the eyes often (%) | 61 | 46 | **0.04** | 65 | 0.32 |

*Data are mean ± SD or number (%).Wilcoxon tests for continuous variables with skewed distribution data (judged based on Shapiro-Wilk normality test); chi-square tests for categorical variables.*

Adjusted between-group analysis suggests differences between exclusive intervention stove group and control were similar for both SBP and DBP in the post-intervention season (Table 3-2). Mixed stove group was associated with higher SBP (9.5 mm Hg [3.7, 15.3]) and DBP (3.0 mm Hg [-0.5, 6.6]) compared to the control group in the post-intervention season (Table 3-2).

In the adjusted within-group changes between pre- and post-intervention seasons, mixed stove use was associated with a significant increase in SBP (post-pre: 4.1 [0.4, 7.8] mm Hg) (Table 3-3). In the control group, DBP was significantly higher in post-intervention than at baseline (mean post-pre: 1.7 [0.1, 3.2] mm Hg) (Table 3-3).

Sensitivity analyses that included participants taking hypertension and diabetes treatment or medication suggest they were not different from the primary results in both between-group and within-group analyses. There was evidence of effect modification by age group. For between-group analysis in the post-intervention season, older participants (≥ 40 years) had significant increase in SBP (18.2 [4.4, 32.0] mm Hg) and DBP (10.8 [2.9, 18.8] mm Hg) compared to younger participants (< 40 years) in the mixed stove group (control group as reference) (Appendix B, Table B-1). Similarly, for within-group analysis, older participants (≥ 40 years) in the mixed stove group were associated with a significant increase in SBP (7.4 [2.8, 12.2] mm Hg) (Appendix B, Table B-2).

Effect modification by BMI group was less apparent but suggests overweight (BMI ≥ 23 kg/m2) and underweight (BMI < 18.5 kg/m2) participants were generally associated with higher SBP and DBP compared to normal weight (18.5 kg/m2 ≥ BMI < 23 kg/m2) participants in the mixed stove group (control group as reference). In the between-group analysis, compared to normal weight participants, overweight participants had higher SBP (24.8 [4.6, 45.0] mm Hg), and DBP (9.6 [-2.9, 22.1] mm Hg). Similarly, underweight participants had higher SBP (14.6 [-0.1, 29.3] mm Hg) and DBP (9.3 [0.2, 18.4] mm Hg) compared to normal weight participants (Appendix B, Table B-1). In the within-group analysis, interactions between stove groups and BMI categories on seasonal change in BP were not significant (Appendix B, Table B-2).

Air pollutant concentrations in the post-intervention season were similar across groups, though the mixed stove group had slightly higher concentrations of $PM_{2.5}$, Abs, as well as Abs: $PM_{2.5}$ ratio compared to the control (Appendix B, Table B-3). Air pollutants parameters ($PM_{2.5}$, Abs, Abs:$PM_{2.5}$) were included in the regression models to fully assess the impact of the intervention. The results showed that effect of stove use on BP were slightly stronger; this outcome was most apparent in the mixed stove group (Table 3-3). In particular, when Abs: $PM_{2.5}$ ratio was included in the model, the mixed stove group was associated with highest seasonal increase in systolic BP (6.0 mm Hg [1.9, 10.0]) compared to base model without air pollutants or when only one pollutant parameter was considered. This trend was also similar for the control group which had the highest seasonal increase in diastolic BP (2.2 mm Hg [0.5, 3.9]) when Abs: $PM_{2.5}$ ratio was included in the model compared to no pollutants or when only a single pollutant was included. For the exclusive intervention stove group, inclusion of pollutants in the model did not change the effect.

The odds of having eye irritation symptoms were statistically significantly reduced in the intervention group, compared to controls (Table 3-4). However, per-protocol analysis showed that these differences were driven by reductions in the mixed stove group who reported significantly reduced odds of burning eye sensation and red eyes. Exclusive intervention stove use was not associated with significantly reduced odds of any of the eye irritation symptoms. There were no differences in reporting of discharge on eyelids in the morning for any of the intervention groups.

**Table 3-2: Adjusted between-group differences in systolic and diastolic BP (mm Hg) associated with intervention groups compared to control in post-intervention season**

| | No. of subjects | | | Intervention (ITT) | Exclusive stove (PP) | Mixed stove (PP) |
|---|---|---|---|---|---|---|
| | **Control** | **Exclusive stove** | **Mixed stove** | **Estimate (95% CI)** | **Estimate (95% CI)** | **Estimate (95% CI)** |
| **SBP** | 92 | 48 | 26 | 3.1 (-1.3, 7.4) | -1.0 (-5.9, 3.9) | **9.5 (3.7, 15.3)** |
| **DBP** | 92 | 48 | 26 | 1.2 (-1.4, 3.8) | 0.0 (-3.0, 3.0) | 3.0 (-0.5, 6.6) |

*Reference group: control (traditional stove users); ITT =intent-to-treat; PP=per-protocol; adjusted for BMI, age, temperature, betel use, self-rating of own health, and irrigated land ownership.*

**Table 3-3:** **Adjusted within-group seasonal differences (post-pre change) in systolic and diastolic BP (mm Hg) by stove groups**

| | Control (ITT) | Intervention (ITT) | Exclusive stove user (PP) | Mixed stove users (PP) |
|---|---|---|---|---|
| | **Estimate (95% CI)** | **Estimate (95% CI)** | **Estimate (95% CI)** | **Estimate (95% CI)** |
| **No pollutant** | N=93 | N=75 | N=49 | N=26 |
| **SBP** | 0.6 (-1.6, 2.8) | 0.4 (-1.9, 2.6) | -1.4 (-4.0, 1.2) | **4.1 (0.4, 7.8)** |
| **DBP** | **1.7 (0.1, 3.2)** | -0.2 (-1.8, 1.3) | -0.3 (-2.2, 1.6) | -0.1 (-2.7, 2.6) |
| **$PM_{2.5}$ in model** | N=76 | N=65 | N= 41 | N=24 |
| **SBP** | 0.7 (-1.8, 3.3) | 0.6 (-1.8, 3.1) | -1.5 (-4.3, 1.4) | **5.0 (1.1, 8.9)** |
| **DBP** | **1.7 (0.0, 3.5)** | -0.1 (-1.8, 1.5) | -0.1 (-2.2, 1.9) | -0.1 (-2.9, 2.7) |
| **Abs in model** | | | | |
| **SBP** | 1.0 (-1.7, 3.8) | 0.8 (-1.8, 3.5) | -1.3 (-4.4, 1.8) | **5.0 (0.9, 9.0)** |
| **DBP** | **2.0 (0.4, 3.9)** | -0.1 (-2.0, 1.7) | -0.1 (-2.3, 2.1) | -0.2 (-3.1, 2.6) |
| **Abs/PM ratio in model** | | | | |
| **SBP** | 1.0 (-1.6, 3.5) | 1.1 (-1.5, 3.7) | -1.2 (-4.1, 1.8) | **6.0 (1.9, 10.0)** |
| **DBP** | **2.2 (0.5, 3.9)** | 0.4 (-1.4, 2.1) | 0.3 (-1.8, 2.4) | 0.6 (-2.2, 3.5) |

*CI=confidence interval; N=sample size; adjusted for BMI, age, temperature, betel use, self-rating of own health, and irrigated land ownership; bold indicates statistical significance of results (p-value <0.05). Within-group analysis with pollutants in the model has a smaller sample size compared to model without air pollutants because it only includes individuals from households with analyzable air pollution data.*

**Table 3-4: Eye irritation symptoms in intervention groups compared to control in the post-intervention season**

| Symptoms | Intervention (ITT) | Exclusive intervention stove | Mixed stove |
|---|---|---|---|
| | Odds Ratio (95% CI) | | |
| Burning sensation in eyes often | **0.28 (0.13, 0.55)** | 0.54 (0.23, 1.21) | **0.11 (0.02, 0.42)** |
| Discharge on eyelids in morning | 1.01 (0.89, 1.14) | 1.13 (0.97, 1.31) | 0.99 (0.82, 1.19) |
| Eyes look red often | **0.82 (0.73, 0.93)** | 0.90 (0.77, 1.06) | **0.80** (0.66, 0.96) |
| Watering of the eyes often | **0.88 (0.76, 1.00)** | 0.95 (0.80, 1.13) | 0.86 (0.70, 1.06) |

*Reference group: control (traditional stove users); adjusted for age, time spent near stove, chimney, and presence of smokers in household.*

## 3.4 Discussion

We evaluated the potential health co-benefits associated with a climate-financed randomized stove intervention, including measurement of household air pollutant concentrations over a period of one year. Both between-group and within-group analyses suggest general patterns of reduced BP in the exclusive intervention stove group, and increased BP in the mixed stove group when compared to either the control group (in between-group analyses) or to their baseline levels (in within-group analyses). All groups experienced increased $PM_{2.5}$ and Abs concentrations with higher increases in $PM_{2.5}$ in the control group. The intervention groups using intervention stoves exclusively or mixed with traditional stoves had higher Abs/$PM_{2.5}$ ratios suggesting higher black carbon content in the emissions from intervention stoves.

Contrary to our prior expectations suggesting increased blood pressure associated with particulate matter exposures (Pope *et al.*, 2009; Baumgartner *et al.*, 2011a), the exclusive intervention stove group had reduced BP despite increased $PM_{2.5}$ and Abs kitchen concentrations in the group compared to the pre-intervention season. This contrasts with several other studies reporting positive correlations between HAP exposures and BP. For example, a randomized intervention trial of chimney stoves in Guatemala reduced mean personal $PM_{2.5}$ exposure from 273 to 174 μg/m3 which was associated with lower SBP and DBP by -3.7 mm Hg (95% CI: –8.1, 0.6) and -1.9 mm Hg (95% CI: –3.5, –0.4), respectively (McCracken *et al.*, 2007). A similar chimney intervention in Bolivia reduced mean $\pm$ SD kitchen concentrations by 80% from 240 $\pm$ 210 to 48 $\pm$ 41 μg/$m^3$, this change was followed by steep reductions in SBP from 114.5 ± 13.0 mm Hg to 109.0 ± 10.4 mm Hg, though the study had a small sample size (N=28), did not adjust for covariates, and lacked a control group (Alexander *et al.*, 2015). However, other studies have not reported reductions in BP following air pollution reductions. An intervention in Nicaragua significantly reduced mean $\pm$ SD in $PM_{2.5}$ from 1801 $\pm$ 1587 μg/m3 to 416 $\pm$ 523 μg/$m^3$, however, BP was not reduced in the general population (Clark, Bachand, *et al.*, 2013). Those authors attributed the lack of change to a non-linear relationship between HAP and certain health risks that is steep at low exposures and flattens out at higher levels (Pope *et al.*, 2009; Baumgartner *et al.*, 2011a; Burnett *et al.*, 2014), meaning much lower exposure levels are needed to see health benefits.

We provide several potential theories on BP changes in the intervention groups that have not been found in existing literature. Although results are not entirely consistent, previous cookstove interventions which have reported reduced pollutant concentrations associated with BP reductions have been primarily from Latin America (McCracken *et al.*, 2007; Clark, Bachand, *et al.*, 2013; Alexander *et al.*, 2014), where population characteristics and prevalence of cardiovascular risk factors are likely to be different from South India, which may affect how intervention influences BP outcomes. For example, half of our study population were underweight; mean $\pm$ SD of BMI was 19.0 $\pm$ 3.3 kg/m$^2$, which was lower compared to the study population in Nicaragua study (27.8 $\pm$ 7.1 kg/m$^2$) (Clark, Bachand, *et al.*, 2013), Guatemala (24.6 $\pm$ 3.1 kg/m$^2$) (McCracken *et al.*, 2007), and Bolivia (23.0 $\pm$ 4.0 kg/m$^2$) (Alexander *et al.*, 2014). In the Nicaragua study, over a third (38%) of the population was overweight compared to only 12% in our study. Having a large susceptible population who are underweight may contribute to unpredictable changes in BP. Clark et al (2013) concluded in the Nicaragua study that susceptible population, such as overweight and older women > 40 years of age are more likely to experience reductions in BP compared to the general population. We are not aware of any studies on how cookstove intervention influences population at the other end of the susceptibility spectrum, such as underweight females. Our study's results on effect modification by BMI suggest that overweight and underweight population are more susceptible as they experienced higher BP levels compared to normal weight participants in the mixed stove groups in both between-group and within-group analyses. Other differences, beyond BMI, may also play a role (e.g., diet, exercise, smoking, genetics).

Slight reductions in BP in the exclusive intervention group despite lack of reduction in $PM_{2.5}$ concentrations compared to its baseline may result from the intervention stove reducing air pollution components that were not measured by the study. Emissions from biomass combustion can consist of thousands of chemical constituents (Naeher *et al.*, 2007). It may also be a result of changes in personal exposures to HAP not measured in our study. Personal exposures tend to be different from stationary kitchen-based measurement because individuals move around and may spend less time near emitting sources (i.e. cookstoves) or conversely be exposed to relatively high ambient air pollution levels (Cynthia *et al.*, 2008; Smith *et al.*, 2010). Intervention stoves may have contributed to behavioral changes where individuals spent less time near source of emission thus having lower personal exposures compared to kitchen-based concentrations. Participant observation on a subset of households (n=45) from our study found that cooks' behavior ranged from sitting near stoves, and walking around the house to completing domestic chores away from the stove (Norris *et al.*, 2016). The intervention stoves may have changed the social routine of cooks using intervention stoves, thus affecting her personal exposure and BP outcomes.

The intervention may have also caused changes to non-air pollution related aspects that contributed to lower BP, such as changes to physical activity and diet. This could include changes in activity patterns during cooking and collecting fuelwood, or types and quantity of food eaten as a result of the use of intervention stoves. A study in Bolivia found increased physical activity one year after a cookstove intervention as measured by respiratory health, self-reported questionnaire (Alexander *et al.*, 2014). In BP literature, increased physical activity is known to lower BP, though these studies are typically focus on hypertensive, normal to overweight populations in developed countries (S. P. Whelton *et al.*, 2002; Warburton, Nicol and Bredin, 2006), and do not represent the characteristics or health conditions of population in this study.

Dietary changes may be occurring as a result of increased options with stoves. Mixed stove homes were known to use two or more stoves (both traditional and new intervention stoves) for cooking activities, which may contribute to higher quantity of food cooked or consumed, and subsequently higher BP in that group. The mixed stove group in our study had statistically significantly higher SBP compared the control (between-group analysis) as well as compared to its baseline levels (within-group analysis). Households continuing to use both old and new stoves and fuels is prevalent in interventions (Masera, Saatkamp and Kammen, 2000; Ruiz-Mercado *et al.*, 2011; Burwen and Levine, 2012; Hanna, Duflo and Greenstone, 2012; Johnson and Bryden, 2012). There may be increased nutritional benefits as a result of meeting "suppressed demand" associated with inefficient traditional stoves (Aung *et al.*, 2016) as households are able to cook more with lower fuel costs, thus increasing their food intake, and BP levels.

When air pollutant parameters ($PM_{2.5}$, Abs, Abs/$PM_{2.5}$ ratio) were included in the within-group analysis, the effect estimates of stove use group on BP were higher compared to base models without the HAP concentrations. The highest effect estimates were seen when Abs/$PM_{2.5}$ ratio was included in the model; the mixed stove group had the highest increase in Abs/$PM_{2.5}$ ratio in post-intervention season compared to control and exclusive intervention stove users. This suggests that change in particle composition (higher black carbon content) may be responsible for the increase in BP in the post-intervention season in the mixed stove group, though the small sample size (N=27) in the mixed stove group precludes definitive conclusions. A repeated cross-sectional analysis of the same population of 45 women found that interquartile range increase in personal exposure to black carbon were associated with acute increases in SBP (Norris *et al.*, 2016).

The BP changes across groups were not likely to be attributable to key participant characteristics known to affect BP since we controlled for known predictors of BP in the analyses, including age, BMI, and temperature. Because we had a control population, BP changes observed in the study are unlikely be a result of seasonal or time-varying factors such as agricultural activities or festivals, as such factors likely affect intervention and control groups equally.

While the study was conducted over a one-year period, a reasonable time to evaluate health outcomes, sustained long-term benefits of the intervention are still unknown. Hanna et al. (2012) is the only study that evaluated air pollution and health outcomes for a cookstove intervention over a 4-year period (previous interventions have been over 1 to 2-year period); they found initial reductions in air pollutant exposure, and improvement in health were not sustained after the first year.

The odds of reporting eye irritation symptoms were lower in the mixed stove group but not in the exclusive stove group. Therefore, it is unlikely that the intervention stove was responsible for the reduced reporting of symptoms. Bias in self-reporting of health symptom has been reported in other intervention studies. A study in Ghana found significant reductions in self-reported eye and respiratory symptoms despite lack of detectable reductions in CO exposure, which the authors attributed to "courtesy bias" resulting from the study participants' working relationship with the NGO implementing the intervention (Burwen and Levine, 2012). In our study, efforts were made to inform participants that the study was independent of the NGO implementing the intervention but collaboration necessary at the field level, i.e. introduction of the study to village committees by the NGO, may have fostered perceptions of association for the participants. A randomized controlled trial in Guatemala attributed a decline in self-reported symptoms in control group to respondents' fatigue with survey questions (Díaz *et al.*, 2007).

Studies on eye health from cookstove interventions are limited and are often obtained from self-reported symptoms. Our questionnaire on eye health has not been validated previously. We are unable to discern how sensitive these questionnaires are in capturing differences in eye health outcomes attributable to changes in exposures or the clinical implications of the results found in our study. Future intervention studies should consider objective eye heath measures as eye irritations represent one of the key concerns for cooks (Pine *et al.*, 2011; Person *et al.*, 2012), and would assist in quantification of eye health benefits from interventions.

### 3.5 Summary

To our knowledge, this was the first study to independently evaluate the health impacts from a climate motivated stove intervention program. While we observed reductions in BP in the exclusive intervention stove group, these did not appear to be related to reductions in kitchen-based indoor $PM_{2.5}$ or Abs concentrations, suggesting that they may be mediated by alternative pathways, such as personal exposure, physical activity, and diet. Further, the finding of increased BP in the mixed stove group suggests stove adoption and use behavior can complicate achievement co-benefits from cookstove interventions. Climate financed cookstove interventions need to align with international guidelines and standards that have been set based on health outcomes in order to maximize co-benefits. Additional studies are needed to investigate relationships between cardiovascular health outcomes and cookstove interventions given this health burden associated with combustion-derived $PM_{2.5}$. Eye irritation symptoms are some of the most commonly reported issue by solid fuel users but least investigated compared to other health outcomes. Future studies should employ objective eye health measures to assess impacts from cookstove intervention.

# Chapter 4: Time-use measurements and livelihood outcomes

## 4.1 Introduction

An estimated 2.7 billion people are dependent on biomass fuels, such as wood, agricultural residues, and animal dung, for cooking and heating which are typically burned in inefficient traditional stoves or open fires (World Energy Outlook/International Energy Agency, 2015). A third of this population resides in India, where the practice is prevalent in rural low-income households (World Energy Outlook/International Energy Agency, 2015). Traditional stoves or open fires can take longer to cook and consume more fuel compared to stoves with well-designed enclosed combustion chambers (Jetter and Kariher, 2009; MacCarty, Still and Ogle, 2010). It is believed that the long hours spent cooking and collecting fuelwood may inhibit social and economic development of rural households as it takes time away from income-generation, education, or social activities.

An increasing number of cookstove interventions have been implemented with an aim to reduce health, climate and socio-economic impacts associated with traditional forms of household biomass burning (Venkataraman *et al.*, 2010; Global Alliance for Clean for Cookstoves, 2013; ECOWAS Centre for Renewable Energy and Energy Efficiency, 2014). While many studies have evaluated health outcomes and emissions from cookstove interventions, there are few studies on how they impact women's time-use and livelihoods. The few studies that evaluated this outcome have relied on self-reported or recall methods on time use or time savings, and assumed that the saved time is used for livelihood improvements such as earning income (García-Frapolli *et al.*, 2010; Malla *et al.*, 2011). However, accuracy of self-reported time-use data has never been verified in the cookstove intervention literature. Further, there is lack of empirical evidence on how saved time from used of improved cookstove is used by women.

## 4.2 Background

Time is considered a finite resource, and how this finite resource is allocated to different activities may be influenced by many factors, including social and cultural norms, gender roles, household demographic (size, age, and gender composition of family members), and economics (income, labor availability, markets) (Kes and Swaminathan, 2006; Asian Development Bank, 2015). In rural developing parts of the world, allocation of time to activities differs greatly between men and women. Women often work longer hours than men, with most of the time spent in unpaid work, such as subsistence production (collecting fuelwood, fetching water), and reproductive tasks (formally defined as domestic tasks that includes cooking, caring for children, the sick and elderly) (Food and Agricultural Organization of the United Nations, The International Fund for Agricultural Development and The International Labour Office, 2010). This tendency results in less time available for economically productive activities by women. It also limits women's time available for sleeping or ability to participate in social and leisure activities that are important to enhancing their quality of life and skills. For example, a survey by the World Bank of 5,000 women from 180 villages across six states in India found that on a daily basis, women spent around 3 hours cooking, 40 minutes collecting fuelwood, 1 hour fetching water, 5 hours on other household production activities (food processing, cleaning dishes and house, child care) leaving just 2 hours for pursuing income-earning activities (World Bank, 2004).

Traditional use of biomass fuels contributes to long hours cooking and collecting fuelwood. A cross-country survey in Zimbabwe, Ethiopia, and India found that women spent on average 44, 138, and 167 minutes per day cooking, respectively (Horrell, Johnson and Mosley, 2008). A survey of 613 households across three states in India (Karnataka, Himachal Pradesh, and Odisha) found that women using traditional stoves spend on average 240 minutes per day cooking (Bloomfield, 2014). The same survey reported that women spend on average 374 hours per year (~1 hour/day) collection fuelwood (Bloomfield, 2014). Similarly, a compilation of time-use surveys in nine developing countries in sub-Saharan Africa, South Asia (including India), and Southeast Asia showed that rural women spend on average over 1.5 hours a day collecting fuelwood (The World Bank, 2008).

Cookstove interventions are growing rapidly to reduce the various adverse effects associated with traditional forms of biomass fuel use (Venkataraman *et al.*, 2010; Global Alliance for Clean for Cookstoves and Ecosystem Marketplace, 2015). It is often assumed that the improved cookstoves will provide time savings from reduced cooking and fuelwood collection time, and improve women's livelihoods. However, evaluations of this outcome have been limited. Studies that have assessed time savings have primarily relied on self-reported methods, which may be biased and inappropriate in rural cultural context. Further, time savings are assumed to be used for income generating activities to improve livelihoods. Critical assessment of these two major assumptions has been lacking and research into time savings has important implications for improving the accuracy of cookstove cost benefit assessments.

***Assumption 1: Self-reported time-use and time-savings are accurate***

Time-use studies on household production activities have primarily relied on self-reported frequency and duration surveys (Parikh and Laxmi, 2000; World Bank, 2004; Bloomfield, 2014). The advantages of time diary or self-reported time-use methods are their ability to be administered to large populations with little logistical and financial costs. However, these methods include potential for recall errors, and inappropriate application in rural settings or cultures where time-specific schedules and tracking one's day in clock-based increments is not the norm.

Reporting total time on an activity can be challenging in informal sectors whose time-activity patterns are highly fractionated. In communities where fuelwood collection is combined with other activities, such as farming, reporting time on one specific activity separately may be difficult. Further, a study on time-activity patterns of rural Nicaraguan housewives found that they frequently switched from one activity to another, completing individual tasks within 5-15 minutes (Gillespie, 1979). This can make recall and allocation of time to specific tasks difficult. While self-reported time methods may be sufficient in understanding relative distribution of time spent by women on various activities, the approach may be complicated when users are asked to report time savings from use of intervention cookstoves. For example, users of more efficient stoves have cited the need for greater supervision of the stove because of faster cooking and the constant requirement for refueling (Chowdhury *et al.*, 2011), potentially preventing them from multitasking, such as sweeping floors, washing dishes, getting children ready for school, etc. Therefore, while cooking time may be reduced, the overall time a woman spends on other household reproductive tasks that used to occur during cooking events may not be significantly changed. As a result, reported time savings may be overestimated.

***Assumption 2: Saved time leads to livelihood improvement***

Livelihood is defined as a system that "*comprises of capabilities, assets (material and social resources) and activities required for a means of living*" (Chambers and Conway, 1992). It is described as a complex web of interactions among institutions, cultures, and resources in which people make a myriad of decisions. According to the Global Alliance for Clean Cookstoves, a United Nations Foundation led agency that aims to introduce clean cookstoves and fuels globally, livelihood benefits from efficient cookstoves can be achieved via multiple pathways. These include: 1) time not spent cooking and on fuelwood collection could be used for income generation; 2) money saved from reduced fuelwood consumption, in households that purchase fuelwood; and 3) local job creation from participating in cookstove-related value chains such as stove product design, manufacturing, marketing and sales (Global Alliance for Clean for Cookstoves, 2016). Whereas the latter two are relatively straightforward to quantify and monetize, associations between time savings and increased participating in income generation activities is less straightforward.

A methodology for cost-benefit analysis (CBA) developed by the World Health Organization (WHO) monetizes time savings by multiplying Gross National Income (GNI) per capita (or with minimum wage or average agricultural wage) times 100 percent of the saved time from cooking and fuelwood collection (Hutton *et al.*, 2006). A study conducting a CBA on cookstove interventions in Nepal, Kenya and Sudan using the WHO methodology reported that time savings accounted for the largest economic benefit, higher than fuel cost savings or health benefits (Malla *et al.*, 2011). Other studies applied similar methods to monetize time-saving benefits by multiplying a certain percentage of saved time with shadow wages (Habermehl, 2007; García-Frapolli *et al.*, 2010).

Empirical evidence is lacking, however, on how saved time from cookstove intervention is used by women. Literature from other rural infrastructure interventions provides some insight. A study evaluating women's time allocation after a rural water supply intervention in Pakistan found that women were more likely to spend the saved time from fetching water on leisure than on income-generating activities (Ilahi and Grimard, 2000). Another water supply intervention in Pakistan also found that while time spent traveling to fetch water reduced significantly, it did not increase women's participation in labor force or hours worked. The authors attributed this result to local employment conditions (high unemployment and underemployment), and cultural settings (restriction on women's employment), and individual preferences for leisure (Asian Development Bank, 2009).

The definition of livelihoods as a complex system of capabilities, assets and activities suggest that time savings alone may not be the only factor needed for improving one's livelihood. Empirical-based studies are needed to shed more light on what women do with the saved time from cooking and collecting fuelwood.

### 4.3 Study purpose and research questions

The purpose of the study was to provide an in-depth investigation of major knowledge gaps on time-use and livelihood evaluation of cookstove interventions. The first objective was to compare observed measures of time use with self-reported measures, for cooking and fuelwood collection activities. Secondly, the observed time-use measures were used to compare time spent on cooking and fuelwood collection in households using different cookstove technologies in a rural Indian community undergoing a large-scale cookstove intervention program. Third, semi-structured interviews were used to understand what women do with saved time, and needs and constraints for pursuing livelihood improvement strategies in the study community were identified.

The study is the first to compare observed measures of time-use with self-reported measures in the cookstove intervention literature, and to provide an in-depth probing of how women may use time savings. The results of the study can contribute to improving evaluation methods for assessing time-use impacts from cookstove interventions, and lead to a better understanding of how they may impact livelihoods.

## 4.4 Methods

### *Study site*

The study site was located in Raichur District in Karnataka State, South India. A 2015-2016 Karnataka state-representative survey indicated that 68% of rural households rely on solid fuels as the primary cooking fuel (International Institute for Population Sciences (IIPS) and Macro, 2016). A survey of 498 households in Raichur District indicated almost all households used wood as the predominant fuel for cooking, which was burned in three stone fires or traditional mud/clay/cement stoves (Fair Climate Network, 2012). Crop residue was used to ignite or start the cooking fire, and dung use was not reported in any of the homes (Fair Climate Network, 2012).

The study village, Chickahonakuni, was the site of an ongoing cookstove intervention effort initiated by the partner NGO in 2009. The study site was chosen at the recommendation of the NGO because of the good relations it has with the community and the village's proximity to the NGO field office, which facilitated the research activities. The intervention in Chickahonakuni village was part of a large-scale intervention to distribute 40,000 alternative cookstoves in 110 villages (21,500 households) in northern Karnataka. The project was approved under the Clean Development Mechanism (CDM), a market tool developed under the United

Nations Framework Convention on Climate Change that allows carbon dioxide reductions from the use of efficient stoves to be sold as carbon credits to help finance the intervention program. Additional information about the CDM financed intervention program in Karnataka is provided elsewhere (Aung *et al.*, 2016). Previously, a study was conducted in a nearby community in Koppal District, Karnataka, undergoing the same CDM-approved cookstove intervention, to evaluate changes in climate and health-relevant air pollutants ($PM_{2.5}$; Absorbance), and health outcomes (blood pressure; eye irritation symptoms) (Aung *et al.*, 2016).

***Intervention stove***

The intervention stove approved by the CDM was a single-pot "rocket-style" biomass cookstove with an elbow-shape insulated combustion chamber made of lightweight ceramic. The stove was manufactured in Karnataka and could be used with the same locally available fuelwood as used in traditional stoves. Approval of the intervention stove by the CDM was contingent upon laboratory results demonstrating increased efficiency compared to the traditional stoves. Laboratory tests of the intervention stove measured thermal efficiency of 30.8% (vs. 10% for a traditional stove) and an estimated 67% reduction in fuelwood consumption relative to a traditional stove (CDM Executive Board, 2006; *Gold Standard Local Stakeholder Consultation Report*, 2009; Central Power Research Institute, 2010). The market price of the intervention stove was 1,398 Rupees (approximately US$21). As part of the CDM program, households paid a one-time registration fee of 200 Rupees (approximately equivalent to the cost of two traditional stoves) and received two new intervention stoves (*Gold Standard Local Stakeholder Consultation Report*, 2009).

### *Study Design and Sample Recruitment*

A cross-sectional study was implemented over a three-month period from May to July 2014. A list of households where the NGO provided intervention stoves was obtained and used to randomly select households by type of stove used: those which rejected the intervention stoves and reverted back to traditional stoves (traditional stove users); those which exclusively used the intervention stoves (exclusive intervention stove users); and those using a mixture of intervention stoves with traditional stoves (mixed stove users).

The study included a total sample size of 50 households: 15 traditional stove homes, 16 exclusive intervention stove homes, and 19 mixed stove homes (Table 4-1). To allow for a more valid comparison of time-use between households with similar occupations, only those households whose primary income earner's occupation was in the agricultural sector were recruited for the study. Agricultural (54%), and daily wage (35%) labor were the predominant occupations in Raichur District (Fair Climate Network, 2012).

Prior to the start of the study, the implementing NGO held meetings with village leaders to introduce the study and gain their understanding and acceptance of the study and its activities. Upon approval from the village leaders, a village-wide meeting was held to introduce the study and its purpose. These introduction activities were recommended as a "protocol" by the NGO partner who has long-term working relationship with the study village, and served as a sign of respect in villages where they work. The randomly selected homes were then visited to explain the nature of the study and obtain oral consent prior to enrolling participants into the study.

### ***Data Collection***

#### *Household survey*

A household survey was administered to collect demographic information, including age, gender, education, caste, family size, income, and occupation of all members in the household. As a measure of household wealth, ownership of the assets was collected, including durable goods (chairs, fans, television, motorcycle. etc.), roof, wall, and floor materials of the house, types and number of livestock, and amount of land owned. Questionnaires were adapted from a previous study in a nearby community (Aung *et al.*, 2016), and had been evaluated by the local NGO staff for social and cultural appropriateness, translated and back-translated between English and the local language, Kannada, and pilot tested in a nearby, similar community.

#### *Observed time-use monitoring*

Direct participant observation of cooking was conducted to monitor cooking times and related domestic production activities during cooking events. As most households cooked two meals a day (morning and evening), two participant observation events were done for all households, except in cases when households skipped evening cooking events. During each participant observation session, start and end times of a cooking event were recorded. These were marked from the start of a cooking fire to when the pot was removed from the stove or as verified by the cook that her cooking activities were completed. In addition, individual dishes cooked were recorded including the time required for cooking. The number and type of stoves used were recorded as was the number of people involved in cooking activities, the number of people consuming the meal, and the types of non-cooking activities done by the main cook during the cooking event, such as floor sweeping. The "entry" and "exit" activities that the participant was engaged in immediately before and after cooking were also recorded. The intrusiveness of the observer was minimized by use of local field staff.

A mini wearable personal Global Positioning System (GPS) Trackstick II Data Logger (Telespial Systems, California, USA) was used to record time spent and distance travelled for fuelwood collection activities. The particular GPS instrument was chosen because it was considered unobtrusive because of its small size and light weight (4.50" x 1.25" x 0.75"; 1.5 oz). Units were worn by participants around their neck. The GPS tracker recorded date, time, longitude, latitude, direction, and altitude every 5 minutes. The local study team downloaded the GPS data points daily if participants went for fuelwood collection, and overlaid the data points on a map obtained from Quickbird images from Google Earth. These data were then shown to each participant on the map to verify actual fuelwood collection activity. Start time and finish time were subtracted to calculate the total time spent during each trip. The elevation profile feature of the route provided information on the total distance travelled.

The GPS trackers were given to all participating households for a 7-day period. In households where more than one individual collected fuelwood, multiple GPS trackers were provided in order to monitor total fuelwood collection time spent by the household. To mitigate ethical risks from use of GPS, tracking was limited to the fuelwood collection period, which was less than 24 hours per day as fuelwood collection generally occurs only during daylight hours. The informed consent form explained in detail the uses and types of data that were produced by GPS, such as time and locations of activities of the wearer. The downloaded GPS data were stored in a laptop that was password-protected and encrypted for additional security. Ethics approval was obtained from the University of British Columbia's Behavioral Research Ethics Board (ID# H14-00648).

Fuelwood was weighed to provide an objective measure for comparing the different stove technologies and to corroborate time measurements. Participants were asked to set aside a pile of fuelwood that would be used in the next 24 hours, which was weighed with a weighing scale. The pile was reweighed after 24 hours; the change in weight is fuelwood consumption. This weighing was repeated over two consecutive days and averaged to obtain 24-hour fuelwood consumption following the Kitchen Performance Test protocol (Bailis, Smith and Edwards, 2007).

*Self-reported time-use survey*

A self-reported time use survey was administered to participants who were observed for cooking and monitored with GPS. The survey included questions regarding average time spent cooking (morning and evening separately), and frequency and average time spent per trip collecting fuelwood in the past seven days. The self-reported survey was administered at the end of the 7-day period in which cooking and GPS monitoring was conducted, to allow for direct comparison with observed measures over the same period.

*Interviews*

Qualitative interviews were conducted with 40 women participants from a subset of households participating in the direct observation and GPS tracking. The interview subjects were randomly selected to obtain approximately equal number of participants from each stove use group, and until point of saturation where the researcher was confident that no new themes were emerging. Interviews were conducted in participants' homes and recorded. The primary purpose of the interviews was to assess how women used the saved time (for households reporting time savings) or *would* use saved time (for those not reporting time savings).

The secondary purpose was to provide context-specific narratives on livelihood constraints in the community. As such, interviews asked study participants about major challenges they faced in carrying out daily activities, and in pursuing other livelihood improvement options. Draft interview questions were shared with the partner NGO to obtain feedback and ensure relevant perspectives were captured and that the interviews meet local culture acceptance and appropriateness. Interview questions are provided in Appendix C.1. Key Informant Interviews (KII) were conducted with four staff members of the NGO implementing the CDM stove intervention program, representing three different levels of the implementation team, including a CDM project trainer, two animators, and a Hobli[4] coordinator. Interview questions are provided in Appendix C.1, and roles and responsibilities of the KII in Appendix C: Table C-1.

**Table 4-1: Sample size by stove-use category and methodology**

| | Stove Use | | | |
|---|---|---|---|---|
| | **Traditional stove** | **Exclusive intervention stove** | **Mixed stove** | **Total** |
| 1) Household Surveys | 15 | 16 | 19 | 50 |
| 2) Participant observation | 15 | 16 | 19 | 50 |
| 3) GPS monitoring + fuel wood weighing | 15 | 16 | 19 | 50 |
| 4) In-depth interviews | | | | |
| Female | 13 | 15 | 17 | 45 |
| Key Informants | | | | 4 |

[4] *Hobli is a cluster of adjoining villages. A group of Hobli constitutes a sub-district.*

## Data Analysis

The results from observed measures on cooking and fuelwood collection time and frequency were compared with self-reported data for each paired household to assess correlation between the different methods. Pearson correlation coefficients were calculated as a measure of the strength of correlation.

For comparison of cooking times across different stove groups, two types of durations were presented: 1) total cooking duration (starting from start of fire to end of cooking activities as determined by extinguishing of the fire or removal of cooking pot from stove); and 2) time per dish obtained from dividing total time by number of dishes cooked during each observed session. The reason for the latter was because some households had more than two stoves, such as in mixed stove homes, where more than two dishes could be cooked at the same time. Therefore, the latter metric accounts for the number of dishes cooked.

Similarly, for comparison of fuelwood collection time and distance travelled between stove groups, total time and distance per week as well as time and distance per trip were presented. The latter was derived by dividing the former with number of fuelwood collection trips completed per week. This metric provides additional information on fuelwood resource access and collection patterns.

Fuelwood consumption was divided by an adult equivalency factor that assigned different weights based on gender and age of household members to normalize by household size following the fuelwood weighing protocol in the Kitchen Performance Test (Bailis, Smith and Edwards, 2007). The protocol is widely used to compare fuelwood efficiencies of stove technologies in the field in several developing countries (Berrueta, Edwards and Masera, 2008; Granderson *et al.*, 2009; Ochieng, Tonne and Vardoulakis, 2013).

The Mann-Whitney-Wilcoxon test was used to compare cooking times, number of dishes cooked, and non-coking activities done, as well as 24-hour fuelwood consumption quantity, number of fuelwood collection trips, and time and distance travelled across different stove groups. For analysis of fuelwood collection time and distance travelled, households where participants forgot to take the GPS during fuelwood collection, or forgot to turn them on during the monitoring period were removed from analysis. The fuelwood collection time and distance were also analyzed with linear regression to control for land ownership and socio-economic related indicators to assess statistical significant differences between the different stove groups (results provided in Supplementary Information). All statistical analyses were conducted using an open source "R" statistical program (***R*** Foundation for *Statistical* Computing, Vienna, Austria).

Recording of interviews in the local language, Kannada, were transcribed and translated into English by field staff. Major concepts and themes and the number of times they appear in the interview responses were extracted by stove use groups. The interview quotes and themes are presented in relevant section topics below.

## 4.5 Results and discussion

The section presents results and discussions by topic as follows: 1) demographic and socio-economic characteristics of the sampled households; 2) correlation between observed and self-reported time spent cooking and collecting fuelwood, and frequency of fuelwood collection trips per week; 3) comparison of time spent cooking and collecting fuelwood between different stove groups; and 4) use of saved time by women participants.

### Household demographic and socio-economic characteristics

Households using intervention stoves (both exclusive and mixed stove groups) had smaller family size compared to traditional stove homes (Table 4-2). Intervention stove users noted in interviews that the intervention stoves limited the quantity of food that could be cooked because large pots could not be placed on the stoves. Traditional stoves allowed for using larger pots and therefore were easier to use for larger meals. This limitation may be one of the reasons why households with more family members were more prevalent in the group that dis-adopted the intervention stoves and instead used traditional stoves.

Exclusive intervention stove homes tended to have lower socio-economic status (SES) compared to traditional stove homes as determined by ownership of household assets, number of rooms, cows, and land (Table 4-2). However, the differences were not statistically significant except for the number of cows owned. The SES indicators were not significantly different between the mixed stove homes and the traditional stove homes.

**Table 4-2: Socio-economic characteristics by stove groups**

| | Traditional stove (N=14) | Exclusive intervention stove (N=16) | p-value[1] | Mixed stove (N=19) | p-value[1] |
|---|---|---|---|---|---|
| Family size | 7.2 ± 2.3 | 5.9 ± 2.0 | 0.15 | 5.7 ± 2.0 | 0.09 |
| Household assets* | 3.5 ± 1.7 | 2.8 ± 1.7 | 0.37 | 2.7 ± 1.9 | 0.23 |
| Number of rooms | 3.2 ± 1.1 | 2.6 ± 1.0 | 0.20 | 2.8 ± 1.3 | 0.31 |
| Cow ownership (number) | 1.1 ± 0.8 | **0.3 ± 0.6** | **0.00** | 1.3 ± 1.6 | 0.92 |
| Total land owned (acre) | 3.4 ± 1.9 | 2.5 ± 2.1 | 0.18 | 4.1 ± 4.3 | 0.71 |
| Land owned that is irrigated (acre) | 2.6 ± 2.2 | 1.9 ± 2.3 | 0.31 | 3.5 ± 4.1 | 0.89 |

*Data are mean ± SD; N=household sample size; [1]significance test using Wilcoxon test compared to traditional stove group; *household assets calculated based on whether household owns the item (1) or not (0) and adding up the values (assets included: plastic chair, radio/Stereo system, fan, TV, motorcycle, bicycle, tractor, and mixer/grinder).*

## Comparison between observed and self-reported time-use

### *Cooking durations*

A total of 40 paired observed and self-reported measures were obtained on time spent cooking (start-to-finish per event) in the past week. The results showed non-significant correlation between the two measures for both morning (Spearman's rank correlation coefficient (rho) = 0.11), and evening meals (Spearman's rank correlation coefficient (rho) = 0.17). There was a tendency to overestimate self-reported time spent cooking compared to actual observed time, the average (SD) of overestimated time for morning cooking event was 67 (48) minutes, and evening cooking was 30 (35) minutes (Appendix C: Figure C-1, C-2).

*Fuelwood collection frequency and time*

A total of 38 paired samples were obtained on observed and self-reported frequency and time spent collecting fuelwood in the past week. For the frequency of fuelwood collection trips conducted in the past week, 61% estimated their frequency within ± 1 day difference with that of GPS recording (34% estimated accurately). About 26% of the participants overestimated their FW collection frequency by 2 days or more, and 13% underestimated their frequency by 2 days or less (Table 4-3). Spearman's rank correlation coefficient (rho) between observed measure and self-reported on the frequency of fuelwood collection in the past week was 0.62.

**Table 4-3: Comparison of observed and self-reported frequency of fuelwood (FW) collection trips**

| | | **Number of days of FW collection (GPS measure)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of responses (percentage of total responses) | | | | | | | | | |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **Number of days of FW collection (self-report questionnaire)** | **0** | 0 | | | | | | | | | |
| | 1 | | 3 (8%) | | 1 (3%) | | | | | | |
| | 2 | | 1 (3%) | 3 (8%) | | | | | | | |
| | 3 | 1 (3%) | 1 (3%) | 3 (8%) | 4 (11%) | | 1 (3%) | | | | |
| | 4 | | 2 (5%) | | 2 (5%) | 1 (3%) | 1 (3%) | | 1 (3%) | | |
| | 5 | | | | | | 0 | 2 (5%) | | | |
| | 6 | | | | | 1 (3%) | | 0 | | 1 (3%) | |
| | 7 | | 1 (3%) | | 2 (5%) | 1 (3%) | 1 (3%) | 1 (3%) | 2 (5%) | | 1 (3%) |
| | 8 | | | | | | | | | 0 | |
| | 9 | | | | | | | | | | 0 |

For time spent collecting fuelwood, correlation between observed measured time and self-reported time was low (Spearman's rank correlation coefficient (rho) = 0.09) (Appendix C: Figure C-3). Self-reported fuelwood collection time was overestimated on average by 82 minutes (standard deviation (SD) = 85) compared to observed measured time. Though several household members may join a fuelwood collection trip, the self-reported survey asked for time spent by the individual who carried the GPS instrument. Thus the overestimation is not likely due to reporting of total time spent by family members who were not tracked individually or specifically by the GPS instrument.

The significant Spearman's rank correlation on frequency of fuelwood collection suggests a better correlation between observed and self-reporting on event counts. However, reporting of time for cooking and fuelwood collection should be taken with precaution as there was a tendency to overestimate time spent on activities.

Interviews with women also revealed a variety in their patterns of fuelwood collection activities that are determined by seasonal work and social routines. During agricultural seasons, fuelwood collection is combined with farm work. During non-agricultural seasons, which overlap with the school summer holidays, the majority of women and children make separate trips just to collect fuelwood. Many of the women also reported going for fuelwood collection with another family member, neighbor or friends for social and security reasons as well as to provide an extra helping hand which was particularly needed when lifting the fuelwood load onto the head. As such reporting of time-savings may be unreliable because of highly fractionated nature of activities where time spent on a single activity (fuelwood harvesting) may be hard to differentiate from time spent on another activity (farming). Time-use surveys can also lead to bias if they do not take into account the seasonal nature of fuelwood collecting that may or may not be combined with farm work. Social routines around fuelwood collection activities also suggest reduced fuelwood use in one's own household may not necessarily lead to time savings. Additional methods, such as interviews, may be need to be combined with survey methods to provide a more complete picture of time-use and time savings in an intervention community.

Inaccuracies in self-reported methods may also result from differences in perceptions of what is considered time saving as illustrated by a response from an exclusive intervention stove user.

**Exclusive stove user 1:**

*Question: Since you started using the intervention stoves, has there been a change in the way you carry out your daily domestic activities?*

*Response: I do not feel any major changes.*

*Q: What benefits do the intervention stoves provide?*

*R: Cooking is faster. Utensils get less dirty (black) on the intervention stove.*

*Q: Do you believe that use of the intervention stove has resulted in time savings relating to cooking activities?*

*R: I have not noticed any time saving related to cooking activities.*

Similar perceptions were found in few other interview responses where interviewees reported reduced cooking time but did not identify that as time savings. It is possible that reduced cooking time was not significant enough to be perceived as time savings. This may occur from a change in the order of activities. It was observed that cooks conduct non-cooking activities, such as washing utensils, brushing teeth, preparing children for school, etc. during cooking sessions. If the intervention stove reduced cooking time by 10 minutes, the non-cooking activities that used to be done during the cooking session may now be done after cooking was completed. Accordingly, women may not perceive this as time savings as the amount of time required in the morning to get ready is the same, even though cooking time is reduced.

## Comparison of time and activity patterns between stove groups

### *Cooking*

Households in the study village cooked twice a day in the morning and evening. The majority of the food was cooked in the morning, including making staple bread (rotis); evening cooking events usually involved reheating food cooked from the morning or cooking a small dish. Average cooking duration in the morning was shortest in the exclusive intervention stove group (85 minutes) followed by traditional stove homes (103 minutes) with mixed stove homes cooking the longest (114 minutes) (Table 4-4). As mentioned above, household size varied by stove use group, so differences in cooking time may partially be attributable to differences in amount of food cooked, as well as stove type. It is also possible that households that cook more or longer are more likely to be a mixed stove home; due to the cross-sectional nature of the study design, it is not possible to determine causation from this association. Analyses below attempt to correct for these household-size differences. When number of dishes cooked was considered, time per dish suggested intervention stove homes (exclusive and mixed stove homes) had slightly lower median cooking time, however, none of the results were statistically significantly different between the stove groups. Evening cooking durations were also similar between the stove groups (Table 4-4).

Mixed stove homes cooked more dishes compared to the other stove groups in both morning and evening sessions (Table 4-4). Some of the mixed stove homes had three cooking fires which was more than the typical number (two cooking fires per household). The increased number of fires in some homes may be why the mixed stove homes were able to cook more dishes on average, without significantly extending the total duration of morning or evening cooking sessions. The fact that mixed stove homes had smaller family size compared to traditional stove homes but cooked more dishes could be due to underlying differences between households or could potentially suggest rebound effects (The United Nations Framework Convention on Climate Change, no date; Michaelowa *et al.*, 2014). The rebound effect is an increase in demand for a service because of reduced costs of the service (CDM Executive Board, no date). The intervention cookstoves may have provided reduced cost of cooking by decreasing quantity of fuelwood required to cook a meal, or reduced time spent cooking. A study in a nearby community with the same intervention stove technology also found evidence of suppressed demand as determined by higher fuelwood consumption (Appendix A: Table A-6; Figure A-12; Appendix A.5) in mixed stove homes compared to other stove groups (Aung *et al.*, 2016).

Non-cooking activities conducted by the main cook during cooking events were categorized into three main groups: house maintenance (cleaning home, kitchen, and utensils); taking care of child and others (feeding baby, serve tea or food to family, children and animals); and self-maintenance/ personal hygiene (brush teeth, take bath, wash face; drink tea, eat breakfast, and stitching). Women from both the exclusive intervention stove and mixed stove homes reported a higher number of non-cooking activities compared to those from traditional stove homes. This may be because of the fact that intervention stove homes had smaller family size thus less help was available to the cook to complete other household reproductive activities.

**Table 4-4: Cooking times and patterns by stove group**

| | Traditional stove (N=13) | | Exclusive intervention stove (N=17) | | Mixed stoves (N=19) | |
|---|---|---|---|---|---|---|
| **Morning** | **Median ($25^{th}$-$75^{th}$ quartile)** | | **Median ($25^{th}$-$75^{th}$ quartile)** | **p-value**[1] | **Median ($25^{th}$-$75^{th}$ quartile)** | **p-value**[1] |
| Cooking time from start-finish (minutes) | 103 (91-119) | - | 85 (61-100) | 0.09 | 114 (89-125) | 0.82 |
| Number of dishes cooked (mean) | 4.0 | - | 3.4 | 0.18 | 4.4 | 0.41 |
| Time per dish (minutes) | 29 (24-30) | - | 23 (20-28) | 0.16 | 24 (21-27) | 0.23 |
| Number of non-cooking activities done | 2.1 | - | 2.5 | 0.96 | 2.8 | 0.07 |
| **Evening** | **(N=11)** | | **(N=24)** | | **(N=11)** | |
| Cooking time from start-finish (minutes) | 52 (39-82) | - | 50 (39-70) | 0.56 | 52 (46-72) | 0.85 |
| Number of dishes cooked (mean) | 2.4 | - | 2.5 | 0.70 | 2.9 | 0.12 |
| Time per dish (minutes) | 27 (18-30) | - | 22 (15-28) | 0.29 | 18 (15-25) | 0.21 |
| Number of non-cooking activities done | 1.3 | - | **2.0** | **0.03** | **2.0** | **0.04** |

[1]*Significance test using Wilcoxon test compared to traditional stove group; N=sample size; the variation in sample size particularly the large sample size in exclusive intervention group for evening cooking observation is a result of mixed stove households only using the intervention stoves since rotis, which are usually made on traditional stoves in mixed stove homes were already made in the morning.*

*Fuelwood Consumption and Collection Patterns*

Traditional and exclusive intervention stove homes had similar amount of fuelwood consumption (3.0 vs. 3.1 kg/day) (Table 4-5). In comparison, mixed stove homes had a slightly higher fuelwood consumption (3.8 kg/day). Due to difference in family size between stove groups, the 24-hour fuelwood consumption was adjusted with adult-equivalency factor following the Kitchen Performance Protocol (Bailis, Smith and Edwards, 2007). After adjusting for family size, mixed stoves homes still had statistically significantly higher fuelwood consumption (1.0 kg/day/adult equivalent) (p=0.02) compared to traditional stove homes. This result again suggests “suppressed demand” in mixed stove homes where households were cooking a higher number of dishes and consuming more fuelwood compared to other stove groups even though the average family size in mixed stove homes was smaller than in the traditional stove homes.

A total of 129 fuelwood collection trips were tracked by GPS during the study period. The majority of the fuelwood collection trips (95%) were separate from farming activities, which was expected as the study period was during the non-agricultural season. Households spent on average about 2 hours per trip (25th-75th percentile: 1 hour 25 minutes - 2 hours 37 minutes) walking an average distance of 3 km (25th-75th percentile: 1.88 km - 3.86 km) per trip for fuelwood collection. Average frequency of trips per week was 3 trips (25th-75th percentile: 1 - 4); some households made 2 - 3 trips per day on some days of the week. A previous study in Karnataka found women spent on average 2 hours/day/household on fuel gathering activities (Shailaja, 2000). India's nationwide self-reported time-use surveys found women spent an average of 40 minutes per day, and over 60 minutes in limited fuelwood areas (World Bank, 2004).

The majority of fuelwood collection trips tracked by GPS in our study were made by females (79%) who often travel on foot to collect dried broken twigs from the ground or wood pieces cut by men, and carried home on their heads. The study population included males (21%) who tended to travel further distances with ox-carts to collect fuelwood.  Females still spent twice as much time collecting fuelwood per trip compared to men; median (25-75th percentile) were 127 (109-157) vs. 62 (52-138) minutes for females and males, respectively. A third of the fuelwood collection trips were made by children below 14 years of age with roughly an equal number of girls and boys. During the interviews, it was indicated that children participate in fuelwood collection activities during school holidays and less when school is in session.

Frequency, distance, and time spent traveling for fuelwood collection trips by stove groups are provided in Table 4-5. Mixed stove group homes went more frequently for fuelwood collection compared to other stove groups. Time spent collecting fuelwood per week was shortest for the traditional stove group (166 minutes/week), and the mixed stove group spent the longest time per week collecting FW (267 minutes/week). However, per trip time was highest for exclusive intervention stove homes (165 minutes/trip).

As time spent collecting fuelwood is related to how far the collector travels, distance traversed was examined to probe further on time differences between stove groups. Distance travelled per week to collect fuelwood was shortest for the traditional stove group (3.8 km/week), whereas mixed stove homes travelled the furthest distance (7.0 km/week). However, when distance travelled per trip was considered, exclusive intervention stove homes travelled the farthest (5.7 km/trip) whereas both traditional and mixed stoves homes travelled similar distances per trip (2.5 km/trip). The distance analysis suggests two possible reasons why exclusive intervention stove users may be traveling farther than other stove groups. Exclusive intervention stove users may have less access to fuelwood resources or their land may be located further away from their homes, hence motivating them to adopt the intervention stoves. The longer distances that need to be traversed may be the motivation behind exclusive use of the intervention stove use due to either real or perceived (because households were told about increased fuelwood efficiency of the intervention stoves) reduction in fuelwood consumption.

It is also possible that intervention stoves may be creating a preference for certain fuelwood species or other characteristics of the fuelwood that are available further away from their village. A study in Malawi found that homes that adopted intervention mud stoves had a preference for fuelwood species that were different from the ones used with traditional stoves (Timko and Kozak, 2016). Additional research would be needed to investigate the relationship between stove type and preference for fuelwood species or characteristics in this community, as well as to elucidate how access to fuelwood resources may vary within a community.

As the mixed stoves group consumed statistically significantly higher quantity of fuelwood compared to the traditional stove group, it is not surprising that this group went more frequently for fuelwood collection, and travelled a longer distance and spent more time collecting fuelwood per week. However, analysis per trip suggest exclusive intervention stove homes travelled the furthest distance per trip, thus spending significantly longer time per trip compared to other stove use groups. Based on a regression analysis, land ownership was not significantly associated with distance travelled per week or trip (Appendix C: Table C-3). However, household assets were inversely associated with distance travelled per week but this did not differ by stove group. For distance travelled per trip, exclusive intervention stove use was associated with 2.6 km longer travel distance compared to traditional stove home after controlling for asset wealth.

Sample size was limited for analysis of the time and distance travelled since only the participants with complete GPS files during the week of monitoring were selected for comparing between stove groups. A total of 19 households (traditional stove (N=5); exclusive intervention stove (N=5); mixed stove (N=9)) had complete GPS files for the week period. Within this group, one traditional stove homes previously collected fuelwood for the entire year and did not go for fuelwood collection during the monitoring period. Three households did not want to participate in the GPS monitoring activities and declined to complete this phase of the study. Some households also went to collect fuelwood just to give GPS data, especially a few households who were excited about the GPS and seeing their routes on a computer. This was confirmed from brief questions during daily visits to the house to download GPS data, and confirm fuelwood collection trips.

Although the intent was to monitor everyone in the household who participated in fuelwood collection, only one person in the household carried the GPS. This may have led to an underestimation of time spent per household on fuelwood collection in instances where two people went together or several people from the same household collected fuelwood. Based on interview results, it was common in all stove use groups to go with family members or neighbors for security or to assist with lifting of the fuelwood load onto the head, the common method of fuelwood load carrying for women. The study was conducted in only one season (dry non-farming season). The findings here on time-use and activity patterns may not be representative of other seasons.

**Table 4-5: Fuelwood (FW) consumption, and collection time and patterns by stove use groups**

| | Traditional stove (N=5) Median (Quartile) | | Exclusive intervention stove (N=5) Median (Quartile) | p-value[4] | Mixed stove (N=9) Median (Quartile) | p-value[4] |
|---|---|---|---|---|---|---|
| FW consumption (kg/day) | 3.0 (2.6 – 3.8) | | 3.1 (2.4 – 3.6) | 0.75 | 3.8 (3.3 – 5.5) | 0.08 |
| FW consumption[1] (kg/day/ adult-equivalent) | 0.7 (0.5 – 0.9) | - | 0.8 (0.6 – 0.9) | 0.56 | **1.0 (0.7 – 1.2)** | **0.02** |
| Frequency/week (number of trips) | 3.0 (1.5 – 4.0) | - | 2.0 (1.0 – 3.0) | 0.75 | 3.0 (2.0 – 5.0) | 0.60 |
| Distance travelled per week (km) | 3.8 (0.6 - 12.1) | - | 5.7 (5.3 – 6.0) | 0.52 | 7.0 (5.2 - 12.9) | 0.21 |
| Distance travelled per trip[2] (km) | 2.5 (0.6 – 3.4) | - | 5.7 (3.3 – 6.0) | 0.12 | 2.5 (2.1 – 3.5) | 0.68 |
| Time collecting FW per week (minutes) | 249 (82 - 401) | - | 205 (165 - 219) | 0.84 | 267 (248 - 636) | 0.36 |
| Time collecting FW per trip[3] (minutes) | 100 (82 – 124) | - | 165 (130 – 205) | 0.10 | 124 (106-133) | 0.39 |

[1]*Person weighed using adult equivalency factor.* [2]*Sum of kilometer from all FW collection trips completed during the week divided by number of trips during the same period.* [3]*Sum of time spent collecting FW during the week divided by number of trips completed during the same period.* [4]*Mann-Whitney-Wilcoxon tests using traditional stove group as reference group. Bold indicates statistical significant difference. Sample size for FW consumption and Frequency/week: traditional stove (N=11); intervention stove only (N=15); mixed stove (N=19).*

The overall results suggested that exclusive use of intervention stoves was associated with less time spent cooking during mornings and fuelwood collection per week. However, the cross-sectional design of the study does not allow for assessment of a causal relationship between use of the intervention stove and time savings. Some of the intervention stove users reported time savings from cooking and fuelwood collection activities in the interviews. It is possible that intervention stove users experienced time savings when switching from the traditional to intervention stoves. It is also possible that reporting of time savings in interviews may be a result of "courtesy bias" (Burwen and Levine, 2012) to please the study team or the NGO partner. Even though participant observation of cooking activities was done in the most unobtrusive way following standard protocol including minimizing conversation with participants, and use of local staff, it was not possible to verify that data collection activities did not change participants' behavior.

**Saved time and livelihoods**

A total of 26 hours of interviews were recorded. When intervention stove users reported time saved from use of intervention stoves, they were asked what they have done with the saved time. The most frequently reported response was going early to farm work (Table 4-6). Farm work is seasonal and therefore, may not be an option available year around. Other uses of saved time included relaxing, doing other household work, and spending time with neighbors (Table 4-6). Participants were asked what they would do if they had extra 1-3 hours in a day. The majority of the response was household work (fetching water, cooking, washing clothes), followed by relaxing or sleeping, and spending time with others (neighbors, relatives, and children) (Table 4-6). These finding are similar to a cross-sectional survey of improved cookstove users in India that found women reported using the saved time in agriculture, family, and social activities (Bloomfield, 2014). The survey included results from Karnataka which found 35% of women reported to giving more time to agricultural activities, followed by 30% of women giving more time to care of children, 17% meeting friends and relatives, and 16% attending community meeting. The amount of time women devote to agricultural activity (or an income generating activity) may differ within and across villages in this region. This variation may also affect how women use their saved time. In this study community, the majority of households were engaged in agriculture work as the main occupation (54%), and study participation was limited to these agricultural households. From observations, both men and women engaged in farm work in this community. It is possible that use of saved time may differ in other households where the main occupation is not agriculture.

Several interviewees reported lack of time to finish household work particularly during farming season which often cuts into their sleeping time as explained by traditional stove user and exclusive stove user below:

**Traditional stove user 1**

*Sometimes there will not be sufficient time to complete all the household work during agricultural season. It is not possible to sleep for longer time as I need to get up early during this season.*

**Exclusive intervention stove user 2**

*We wake up at 6 am during non-agricultural season but when there is farm work we get up at 3 or 4 am in the morning so we can finish household work before going to the farm.*

The everyday challenge of balancing household work burden in limited time was confirmed by responses from interviewees about what they would do if they had extra 1 to 3 hours in a day. The most common response was doing household work, including cooking and washing clothes (Table 4-6). Interviewees also expressed a desire to relax or sleep, and spend time with neighbors, children or visiting relatives if they had extra time in a day (Table 4-6). This suggest that as a result of time poverty, women are making trade-offs, giving up rest, leisure and social activities to complete household work and livelihood related activities. It is interesting to note that a desire to engage in income-generating activities was not mentioned in the interview responses, despite it being one of the primary motivations for cookstove intervention programs.

In some households, time and fuel savings may not be a priority as revealed in an interview with a traditional stove user who has recently dis-adopted the intervention stoves, despite knowing and experiencing their benefits:

> **Traditional stove user 2**:
>
> *Q: What stoves are you using now?*
>
> *R. We are now cooking all the food on traditional stoves. We are not using the intervention stoves anymore. We were cooking rice, sambar, subji, etc. on the intervention stoves.*
>
> *Q: What benefits did the intervention stoves provide?*
>
> *R: Cooking was faster on the intervention stoves, produced less smoke, and used less quantity of fuel wood burning. But we cannot cook large quantity of food or roti on the intervention stoves. Traditional stoves are convenient to make rotis and we can cook all kinds of food, and more quantity of food, but the consumption of fuelwood is more on traditional stoves.*
>
> *Q: Why do you not keep the intervention stoves around anymore?*
>
> *R: We do not have place to install them at our house.*

In this case, ability to cook larger quantity of food and ease of making rotis on traditional stoves may be more of a priority for this household than was time savings. A systematic review of factors influencing adoption of improved cookstoves found that larger family size is a barrier to adoption, likely due to two reasons: 1) the need to cook a greater quantity of food which may not be feasible with intervention stoves; and 2) more hands available in the household leading to lower prioritization of time and labor needed for fuelwood collection (Rehfuess *et al.*, 2014). Pine et al. (2011) also suggested that larger family size means senior members of the family may be living under the same roof, such as the mother-in-law, who are unwilling to adopt intervention stoves (Pine *et al.*, 2011). In our study, the traditional stove group had the largest number of household family members compared to stove use groups that used intervention stoves.

In order to probe livelihood challenges and constraints faced by women in the study community, they were asked about major challenges they faced in carrying out daily activities as well as in pursuing additional income-generating activities. Major challenges in carrying out daily activities were related to health, labor shortage on farm, and to a lesser extent finances (Table 4-6). These three themes were common across all three stove use groups. Many women reported being tired with body aches and pain due to hard labor work in household and on farms. A shortage of agricultural laborers was also frequently mentioned as a major challenge in their current occupation as a result of people preferring to work elsewhere for higher pay, such as migrating to Bangalore (the nearest major city) to work on construction sites. Physical access to markets was also mentioned as one of the major issues in their current occupation since agricultural products fetch higher prices if they can be sold at larger markets, which require higher transport charges. When asked about challenges that were preventing participants from pursuing other livelihood improvement opportunities, the responses were similar to previously mentioned challenges such as health and finances but also included family responsibilities, including taking care of young children (Table 4-6).

Interviews with key informants also confirmed that key livelihood challenges faced by the community are related to lack of money, labor shortage, being located far from markets for selling their crops, and facing shocks from weather related crop loss events. They confirmed that many villagers migrate to cities for higher pay work, or take loans from micro-credit groups. The responses on livelihood constraints from both village participants and key informants suggest that health and external factors (i.e. labor shortage and market access) affected the women in the study village.

**Table 4-6: Summary of key responses (number of times they were mentioned) by stove use groups**

| Questions | Stove Use Groups | | |
|---|---|---|---|
| | **Traditional** | **Exclusive** | **Mixed** |
| **Actual saved time** | | | |
| Cooking saved time | -NA- | Go early to farm work (if any) (6)<br>Relax (5)<br>Do household work (3)<br>Spend time w/ neighbors (1) | Go early to farm work (if any) (3)<br>Do household work (2) |
| Saved time from FW collection | -NA- | - | Farm work (if any) (3)<br>Relax (1) |
| **Theoretical saved time** | | | |
| What would you do if you have extra 1-3 hours in your day? | Household work (15)<br>Relax/rest (7)<br>Spend time w/ neighbors (3)<br>Spend time w/ children (2)<br>Watch TV (1) | Household work (17)<br>Relax/sleep (12)<br>Spend time w/ neighbors (10)<br>Visit relatives (5)<br>Spend time w/ children(2)<br>Attend SHG meetings (2)<br>Fuelwood collection (2)<br>Watch TV (2)<br>Take children to school (1) | Household work (18)<br>Relax/rest (12)<br>Spend time w/ neighbors /relatives (8)<br>Spend time w/ children (2)<br>Attend credit group meetings (2)<br>Watch TV (1) |
| **Challenges** | | | |
| What are the major challenges that you face in carrying out daily activities (job/ and domestic activities) | Health problem (12)<br>Labor shortage (4)<br>Financial (1) | Health problem (14)<br>Labor shortage (4)<br>Low wage (1)<br>Taking care of children (1) | Health problem (15)<br>Labor shortage (5)<br>Financial (1) |
| If you are interested in pursuing other livelihood options, what are the major challenges that you face in doing so? | Family responsibilities (2)<br>Health problem (1)<br>Financial (1) | Financial (3)<br>Health problem (3)<br>Young children (2) | Young children (2)<br>Financial (1) |

## 4.6 Conclusion

In this study, we provided empirical evidence for evaluating two common assumptions that: 1) self-reported time savings are accurate; and that 2) the saved time is used by women to engage in income generating activities to improve their livelihoods. Current methods used to assess time-use changes from improved stove interventions are limited to self-report and recall methods. These methods have never been verified with observed measures in the cookstove literature, making this study the first to do so within a cookstove intervention context. The study found that observed and self-reported measures on count events (e.g. number of fuelwood collection trips in the past week) were correlated but self-reported time spent cooking and collecting fuelwood tends to be overestimated compared to the observed measures. The results on fuelwood collection time should be interpreted with caution because of small sample size of participants. However, overall results suggest observed measures may be needed to verify self-reported methods situated in a study context.

The observed measured time spent cooking and collecting fuelwood did not differ significantly between stove use groups. Mixed stove homes on the other hand cooked more dishes and consumed more fuelwood compared to other stove groups suggesting "suppressed demand".

The interviews with women suggested saved time may not always be used for income-generating activities as farm work is seasonal. There was a strong desire to use theoretical saved time for household work or relaxing and socializing activities. Assumptions of livelihood improvements from cookstove interventions needed to be grounded in a local context that takes into account many factors, i.e. social and cultural norms, employment and market conditions, which can influence women's livelihood options.

# Chapter 5: Conclusion

## 5.1 Summary of findings

This doctoral dissertation evaluated climate and health-relevant air pollutants, blood pressure, eye health, time savings, and livelihood outcomes from the first CDM-approved cookstove intervention in India. All analyses were based on primary data collected from two field-based studies of the same CDM-approved intervention program. The first was a randomized controlled intervention study in a village in rural Karnataka that measured household air pollution and health outcomes before and after the intervention. The second study was a cross-sectional study in a nearby village that compared observed and self-reported time use, time spent cooking and collecting fuelwood between stove groups, and livelihood outcomes.

In the randomized controlled study, 60% of households exclusively used the intervention stoves, and the remaining households continued using the traditional stoves in combination with intervention stoves. Despite laboratory results of 67% reduction in fuelwood consumption relative to a traditional stove, we did not observe significant differences between the stove groups in 24-hour fuelwood use following the intervention. Based on intent-to-treat analysis (ITT), there were minor and overlapping reductions (post- minus pre-intervention change) between control and intervention groups for median (95% CI) fuel use [-0.60 (-1.02, -0.22) vs. -0.52 (-1.07, 0.00) kg $day^{-1}$]. Based on per-protocol analysis (PP), homes exclusively using intervention stoves experienced a larger median reduction in fuelwood use [-0.72 (-1.50, 0.05) kg $d^{-1}$], and mixed stove homes (use both intervention and traditional stoves) had the smallest median fuelwood reduction [-0.20 (-1.03, 0.55) kg $d^{-1}$] in the post-intervention season.

For 24-hr measured indoor air pollutant concentrations, there was a seasonal increase (post- minus pre-intervention change) in all stove groups. However, the magnitude of the median (95% CI) $PM_{2.5}$ increase was smaller for the exclusive intervention stove group compared to the control group [51 (-58, 161) vs. 139 (61, 229) μg $m^{-3}$]. The median (95% CI) increase in fine particle Abs was similar across all stove groups: control [35 (18, 60) x $10^{-6}$ $m^{-1}$]; exclusive intervention stove [31 (16, 45) x $10^{-6}$ $m^{-1}$], and mixed stove [48 (19, 85) x $10^{-6}$ $m^{-1}$].

We also estimated the proportion of black carbon in particle mass by taking a ratio of absorbance to $PM_{2.5}$ mass. The median (95% CI) absorbance-to-mass ratios in the exclusive intervention stove group [0.08 (0.04, 0.13) $m^2$ $g^{-1}$], and the mixed stove group [0.11 (0.05, 0.19) $m^2$ $g^{-1}$] were two or more times higher than in the control group [0.04 (0.01, 0.06) $m^2$ $g^{-1}$]. This finding suggests that the proportion of $PM_{2.5}$ that is black carbon is higher for the intervention stoves than traditional stoves, although it is still possible that interventions stoves resulted in lower overall black carbon emissions compared to traditional stoves.

For health outcomes, exclusive use of the intervention stove was associated with a median (95% CI) decrease in SBP [-1.2 (-3.6, 1.3) mm Hg] compared to its baseline (pre-intervention) levels. Mixed stove use was associated with higher SBP [4.2 (0.7, 7.7) mm Hg] compared to its baseline level. Odds of reporting eye irritation symptoms were significantly reduced for two symptoms in the mixed stove group (burning sensation in eyes often [0.11 (0.02, 0.42)], and eyes look red often [0.80 **(**0.66, 0.96)] but not in the exclusive intervention stove when compared to the control group.

Observed and self-reported frequency of fuelwood collection trips in the past week were correlated (Spearman's rank correlation coefficient (rho) of 0.62 (*P* <0.001)). However, self-reported time was overestimated on average (standard deviation) by 82 (85) minutes (fuelwood collection duration), 67 (48) minutes (morning cooking event), and 30 (35) minutes (evening cooking event) compared to the observed time. The exclusive intervention stove group travelled a longer distance per trip (5.7 vs. 2.5 km/trip) and spent more time collecting fuelwood (165 vs. 100 minutes/trip) compared to the control group. This suggests that households exclusively using the intervention stoves may be motivated to use the stoves because of the longer travel distance and time required to collect fuelwood.

Compared to control homes using traditional stoves and homes exclusively using the intervention stoves, homes using mixed stoves consumed the highest quantity of fuelwood. Female participants reported using saved time for farm work (seasonal), relaxing, and household work. Interview results in this community suggest health and external factors (shortage of labor; market access) as major barriers for increasing household income.

In both studies, there was evidence that rebound effect may have been at play in the mixed stove group, where some households used more than the usual two stoves for cooking. In the first study, fuelwood moisture was the lowest in mixed stove homes compared to other stove use groups, meaning less fuelwood may be required for cooking. However, seasonal (post- minus pre-intervention) reduction in fuelwood use in the mixed stove homes was the lowest compared to the control and exclusive intervention stove homes. In the second study, the mixed stove group consumed the highest quantity of fuelwood per day, and was found to cook more dishes compared to the traditional stove and exclusive intervention stove homes. This suggests that the mixed stove group may be experiencing benefits in other ways, i.e. increased food consumption as a result of being able to overcome suppressed demand associated with traditional stoves.

## 5.2 Strengths and limitations

A major strength of the research was that both studies were implemented in close collaboration with a local NGO who has been working in the region for the past 30 years on social and development issues. Frequent consultations with the NGO were done on research designs and methods to ensure that they were feasible and acceptable in the local cultural context. This provides more confidence in the research methods to provide sensitive and key variables that may be important in analyses of outcomes. The close collaboration also provided unique insight into challenges associated with implementing a large-scale carbon-financed intervention program at the ground level, allowing the studies to formulate practical and meaningful recommendations.

The randomized controlled design of the first study where intervention stoves were randomly distributed, with a control population in a single village helps limit bias and potential confounders (Concato, Shah and Horwitz, 2000). Many field-based evaluations of stove interventions rely on pre-post designs that lack a control population (Berrueta, Edwards and Masera, 2008; Pennise *et al.*, 2009; Berkeley Air Monitoring Group, 2011; Alexander *et al.*, 2015; Patange *et al.*, 2015). Without a control group, one cannot be certain that changes are due to the treatment (use of intervention stove) as many factors may influence fuelwood use, emissions, or exposures, such as changes in wood moisture, types of food cooked, and cultural practices that can vary over time or seasons. However, when measurements are conducted back-to-back to limit such unmeasured changes, users are more likely to cook with their new stoves and may not reflect the intervention's true effect. For this randomized controlled study, there was a minimum of 124 days (average of 194 days) between pre- and post-intervention measurements.

Further, distribution of the intervention stoves was randomized, and as such the study was more likely to provide a realistic representation of adoption and use patterns in a community. Without randomization, stove adoption may be biased by many factors, such as income and education (Lewis and Pattanayak, 2012), which can impact health outcomes (Foote *et al.*, 2013).

The second study was limited by a small sample size, however, it was designed to be a pilot investigation on feasibility of deploying relatively novel methods (GPS tracking, and participant observation) in evaluating cookstove intervention on time savings and livelihood impacts. The cross-sectional design of the second study also limits drawing causal inference. However, as the second study built on the experience of the first study, only a cross-sectional study could be implemented as the intervention had proceeded as part of the larger intervention program. A larger sample size in the second study may have provided more precise data to detect significant differences on time-use between stove groups.

### 5.3 Research contribution

This was the first study to independently and rigorously evaluate a CDM-approved cookstove intervention in the field. Local and international cookstove intervention efforts are leveraging carbon financing, posited to transform the rural household energy sector. However, their potential to provide co-benefits for air quality, health, and livelihoods has never been evaluated in the field. In addition, this research evaluated an intervention that was happening in the real world (i.e. not investigator-initiated), therefore, the results are more likely to represent a realistic assessment of the intervention's impact as it scales up.

The study confirmed that lab results do not reflect field performance but extends this knowledge into the largest carbon financing program (the CDM). This is important because the CDM approval process is based on laboratory-based Water Boiling Tests. As field-based testing can be costly and time consuming, implementing NGOs typically provide fuel efficiency of stoves based on laboratory tests to gain carbon credit approval. As demonstrated in this research, the reliance on lab-based testing can overestimate fuelwood savings. In addition, the narrow focus on fuelwood saving component of a cookstove technology can lead to trade-offs or unintended consequences, as the intervention stoves mitigated the seasonal increase in $PM_{2.5}$ but increased absorbent properties of the particle pollution, which can impact regional climate.

The research contributes to cookstove intervention literature on time-use methods and livelihood assumptions. Time spent on household reproductive activities and the routines around them can be complex in the lives of rural women in a developing country. The second study showed that frequency and pattern of fuelwood collection activities varied depending on season as they may be combined with farming activities during agricultural season or done separately at other times. Children also assist in fuelwood collection activities but mostly during summer season when schools are closed. In addition, women may accompany their neighbors and friends, and family members during fuelwood collection activities for social and security reasons, or to provide an extra helping hand to lift fuelwood loads onto their heads. As a result, simple surveys on time savings from highly fractionated group of activities, or methods that do not take into account seasonal variation or social and cultural routines may be unreliable in reporting time savings.

Proponents of cookstove interventions often claim that efficient cookstoves improve livelihoods however; this assumption is not backed by empirical evidence. In this study, some women reported using saved time for more agricultural work but this work was seasonal and not available year round. Some also reported using saved time for household work, sleeping, spending more time with children and neighbors, and watching TV. The simplistic assumption that saved time is used for livelihood improvement may be harmful because it could potentially exclude additional efforts needed to address constraints faced by rural women in improving their livelihood options, such as access to markets, skill development resources, and health care services.

### 5.4 Unanswered questions and future research needs

This study raised important questions on adoption and sustained use of stoves. One of the major criticisms of previous cookstove interventions has been their inability to fulfill local culture and user needs (F. R. Manibog, 1984). In this study, intensive efforts were made by the local NGO to ensure that the intervention stoves would be acceptable to users while meeting fuel efficiency requirements of the CDM program. The NGO had substantial social and cultural capita given over three decades of their experience working on socio-economic development issues in northern Karnataka. This pre-existing relationship was essential in convincing households to adopt the intervention stoves. Design and development of the stoves involved frequent piloting by the NGO in the communities and incorporating users' comments to fit the local culture and needs of the users. The implementing NGO paid frequent visits to the intervention village to train and encourage usage of the intervention stoves, including organizing raffle prize draws. Despite this level of trust, familiarity, and incentives, the program was not able to overcome inherent issues of stove stacking.

It is possible that if the intervention stoves were significantly more efficient and provided co-benefits valued by users, such as fuelwood use reductions and time savings, then their use might be higher. However, in our study population, the major reason for continuing to use traditional stoves were their ease and ability to make roti bread properly. As part of the intervention program, the NGO organized demonstrations to teach women how to avoid burning rotis on the intervention stoves. The NGO also introduced different shape pans to reduce burning, and some users also developed their own adaptation by putting a layer of mud behind their roti pan to reduce heat to stop rotis from getting burnt. It is possible that stove usage is higher since the two studies were conducted as the NGO learned to advocate and promote adoption and sustained use, and the users adapt to the new technology. Further research is needed to evaluate impacts of such on-the-ground efforts to promote adoption and use behavior, as they could provide useful knowledge for future stove intervention programs. In particular, as intervention technology moves towards more advanced models and fuels, it is likely to move further away from meeting sociocultural or traditional cooking needs and practices. Such studies can bridge the gap between technology-focused interventions and social factors that influence their sustained use in the field.

Many uncertainties remain on extent to which an intervention stove contributes to climate mitigation. In addition to this study, there are now few more field-based studies measuring black carbon from intervention stoves (Kar *et al.*, 2012; Patange *et al.*, 2015). Intervention stoves may also reduce organic carbon emissions, a climate cooling pollutant (Grieshop, Marshall and Kandlikar, 2011; Just, Rogak and Kandlikar, 2013). Therefore, additional studies that provide a comprehensive emission analysis of emerging cookstove technologies are needed to better understand and estimate climate mitigation impacts.

## 5.5 Policy and program implications

Carbon financing of cookstove interventions provides potential for transforming rural household energy and may provide co-benefits for environment, health and welfare. In these study communities, it is not likely that a cookstove intervention project of this scale would have been implemented without the availability of carbon financing. Hence, the additionality criterion for carbon financing is met, though in practice, $CO_2$ emission reductions were not apparent from fuelwood consumption results in the pilot intervention village. It is possible that significantly more efficient cookstove technologies or modern fuels could have provided measurable emission reductions and co-benefit, although fossil fuels such as LPG are not supported by the CDM.

Today, there are increasing efforts to promote more advanced biomass stoves, such as gasifiers and forced draft stoves, to provide significant emission reductions that may be necessary for health benefits to be achieved (Ministry of New and Renewable Energy, 2012; Simon *et al.*, 2014). Field-based evaluations at the community level are essential for assessing their true impacts. While laboratory studies have shown advanced stoves to have substantial emission reductions compared to traditional stoves and basic improved rocket stoves (Jetter and Kariher, 2009; Roden *et al.*, 2009; MacCarty, Still and Ogle, 2010), these technologies are bound to repeat the same failures if their performance is not evaluated in the field.

Further, effectiveness of the stove intervention program depends not only on the technology's ability to provide significant emission reductions but also on achieving high stove adoption and sustained usage. In this regard, this thesis provides several recommendations for stove engineers to assist in improving the development and testing of stoves to ensure they are acceptable and used correctly. Stove designs that are user friendly and easy to control cooking temperatures, could increase adoption. In this study, users were unable to control the centrally concentrated high heat which led to burning of rotis. Burnt rotis were the primary reason for households' continued use of traditional stoves. Although laboratory conditions can never replicate field conditions, the more the stove testing can imitate types of fire and heating power needed to cook specific types of food can assist in more accurate measure of emission efficiencies. Further, intervention stoves can deteriorate over time and contribute to their dis-adoption (Hanna, Duflo and Greenstone, 2012). The long-term quality of stoves should be tested by replicating frequency and duration of cooking events that would occur in actual households. This would also provide information on "useful life" of the intervention stove as well emission and fuelwood consumption efficiencies that can change over stoves' usage.

Carbon financed programs need to link up with recently developed international standards, such as the International Standard Organization (ISO) International Workshop Agreement (IWA) on Clean and Efficient Cookstoves that provides an interim guideline for categorizing stove performance based on fuel use/efficiency, total emission, indoor emission, and safety (ISO, 2012). The CDM program is narrowly focused on fuelwood efficiency as the primary parameter for carbon credit approval with little attention paid to emissions of health or other climate-relevant pollutants. Such narrowly defined focus may lead to unintended and unfair consequences. For example, current carbon-financed programs only consider GHGs included in the Kyoto Protocol, such as $CO_2$ and methane ($CH_4$), but do not consider black carbon (BC) (Freeman and Zerriffi, 2014). While location of GHG emission reductions is irrelevant because of their global impact, the location of BC abatement is important due its significant regional impacts. While the current ISO/IWA guidelines do not include BC, there are ongoing efforts to account for BC in the voluntary carbon market (The Gold Standard, no date).

Future stove interventions should include in their evaluation and monitoring framework specific measures on time savings that are appropriate to the local cultural context. The common assumption that time saved is used for income generating activities needs to be grounded in local context in which these interventions are situated. Interventions that want to improve livelihoods may need to develop complementary activities or programs to address sociocultural and economic constraints faced by rural women in developing countries.

## References


Akbar, S., Barnes, D., Eil, A. and Gnezditskaia, A. (2011) *Household cookstoves, environment, health, and climate change: a new look at an old problem*. RPRT. Washington, DC: The World Bank.

Albalak, R., Bruce, N., McCracken, J. P., Smith, K. R. and de Gallardo, T. (2001) 'Indoor respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in a rural Guatemalan community', *Environmental Science & Technology*. American Chemical Society, 35(13), pp. 2650–2655. doi: 10.1021/es001940m.

Alexander, D., Larson, T., Bolton, S. and Vedal, S. (2015) 'Systolic blood pressure changes in indigenous Bolivian women associated with an improved cookstove intervention', *Air Quality, Atmosphere & Health*, 8(1), pp. 47–53. doi: 10.1007/s11869-014-0267-6.

Alexander, D., Linnes, J. C., Bolton, S. and Larson, T. (2014) 'Ventilated cookstoves associated with improvements in respiratory health-related quality of life in rural Bolivia', *Journal of Public Health* , 36(3), pp. 460–466. doi: 10.1093/pubmed/fdt086.

Arnold, M., Kohlin, G., Persson, R. and Shepherd, G. (2003) *Fuelwood revisited: what has changed since the last decade?*, *Center for International Forestry Research (CIFOR)*. RPRT. Indonesia: Center for International Forestry Research (CIFOR).

Asian Development Bank (2009) *Impact of rural water supply and sanitation in Punjab, Pakistan*. Manila, Philippines, Philippines. doi: IES: PAK 2009-26.

Asian Development Bank (2015) *Balancing the Burden? Desk review of women's time poverty and infrastructure in Asia and the Pacific*. Manila, Philippines. Available at: https://www.adb.org/publications/balancing-burden-womens-time-poverty-and-infrastructure.

Aung, T., Jain, G., Sethuraman, K., Baumgartner, J., Reynolds, C., Grieshop, A. P., Marshall, J. D. and Brauer, M. (2016) 'Health and Climate-Relevant Pollutant Concentrations from a Carbon-Finance Approved Cookstove Intervention in Rural India', *Environmental Science & Technology*. American Chemical Society, 50(13), pp. 7228–7238. doi: 10.1021/acs.est.5b06208.

Bailis, R., Berrueta, V., Chengappa, C., Dutta, K., Edwards, R., Masera, O., Still, D. and Smith, K. (2007) 'Performance testing for monitoring improved biomass stove interventions: experiences of the Household Energy and Health Project', *Energy for Sustainable Development*, 11(2), pp. 57–70. doi: 10.1016/S0973-0826(08)60396-8.

Bailis, R., Chatellier, J. L. and Ghilardi, A. (2012) 'Ecological sustainability of woodfuel as an energy source in rural communities', in Ingram, C. J., DeClerck, F., and del Rio, C. (eds) *Integrating Ecology and Poverty Reduction: Ecological Dimensions*. New York, NY, NY: Springer New York, pp. 299–325. doi: 10.1007/978-1-4419-0633-5_18.

Bailis, R., Drigo, R., Ghilardi, A. and Masera, O. (2015) 'The carbon footprint of traditional woodfuels', *Nature Clim. Change*. Nature Publishing Group, 5(3), pp. 266–272. Available at: http://dx.doi.org/10.1038/nclimate2491.

Bailis, R., Smith, K. and Edwards, R. (2007) *Kitchen Performance Test (KPT): KPT Version 3.0*, *Household Energy and Health Programme, Shell Foundation*. Available at: https://cleancookstoves.org/binary-data/DOCUMENT/file/000/000/83-1.pdf (Accessed: 14 January 2016).

Balakrishnan, K., Cohen, A. and Smith, K. R. (2014) ‘Addressing the burden of disease attributable to air pollution in india: The need to integrate across household and ambient air pollution exposures’, *Environmental health perspectives*, 122(1). doi: http://dx.doi.org/10.1289/ehp.1307822.

Balakrishnan, K., Thangavel, G., Ghosh, S., Sambandam, S., Mukhopadhyay, K., Adair-Rohani, H., Bruce, N. and Smith, K. R. (2011) *The Global Household Air Pollution Database 2011 (Version 3.0), World Health Organization*. Available at: http://www.who.int/indoorair/health_impacts/databases_iap/en/ (Accessed: 28 January 2016).

Barnes, D. F., Openshaw, K., Smith, K. R. and van der Plas, R. (1994) *What makes people cook with improved Biomass stoves? A comparative international review of stove programs, Energy Series*. RPRT. Washington D.C.: World Bank.

Barnett, A. G., Sans, S., Salomaa, V., Kuulasmaa, K., Dobson, A. J. and Project,  for the W. H. O. M. (2007) ‘The effect of temperature on systolic blood pressure’, *Blood Pressure Monitoring*, 12(3). Available at: http://journals.lww.com/bpmonitoring/Fulltext/2007/06000/The_effect_of_temperature_on_systolic_blood.10.aspx.

Baumgartner, J., Schauer, J. J., Ezzati, M., Lu, L., Cheng, C., Patz, J. A. and Bautista, L. E. (2011a) ‘Indoor air pollution and blood pressure in adult women living in rural China’, *Environ Health Perspect*. National Institute of Environmental Health Sciences, 119(10). doi: 10.1289/ehp.1003371.

Baumgartner, J., Schauer, J. J., Ezzati, M., Lu, L., Cheng, C., Patz, J. A. and Bautista, L. E. (2011b) ‘Patterns and predictors of personal exposure to indoor air pollution from biomass combustion among women and children in rural China’, *Indoor Air*. Blackwell Publishing Ltd, 21(6), pp. 479–488. doi: 10.1111/j.1600-0668.2011.00730.x.

Baumgartner, J., Zhang, Y., Schauer, J. J., Huang, W., Wang, Y. and Ezzati, M. (2014) ‘Highway proximity and black carbon from cookstoves as a risk factor for higher blood pressure in rural China’, *Proceedings of the National Academy of Sciences* , 111(36), pp. 13229–13234. doi: 10.1073/pnas.1317176111.

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

Berkeley Air Monitoring Group (2012) *Stove Performance Inventory Report*. Berkeley. Available at: http://berkeleyair.com/wp-content/publications/SPT_Inventory_Report_v3_0.pdf.

Berrueta, V. M., Edwards, R. D. and Masera, O. R. (2008) ‘Energy performance of wood-burning cookstoves in Michoacan, Mexico’, *Renewable Energy*, 33(5), pp. 859–870. doi: 10.1016/j.renene.2007.04.016.

Bloomfield, E. (2014) *Gender and Livelihoods Impacts of Clean Cookstoves in South Asia*. United Kingdom. doi: Report Processing Number: 2012.86.

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwarz, J. P., Shindell, D., Storelvmo, T., Warren, S. G. and Zender, C. S. (2013) ‘Bounding the role of black carbon in the climate system: A scientific assessment’, *Journal of Geophysical Research: Atmospheres*. John Wiley & Sons, Inc, 118(11), pp. 5380–5552. doi: 10.1002/jgrd.50171.

Bond, T. C., Venkataraman, C. and Masera, O. (2004) 'Global atmospheric impacts of residential fuels', *Energy for Sustainable Development*, 8(3), pp. 20–32. doi: 10.1016/S0973-0826(08)60464-0.

Bonjour, S., Adair-Rohani, H., Wolf, J., Bruce, N. G., Mehta, S., Prüss-Ustün, A., Lahiff, M., Rehfuess, E. A., Mishra, V. and Smith, K. R. (2013) 'Solid fuel use for household cooking: country and regional estimates for 1980-2010', *Environmental Health Perspectives (Online)*. Research Triangle Park: National Institute of Environmental Health Sciences, 121(7), p. 784. Available at: http://ezproxy.library.ubc.ca/login?url=http://search.proquest.com/docview/1661373790?accountid=14656.

Breuer, E., Lee, L., De Silva, M. and Lund, C. (2016) 'Using theory of change to design and evaluate public health interventions: a systematic review', *Implementation Science*, 11(1), pp. 1–17. doi: 10.1186/s13012-016-0422-6.

Brook, R. D., Rajagopalan, S., Pope, C. A., Brook, J. R., Bhatnagar, A., Diez-Roux, A. V, Holguin, F., Hong, Y., Luepker, R. V, Mittleman, M. A., Peters, A., Siscovick, D., Smith, S. C., Whitsel, L., Kaufman, J. D. and on behalf of the American Heart Association Council on Epidemiology and Prevention and Council on Nutrition, Physical Activity and Metabolism, C. on the K. in C. D. (2010) 'Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement From the American Heart Association ', *Circulation* , 121(21), pp. 2331–2378. doi: 10.1161/CIR.0b013e3181dbece1.

Burnett, R. T., Pope III, C. A., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., Shin, H. H., Singh, G., Hubbell, B., Brauer, M., Anderson, H. R., Smith, K. R., Balmes, J. R., Bruce, N. G. and Kan, H. (2014) 'An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure', *Environmental Health Perspectives (Online)*. Research Triangle Park: National Institute of Environmental Health Sciences, 122(4), p. 397. doi: http://dx.doi.org/10.1289/ehp.1307049.

Burroughs Peña, M., Romero, K. M., Velazquez, E. J., Davila-Roman, V. G., Gilman, R. H., Wise, R. A., Miranda, J. J. and Checkley, W. (2015) 'Relationship between daily exposure to biomass fuel smoke and blood pressure in high-altitude Peru', *Hypertension*, 65(5), pp. 1134–1140. doi: 10.1161/HYPERTENSIONAHA.114.04840.

Burwen, J. and Levine, D. I. (2012) 'A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana', *Energy for Sustainable Development*, 16(3), pp. 328–338. doi: 10.1016/j.esd.2012.04.001.

Carter, E. M., Shan, M., Yang, X., Li, J. and Baumgartner, J. (2014) 'Pollutant emissions and energy efficiency of chinese gasifier cooking stoves and implications for future intervention studies', *Environmental Science & Technology*. American Chemical Society, 48(11), pp. 6461–6467. doi: 10.1021/es405723w.

CDM – Executive Board (2010) *Clean Development Mechanism Project Design Document Form: Improved Cook Stoves CDM project of JSMBT, Version: 1.1*. Available at: https://cdm.unfccc.int/filestorage/7/V/2/7V2LCKYM6B1RT8O4309SJIQZEAXWPH/PDD_JSMBT.pdf?t=NGN8bnk2b2V2fDCiEOGIkkZQ3UzFQEO3J504 (Accessed: 20 July 2012).

CDM Executive Board (2006) *Project Design Document Form (CDM-SSC-PDD) - Version 03*. RPRT. UNFCCC. Available at: https://cdm.unfccc.int/filestorage/J/N/U/JNUDT2M91LHKY7PXF65C40ZISRQ8B3/PDD_SAMUHA.pdf?t=TFR8bzNoc3kwfDDGcMLSUt6_R4UC4qw2KVLm.

CDM Executive Board (no date) *Annex 2: Guidelines on the consideration of Suppressed Demand in*

*CDM methodologies (Version 02.0). EB 68 Report Annex 2*. Bonn, Germany, Germany. Available at: https://cdm.unfccc.int/Reference/Guidclarif/meth/meth_guid41.pdf.

Cecelski, E. (1987) ‘Energy and rural women’s work: crisis, response and policy alternatives’, *International Labour Review*, 126(1).

Central Power Research Institute (2010) *Performance test of wood burning stove*. RPRT. Bangalore, India. Available at: http://chulika.co.in/wp-content/uploads/2010/07/cpri_chulika_20jan102.pdf (Accessed: 12 August 2011).

Chafe, Z., Brauer, M., Klimont, Z., Van Dingenen, R., Mehta, S., Rao, S., Riahi, K., Dentener, F. and Smith, K. (2014) ‘Household cooking with solid fuels contributes to ambient PM2.5 air pollution and the burden of disease’, *Environ Health Perspect*, 122, pp. 1314–1320. doi: http://dx.doi.org/10.1289/ehp.1206340.

Chambers, R. and Conway, G. R. (1992) *Sustainable Rural Livelihoods: Practical Concepts for the 21st Century, IDS Discussion Paper no. 296*. RPRT. Brighton, UK: University of Sussex Institute of Development Studies.

Chandar, M. and Tandon, V. (2004) *LPG: A Key to Empowerment of Hill Women*. Himachal Pradesh, India, India.

Chengappa, C., Edwards, R., Bajpai, R., Shields, K. N. and Smith, K. R. (2007) ‘Impact of improved cookstoves on indoor air quality in the Bundelkhand region in India’, *Energy for Sustainable Development*, 11(2), pp. 33–44. doi: 10.1016/S0973-0826(08)60398-1.

Chiquet, C. (2015) *Project database updated with 100 new projects, Global Alliance for Clean Cookstoves*. Available at: http://carbonfinanceforcookstoves.org/project-database-updated-with-100-new-projects/ (Accessed: 9 February 2015).

Chobanian, A. V, Bakris, G. L., Black, H. R., Cushman, W. C., Green, L. A., Izzo, J. L., Jones, D. W., Materson, B. J., Oparil, S., Wright, J. T., Roccella, E. J. and the National High Blood Pressure Education Program Coordinating Committee (2003) ‘Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure’, *Hypertension*, 42(6), pp. 1206–1252. doi: 10.1161/01.HYP.0000107251.49515.c2.

Chowdhury, M. S. H., Koike, M., Akther, S. and Miah, D. (2011) ‘Biomass fuel use, burning technique and reasons for the denial of improved cooking stoves by Forest User Groups of Rema-Kalenga Wildlife Sanctuary, Bangladesh’, *International Journal of Sustainable Development & World Ecology*. Taylor & Francis, 18(1), pp. 88–97. doi: 10.1080/13504509.2010.532906.

Clark, M. L., Bachand, A. M., Heiderscheidt, J. M., Yoder, S. A., Luna, B., Volckens, J., Koehler, K. A., Conway, S., Reynolds, S. J. and Peel, J. L. (2013) ‘Impact of a cleaner-burning cookstove intervention on blood pressure in Nicaraguan women’, *Indoor Air*, 23(2), pp. 105–114.

Clark, M. L., Bazemore, H., Reynolds, S. J., Heiderscheidt, J. M., Conway, S., Bachand, A. M., Volckens, J. and Peel, J. L. (2011) ‘A baseline evaluation of traditional cook stove smoke exposures and indicators of cardiovascular and respiratory health among Nicaraguan women’, *International Journal of Occupational and Environmental Health*, 17(2), pp. 113–121.

Clark, M. L., Peel, J. L., Balakrishnan, K., Breysse, P. N., Chillrud, S. N., Naeher, L. P., Rodes, C. E., Vette, A. F. and Balbus, J. M. (2013) ‘Health and Household Air Pollution from Solid Fuel Use: The Need for Improved Exposure Assessment’, *Environmental Health Perspectives*, 121(10).

Clark, M. L., Peel, J. L., Burch, J. B., Nelson, T. L., Robinson, M. M., Conway, S., Bachand, A. M. and Reynolds, S. J. (2009) ‘Impact of improved cookstoves on indoor air pollution and adverse health effects among Honduran women’, *International Journal of Environmental Health Research*. Taylor & Francis, 19(5), p. 357. doi: 10.1080/09603120902842705.

Clean Development Mechanism (no date) *CDM Rulebook, What is additionality?* Available at: http://www.cdmrulebook.org/165.html (Accessed: 3 November 2016).

Coleman, A., Freeman, P., Steel, S. and Shennan, A. (2006) ‘Validation of the Omron 705IT (HEM-759-E) oscillometric blood pressure monitoring device according to the British Hypertension Society protocol’, *Blood Pressure Monitoring*, 11(1). Available at: http://journals.lww.com/bpmonitoring/Fulltext/2006/02000/Validation_of_the_Omron_705IT__HEM_759_E_.6.aspx.

Commodore, A. A., Zhang, J. J., Chang, Y., Hartinger, S. M., Lanata, C. F., Mäusezahl, D., Gil, A. I., Hall, D. B., Aguilar-Villalobos, M., Vena, J. E., Wang, J.-S. and Naeher, L. P. (2013) ‘Concentrations of urinary 8-hydroxy-2’-deoxyguanosine and 8-isoprostane in women exposed to woodsmoke in a cookstove intervention study in San Marcos, Peru’, *Environment international*, 60, pp. 112–22. doi: 10.1016/j.envint.2013.08.013.

Concato, J., Shah, N. and Horwitz, R. I. (2000) ‘Randomized, Controlled Trials, Observational Studies, and the Hierarchy of Research Designs’, *N Engl J Med*. Massachusetts Medical Society, 342(25), pp. 1887–1892. doi: 10.1056/NEJM200006223422507.

Crowe, T. L. (2013) ‘The potential of the CDM to deliver pro-poor benefits’, *Climate Policy*, 13(1), pp. 58–79. Available at: http://ezproxy.library.ubc.ca/login?url=http://search.proquest.com.ezproxy.library.ubc.ca/docview/1468444369?accountid=14656.

Crutzen, P. J. and Andreae, M. O. (1990) ‘Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles’, *Science*. American Association for the Advancement of Science, 250(4988), pp. 1669–1678. Available at: http://www.jstor.org/stable/2878539.

Cynthia, A. A., Edwards, R. D., Johnson, M., Zuk, M., Rojas, L., Jiménez, R. D., Riojas-Rodriguez, H. and Masera, O. (2008) ‘Reduction in personal exposures to particulate matter and carbon monoxide as a result of the installation of a Patsari improved cook stove in Michoacan Mexico.’, *Indoor air*, 18(2), pp. 93–105. doi: 10.1111/j.1600-0668.2007.00509.x.

Dechambre, G. (1983) ‘Les foyers ameliores au Sahel: bilan et perspectives’, in *Manibog, Fernando R. Improved Cooking Stoves in Developing Countries, Problems and Opportunities. Annual Review of Energ, 1984. 9: 199-227*. Marseille (France). Available at: http://agris.fao.org/agris-search/search.do?recordID=XF2015039206#.V8hdpKk9jEU.mendeley (Accessed: 1 September 2016).

Dherani, M., Pope, D., Mascarenhas, M., Smith, K. R., Weber, M. and Bruce, N. (2008) ‘Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis’, *Bulletin of the World Health Organization*. World Health Organization, 86(5), pp. 390–398. doi: 10.2471/BLT.07.044529.

Díaz, E., Smith-Sivertsen, T., Pope, D., Lie, R. T., Díaz, A., McCracken, J., Arana, B., Smith, K. R. and Bruce, N. (2007) ‘Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomised stove intervention trial’, *Journal of Epidemiology and Community Health* , 61(1), pp. 74–79. doi: 10.1136/jech.2006.043133.

Dutta, A., Ray, M. R., Mukherjee, B. and Chowdhury, S. (2013) 'Increased cardiovascular risk in association with chronic airflow obstruction among premenopausal rural women of india who cook exclusively with biomass', *Air Quality, Atmosphere, & Health*, 6(1), pp. 307–315. doi: 10.1007/s11869-012-0173-8.

Dutta, K., Shields, K. N., Edwards, R. and Smith, K. R. (2007) 'Impact of improved biomass cookstoves on indoor air quality near Pune, India', *Energy for Sustainable Development*, 11(2), pp. 19–32. doi: 10.1016/S0973-0826(08)60397-X.

Ecosystem Marketplace and Global Alliance for Clean Cookstoves (2014) *Results report 2013: sharing progress on the path to adoption of cleaner and more efficient cooking solutions*. Washington D.C. Available at: http://cleancookstoves.org/resources/285.html.

ECOWAS Centre for Renewable Energy and Energy Efficiency (2014) *West African Clean Cooking Alliance*. Available at: http://www.ecreee.org/page/west-african-clean-cooking-alliance-wacca (Accessed: 16 November 2014).

Edwards, R. D., Liu, Y., He, G., Yin, Z., Sinton, J., Peabody, J. and Smith, K. R. (2007) 'Household CO and PM measured as part of a review of China's National Improved Stove Program', *Indoor Air*. Blackwell Publishing Ltd, 17(3), pp. 189–203. doi: 10.1111/j.1600-0668.2007.00465.x.

Ellegård, A. (1997) 'Tears while Cooking: An Indicator of Indoor Air Pollution and Related Health Effects in Developing Countries', *Environmental Research*, 75(1), pp. 12–22. doi: http://dx.doi.org/10.1006/enrs.1997.3771.

Fair Climate Network (2012) *Baseline Information: Koppal Taluk, Karnataka*. RPRT. Karnataka.

Falkingham, J. and Namazie, C. (2002) *Measuring health and poverty: a review of approaches to identifying the poor*. London. Available at: http://r4d.dfid.gov.uk/PDF/Outputs/HOppsIssuesPaperFalkingham.pdf.

Feigin, V. L., Krishnamurthi, R. V, Parmar, P., Norrving, B., Mensah, G. A., Bennett, D. A., Barker-Collo, S., Moran, A. E., Sacco, R. L., Truelsen, T., Davis, S., Pandian, J. D., Naghavi, M., Forouzanfar, M. H., Nguyen, G., Johnson, C. O., Vos, T., Meretoja, A., Murray, C. J. L. and Roth, G. A. (2015) 'Update on the Global Burden of Ischemic and Hemorrhagic Stroke in 1990-2013: The GBD 2013 Study', *Neuroepidemiology*, 45(3), pp. 161–176. Available at: http://www.karger.com/DOI/10.1159/000441085.

Fitzgerald, C., Aguilar-Villalobos, M., Eppler, A. R., Dorner, S. C., Rathbun, S. L. and Naeher, L. P. (2012) 'Testing the effectiveness of two improved cookstove interventions in the Santiago de Chuco Province of Peru.', *The Science of the total environment*, 420, pp. 54–64. doi: 10.1016/j.scitotenv.2011.10.059.

Foell, W., Pachauri, S., Spreng, D. and Zerriffi, H. (2011) 'Household cooking fuels and technologies in developing economies', *Energy Policy*, 39(12), pp. 7487–7496. doi: 10.1016/j.enpol.2011.08.016.

Food and Agricultural Organization of the United Nations, The International Fund for Agricultural Development and The International Labour Office (2010) *Gender dimensions of agricultural and rural employment: Differentiated pathways out of poverty: Status, trends and gaps*. RPRT. Rome.

Foote, E. M., Gieraltowski, L., Ayers, T., Sadumah, I., Hamidah Faith, S., Silk, B. J., Cohen, A. L., Were, V., Hughes, J. M. and Quick, R. E. (2013) 'Impact of locally-produced, ceramic cookstoves on respiratory disease in children in rural western Kenya', *American Journal of Tropical Medicine and Hygiene*, 88.1, pp. 132–137.

Forouzanfar, M. H., Alexander, L., Anderson, H. R., Bachman, V. F., Biryukov, S., Brauer, M., Burnett, R., Casey, D., Coates, M. M., Cohen, A., Delwiche, K., Estep, K., Frostad, J. J., KC, A., Kyu, H. H., Moradi-Lakeh, M., Ng, M., Slepak, E. L., Thomas, B. A., Wagner, J., Aasvang, G. M., Abbafati, C., Ozgoren, A. A., Abd-Allah, F., Abera, S. F., Aboyans, V., Abraham, B., Abraham, J. P., Abubakar, I., Abu-Rmeileh, N. M. E., Aburto, T. C., Achoki, T., Adelekan, A., Adofo, K., Adou, A. K., Adsuar, J. C., Afshin, A., Agardh, E. E., Al Khabouri, M. J., Al Lami, F. H., Alam, S. S., Alasfoor, D., Albittar, M. I., Alegretti, M. A., Aleman, A. V, Alemu, Z. A., Alfonso-Cristancho, R., Alhabib, S., Ali, R., Ali, M. K., Alla, F., Allebeck, P., Allen, P. J., Alsharif, U., Alvarez, E., Alvis-Guzman, N., Amankwaa, A. A., Amare, A. T., Ameh, E. A., Ameli, O., Amini, H., Ammar, W., Anderson, B. O., Antonio, C. A. T., Anwari, P., Cunningham, S. A., Arnlöv, J., Arsenijevic, V. S. A., Artaman, A., Asghar, R. J., Assadi, R., Atkins, L. S., Atkinson, C., Avila, M. A., Awuah, B., Badawi, A., Bahit, M. C., Bakfalouni, T., Balakrishnan, K., Balalla, S., Balu, R. K., Banerjee, A., Barber, R. M., Barker-Collo, S. L., Barquera, S., Barregard, L., Barrero, L. H., Barrientos-Gutierrez, T., Basto-Abreu, A. C., Basu, A., Basu, S., Basulaiman, M. O., Ruvalcaba, C. B., Beardsley, J., Bedi, N., Bekele, T., Bell, M. L., Benjet, C., Bennett, D. A., Benzian, H., Bernabé, E., Beyene, T. J., Bhala, N., Bhalla, A., Bhutta, Z. A., Bikbov, B., Abdulhak, A. A. Bin, Blore, J. D., Blyth, F. M., Bohensky, M. A., Başara, B. B., Borges, G., Bornstein, N. M., Bose, D., Boufous, S., Bourne, R. R., Brainin, M., Brazinova, A., Breitborde, N. J., Brenner, H., Briggs, A. D. M., Broday, D. M., Brooks, P. M., Bruce, N. G., Brugha, T. S., Brunekreef, B., Buchbinder, R., Bui, L. N., Bukhman, G., Bulloch, A. G., Burch, M., Burney, P. G. J., Campos-Nonato, I. R., Campuzano, J. C., Cantoral, A. J., Caravanos, J., Cárdenas, R., Cardis, E., Carpenter, D. O., Caso, V., Castañeda-Orjuela, C. A., Castro, R. E., Catalá-López, F., Cavalleri, F., Çavlin, A., Chadha, V. K., Chang, J., Charlson, F. J., Chen, H., Chen, W., Chen, Z., Chiang, P. P., Chimed-Ochir, O., Chowdhury, R., Christophi, C. A., Chuang, T.-W., Chugh, S. S., Cirillo, M., Claßen, T. K., Colistro, V., Colomar, M., Colquhoun, S. M., Contreras, A. G., Cooper, C., Cooperrider, K., Cooper, L. T., Coresh, J., Courville, K. J., Criqui, M. H., Cuevas-Nasu, L., Damsere-Derry, J., Danawi, H., Dandona, L., Dandona, R., Dargan, P. I., Davis, A., Davitoiu, D. V, Dayama, A., de Castro, E. F., De la Cruz-Góngora, V., De Leo, D., de Lima, G., Degenhardt, L., del Pozo-Cruz, B., Dellavalle, R. P., Deribe, K., Derrett, S., Jarlais, D. C. Des, Dessalegn, M., deVeber, G. A., Devries, K. M., Dharmaratne, S. D., Dherani, M. K., Dicker, D., Ding, E. L., Dokova, K., Dorsey, E. R., Driscoll, T. R., Duan, L., Durrani, A. M., Ebel, B. E., Ellenbogen, R. G., Elshrek, Y. M., Endres, M., Ermakov, S. P., Erskine, H. E., Eshrati, B., Esteghamati, A., Fahimi, S., Faraon, E. J. A., Farzadfar, F., Fay, D. F. J., Feigin, V. L., Feigl, A. B., Fereshtehnejad, S.-M., Ferrari, A. J., Ferri, C. P., Flaxman, A. D., Fleming, T. D., Foigt, N., Foreman, K. J., Paleo, U. F., Franklin, R. C., Gabbe, B., Gaffikin, L., Gakidou, E., Gamkrelidze, A., Gankpé, F. G., Gansevoort, R. T., García-Guerra, F. A., Gasana, E., Geleijnse, J. M., Gessner, B. D., Gething, P., Gibney, K. B., Gillum, R. F., Ginawi, I. A. M., Giroud, M., Giussani, G., Goenka, S., Goginashvili, K., Dantes, H. G., Gona, P., de Cosio, T. G., González-Castell, D., Gotay, C. C., Goto, A., Gouda, H. N., Guerrant, R. L., Gugnani, H. C., Guillemin, F., Gunnell, D., Gupta, R., Gupta, R., Gutiérrez, R. A., Hafezi-Nejad, N., Hagan, H., Hagstromer, M., Halasa, Y. A., Hamadeh, R. R., Hammami, M., Hankey, G. J., Hao, Y., Harb, H. L., Haregu, T. N., Haro, J. M., Havmoeller, R., Hay, S. I., Hedayati, M. T., Heredia-Pi, I. B., Hernandez, L., Heuton, K. R., Heydarpour, P., Hijar, M., Hoek, H. W., Hoffman, H. J., Hornberger, J. C., Hosgood, H. D., Hoy, D. G., Hsairi, M., Hu, G., Hu, H., Huang, C., Huang, J. J., Hubbell, B. J., Huiart, L., Husseini, A., Iannarone, M. L., Iburg, K. M., Idrisov, B. T., Ikeda, N., Innos, K., Inoue, M., Islami, F., Ismayilova, S., Jacobsen, K. H., Jansen, H. A., Jarvis, D. L., Jassal, S. K., Jauregui, A., Jayaraman, S., Jeemon, P., Jensen, P. N., Jha, V., Jiang, F., Jiang, G., Jiang, Y., Jonas, J. B., Juel, K., Kan, H., Roseline, S. S. K., Karam, N. E., Karch, A., Karema, C. K., Karthikeyan, G., Kaul, A., Kawakami, N., Kazi, D. S., Kemp, A. H., Kengne, A. P., Keren, A., Khader, Y. S., Khalifa, S. E. A. H., Khan, E. A., Khang, Y.-H., Khatibzadeh, S., Khonelidze, I., Kieling, C., Kim, D., Kim, S., Kim, Y., Kimokoti, R. W., Kinfu, Y., Kinge, J. M., Kissela, B. M., Kivipelto, M., Knibbs, L. D., Knudsen, A. K., Kokubo, Y., Kose, M. R., Kosen, S., Kraemer, A., Kravchenko, M., Krishnaswami, S., Kromhout, H., Ku, T., Defo, B. K., Bicer, B. K., Kuipers, E. J., Kulkarni, C., Kulkarni, V. S., Kumar, G. A., Kwan, G. F., Lai, T., Balaji, A. L., Lalloo, R., Lallukka, T., Lam, H., Lan, Q., Lansingh, V. C., Larson, H. J., Larsson, A., Laryea, D. O., Lavados, P. M., Lawrynowicz, A. E., Leasher, J. L., Lee, J.-T., Leigh, J., Leung, R., Levi, M., Li, Y., Li, Y., Liang, J., Liang, X., Lim, S. S., Lindsay, M. P., Lipshultz, S. E., Liu, S., Liu, Y., Lloyd, B. K., Logroscino, G., London, S. J., Lopez, N., Lortet-Tieulent, J., Lotufo, P. A., Lozano, R., Lunevicius, R., Ma, J., Ma, S., Machado, V. M. P., MacIntyre, M. F., Magis-Rodriguez, C., Mahdi, A. A., Majdan, M., Malekzadeh, R., Mangalam, S., Mapoma, C. C., Marape, M., Marcenes, W., Margolis, D. J., Margono, C., Marks, G. B., Martin, R. V, Marzan, M. B., Mashal, M. T., Masiye, F., Mason-Jones, A. J., Matsushita, K., Matzopoulos, R., Mayosi, B. M., Mazorodze, T. T., McKay, A. C., McKee, M., McLain, A., Meaney, P. A., Medina, C., Mehndiratta, M. M., Mejia-Rodriguez, F., Mekonnen, W., Melaku, Y. A., Meltzer, M., Memish, Z. A., Mendoza, W., Mensah, G. A., Meretoja, A., Mhimbira, F. A., Micha, R., Miller, T. R., Mills, E. J., Misganaw, A., Mishra, S., Ibrahim, N. M., Mohammad, K. A., Mokdad, A. H., Mola, G. L., Monasta, L., Hernandez, J. C. M., Montico, M., Moore, A. R., Morawska, L., Mori, R., Moschandreas, J., Moturi, W. N., Mozaffarian, D., Mueller, U. O., Mukaigawara, M., Mullany, E. C., Murthy, K. S., Naghavi, M., Nahas, Z., Naheed, A., Naidoo, K. S., Naldi, L., Nand, D., Nangia, V., Narayan, K. V., Nash, D., Neal, B., Nejjari, C., Neupane, S. P., Newton, C. R., Ngalesoni, F. N., de Dieu Ngirabega, J., Nguyen, G., Nguyen, N. T., Nieuwenhuijsen, M. J., Nisar, M. I., Nogueira, J. R., Nolla, J. M., Nolte, S., Norheim, O. F., Norman, R. E., Norrving, B., Nyakarahuka, L., Oh, I.-H., Ohkubo, T., Olusanya, B. O., Omer, S. B., Opio, J. N., Orozco, R., Pagcatipunan, R. S., Pain, A. W., Pandian, J. D., Panelo, C. I. A., Papachristou, C., Park, E.-K., Parry, C. D., Caicedo, A. J. P., Patten, S. B., Paul, V. K., Pavlin, B. I., Pearce, N., Pedraza, L. S., Pedroza, A., Stokic, L. P., Pekericli, A., Pereira, D. M., Perez-Padilla, R., Perez-Ruiz, F., Perico, N., Perry, S. A. L., Pervaiz, A., Pesudovs, K., Peterson, C. B., Petzold, M., Phillips, M. R., Phua, H. P., Plass, D., Poenaru, D., Polanczyk, G. V, Polinder, S., Pond, C. D., Pope, C. A., Pope, D., Popova, S., Pourmalek, F., Powles, J., Prabhakaran, D., Prasad, N. M., Qato, D. M., Quezada, A. D., Quistberg, D. A. A., Racapé, L., Rafay, A., Rahimi, K., Rahimi-Movaghar, V., Rahman, S. U., Raju, M., Rakovac, I., Rana, S. M., Rao, M., Razavi, H., Reddy, K. S., Refaat, A. H., Rehm, J., Remuzzi, G., Ribeiro, A. L., Riccio, P. M., Richardson, L., Riederer, A., Robinson, M., Roca, A., Rodriguez, A., Rojas-Rueda, D., Romieu, I., Ronfani, L., Room, R., Roy, N., Ruhago, G. M., Rushton, L., Sabin, N., Sacco, R. L., Saha, S., Sahathevan, R., Sahraian, M. A., Salomon, J. A., Salvo, D., Sampson, U. K., Sanabria, J. R., Sanchez, L. M., Sánchez-Pimienta, T. G., Sanchez-Riera, L., Sandar, L., Santos, I. S., Sapkota, A., Satpathy, M., Saunders, J. E., Sawhney, M., Saylan, M. I., Scarborough, P., Schmidt, J. C., Schneider, I. J. C., Schöttker, B., Schwebel, D. C., Scott, J. G., Seedat, S., Sepanlou, S. G., Serdar, B., Servan-Mori, E. E., Shaddick, G., Shahraz, S., Levy, T. S., Shangguan, S., She, J., Sheikhbahaei, S., Shibuya, K., Shin, H. H., Shinohara, Y., Shiri, R., Shishani, K., Shiue, I., Sigfusdottir, I. D., Silberberg, D. H., Simard, E. P., Sindi, S., Singh, A., Singh, G. M., Singh, J. A., Skirbekk, V., Sliwa, K., Soljak, M., Soneji, S., Søreide, K., Soshnikov, S., Sposato, L. A., Sreeramareddy, C. T., Stapelberg, N. J. C., Stathopoulou, V., Steckling, N., Stein, D. J., Stein, M. B., Stephens, N., Stöckl, H., Straif, K., Stroumpoulis, K., Sturua, L., Sunguya, B. F., Swaminathan, S., Swaroop, M., Sykes, B. L., Tabb, K. M., Takahashi, K., Talongwa, R. T., Tandon, N., Tanne, D., Tanner, M., Tavakkoli, M., Te Ao, B. J., Teixeira, C. M., Téllez Rojo, M. M., Terkawi, A. S., Texcalac-Sangrador, J. L., Thackway, S. V, Thomson, B., Thorne-Lyman, A. L., Thrift, A. G., Thurston, G. D., Tillmann, T., Tobollik, M., Tonelli, M., Topouzis, F., Towbin, J. A., Toyoshima, H., Traebert, J., Tran, B. X., Trasande, L., Trillini, M., Trujillo, U., Dimbuene, Z. T., Tsilimbaris, M., Tuzcu, E. M., Uchendu, U. S., Ukwaja, K. N., Uzun, S. B., van de Vijver, S., Van Dingenen, R., van Gool, C. H., van Os, J., Varakin, Y. Y., Vasankari, T. J., Vasconcelos, A. M. N., Vavilala, M. S., Veerman, L. J., Velasquez-Melendez, G., Venketasubramanian, N., Vijayakumar, L., Villalpando, S., Violante, F. S., Vlassov, V. V., Vollset, S. E., Wagner, G. R., Waller, S. G., Wallin, M. T., Wan, X., Wang, H., Wang, J., Wang, L., Wang, W., Wang, Y., Warouw, T. S., Watts, C. H., Weichenthal, S., Weiderpass, E., Weintraub, R. G., Werdecker, A., Wessells, K. R., Westerman, R., Whiteford, H. A., Wilkinson, J. D., Williams, H. C., Williams, T. N., Woldeyohannes, S. M., Wolfe, C. D. A., Wong, J. Q., Woolf, A. D., Wright, J. L., Wurtz, B., Xu, G., Yan, L. L., Yang, G., Yano, Y., Ye, P., Yenesew, M., Yentür, G. K., Yip, P., Yonemoto, N., Yoon, S.-J., Younis, M. Z., Younoussi, Z., Yu, C., Zaki, M. E., Zhao, Y., Zheng, Y., Zhou, M., Zhu, J., Zhu, S., Zou, X., Zunt, J. R., Lopez, A. D., Vos, T. and Murray, C. J. (2015) ‘Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013’, *The Lancet*. doi: 10.1016/S0140-6736(15)00128-2.

Freeman, O. E. and Zerriffi, H. (2014) ‘How you count carbon matters: implications of differing cookstove carbon credit methodologies for climate and development cobenefits’, *Environmental Science & Technology*. American Chemical Society, 48(24), pp. 4112–14120. doi: 10.1021/es503941u.

Fullerton, D. G., Bruce, N. and Gordon, S. B. (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), pp. 843–851.

García-Frapolli, E., Schilmann, A., Berrueta, V. M., Riojas-Rodríguez, H., Edwards, R. D., Johnson, M., Guevara-Sanginés, A., Armendariz, C. and Masera, O. (2010) ‘Beyond fuelwood savings: Valuing the economic benefits of introducing improved biomass cookstoves in the Purépecha region of Mexico’, *Ecological Economics*, 69(12), pp. 2598–2605. doi: 10.1016/j.ecolecon.2010.08.004.

Gavaldão, M., Battye, W., Grapeloup, M. and François, Y. (2012) ‘Suppressed demand and the carbon markets: does development have to become dirty before it qualifies to become clean?’, *Field Actions Science Reports*, (7).

Gill, J. (1987) ‘Improved stoves in developing countries’, *Energy Policy*, 15(2), pp. 135–144. doi: http://dx.doi.org/10.1016/0301-4215(87)90121-2.

Gillespie, V. H. (1979) ‘Rural Women’s Time Use’, *Studies in family planning*. Population Council, 10(11/12, Learning About Rural Women), pp. 383–384. Available at: http://www.jstor.org.ezproxy.library.ubc.ca/stable/1966097.

Global Alliance for Clean Cookstoves (no date a) *Carbon Finance: The Opportunity*. Available at: http://carbonfinanceforcookstoves.org/carbon-finance/the-opportunity/ (Accessed: 20 July 2015).

Global Alliance for Clean Cookstoves (no date b) *Connect With Testing Centers*. Available at: http://cleancookstoves.org/technology-and-fuels/testing/centers.html (Accessed: 22 July 2015).

Global Alliance for Clean for Cookstoves (2013) *Alliance Mission and Goals*. United Nations Foundation. Available at: http://www.cleancookstoves.org/the-alliance/ (Accessed: 20 November 2014).

Global Alliance for Clean for Cookstoves (2014a) *Clean Cookstoves and Fuels: A Catalog of Carbon Offset Projects and Advisory Service Providers*. Washington D.C. Available at: http://cleancookstoves.org/binary-data/RESOURCE/file/000/000/381-1.pdf.

Global Alliance for Clean for Cookstoves (2014b) *The Water Boiling Test, Version 4.2.3*. Available at: https://cleancookstoves.org/binary-data/DOCUMENT/file/000/000/399-1.pdf (Accessed: 14 January 2016).

Global Alliance for Clean for Cookstoves (2016) *Impact Areas: Livelihoods*.

Global Alliance for Clean for Cookstoves and Ecosystem Marketplace (2015) *Results report 2014: sharing progress on the path to adoption of clean and efficient cooking solutions*. Washington D.C. Available at: file:///C:/Users/User/Downloads/2015cookstovesreport-v2 (2).pdf.

*Gold Standard Local Stakeholder Consultation Report* (2009). India. Available at: https://mer.markit.com/brreg/PublicReport.action?getDocumentById=true&document_id=103000000004265 (Accessed: 5 August 2015).

Gordon, S. B., Bruce, N. G., Grigg, J., Hibberd, P. L., Kurmi, O. P., Lam, K. H., Mortimer, K., Asante, K. P., Balakrishnan, K., Balmes, J., Bar-Zeev, N., Bates, M. N., Breysse, P. N., Buist, S., Chen, Z., Havens, D., Jack, D., Jindal, S., Kan, H., Mehta, S., Moschovis, P., Naeher, L., Patel, A., Perez-Padilla, R., Pope, D., Rylance, J., Semple, S. and Martin II, W. J. (2014) 'Respiratory risks from household air pollution in low and middle income countries', *The Lancet Respiratory Medicine*, 2(10), pp. 823–860. doi: http://dx.doi.org/10.1016/S2213-2600(14)70168-7.

Government of India (2011) *Census of India 2011*. New Delhi. Available at: http://www.censusindia.gov.in/.

Granderson, J., Sandhu, J. S., Vasquez, D., Ramirez, E. and Smith, K. R. (2009) 'Fuel use and design analysis of improved woodburning cookstoves in the Guatemalan Highlands', *Biomass and Bioenergy*, 33(2), pp. 306–315. doi: 10.1016/j.biombioe.2008.06.003.

Grieshop, A. P., Marshall, J. D. and Kandlikar, M. (2011) 'Health and climate benefits of cookstove replacement options', *Clean Cooking Fuels and Technologies in Developing Economies*, 39(12), pp. 7530–7542. doi: http://dx.doi.org/10.1016/j.enpol.2011.03.024.

Grieshop, A. P., Reynolds, C., Kandlikar, M. and Dowlatabadi, H. (2009) 'A black-carbon mitigation wedge', *Nature Geosci*. Nature Publishing Group, 2(8), pp. 533–534. Available at: http://dx.doi.org/10.1038/ngeo595.

Habermehl, H. (2007) *Economic evaluation of the improved household cooking stove dissemination programmer in Uganda*. RPRT. Eschborn: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). Available at: http://www.energytoolbox.org/cookstoves/Resources/M+E/M+E1-Cost-Benefit-Analysis-Uganda-2007.pdf.

Hankey, S., Sullivan, K., Kinnick, A., Koskey, A., Grande, K., Davidson, J. H. and Marshall, J. D. (2015) 'Using objective measures of stove use and indoor air quality to evaluate a cookstove intervention in rural Uganda', *Energy for Sustainable Development*, 25, pp. 67–74. doi: 10.1016/j.esd.2014.12.007.

Hanna, R., Duflo, E. and Greenstone, M. (2012) *Up in smoke: the influence of household behavior on the long-run impact of improved cooking stoves, NBER Working Paper No. 12-10*. RPRT. Cambridge, Massachusetts. Available at: http://www.nber.org/papers/w18033.

Heck, J. E., Marcotte, E. L., Argos, M., Parvez, F., Ahmed, A., Islam, T., Sarwar, G., Hasan, R., Ahsan, H. and Chen, Y. (2012) 'Betel quid chewing in rural Bangladesh: prevalence, predictors and relationship to blood pressure', *International Journal of Epidemiology* , 41(2), pp. 462–471. doi: 10.1093/ije/dyr191.

Horrell, S., Johnson, H. and Mosley, P. (2008) *Work, female empowerment and economic development*. London: Routledge.

Hosgood, H Dean, I., Boffetta, P., Greenland, S., Lee, Y.-C. A., McLaughlin, J., Seow, A., Duell, E. J., Andrew, A. S. and Zaridze, D. (2010) 'In-Home Coal and Wood Use and Lung Cancer Risk: A Pooled Analysis of the International Lung Cancer Consortium', *Environ Health Perspect*, 118(12), pp. 1743–1747. doi: 10.1289/ehp.1002217.

Hutton, G., Rehfuess, E. and Tediosi, F. (2007) 'Evaluation of the costs and benefits of interventions to reduce indoor air pollution', *Energy for Sustainable Development*, 11(4), pp. 34–43. doi: 10.1016/S0973-0826(08)60408-1.

Hutton, G., Rehfuess, E., Tediosi, F. and Weiss, S. (2006) *Evaluation of the costs and benefits of household energy and health interventions at global and regional levels*. Geneva, Switzerland, Switzerland. Available at: http://www.who.int/indoorair/publications/household_energy_health_intervention.pdf.

Ilahi, N. and Grimard, F. (2000) 'Public Infrastructure and Private Costs: Water Supply and Time Allocation of Women in Rural Pakistan', *Economic Development and Cultural Change*. The University of Chicago Press, 49(1), pp. 45–75. doi: 10.1086/452490.

Indoor Air Pollution Team and Center for Entrepreneurship in International Health and Development (CEIHD) and University of California-Berkeley (2005) *Standard Operating Procedure: Installing Indoor Air Pollution Instruments in a Home (Version 5.1)*. Available at: http://berkeleyair.com/wp-content/publications/guidelines-for-instrument-placement.pdf (Accessed: 5 March 2011).

International Energy Agency (2002) *World Energy Outlook*. Paris, France.

International Energy Agency (2011) *Energy for All: Financing Access for the Poor, World Energy Outlook 2011*. RPRT. Paris, France: OECD/IEA.

International Energy Agency (2015) *Energy access database: WEO 2015 Biomass database*. Available at: http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/ (Accessed: 18 June 2016).

International Institute for Population Sciences (IIPS) and Macro (2016) *National Family Health Survey (NFHS-4), 2015–16: Karnataka, Key Findings*. Mumbai: IIPS. Available at: http://rchiips.org/nfhs/pdf/NFHS4/KA_FactSheet.pdf.

ISO (2012) *IWA 11:2012 - Guidelines for evaluating cookstove performance*. Switzerland.

ISO/TC 146/SC 3 (1993) *ISO 9835:1993 - Ambient air -- Determination of a black smoke index (reviewed 2010)*. Geneva, Switzerland. Available at: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=17715 (Accessed: 8 June 2015).

Jackson, S. C. (2009) 'Parallel pursuit of near-term and long-term climate mitigation', *Science*, 326(5952), pp. 526–527. doi: 10.1126/science.1177042.

Janssen, N. A. H., Gerlofs-Nijland, M., Lanki, T., Salonen, R. O., Cassee, F., Hoek, G., Fischer, P., Brunekreef, B. and Krzyzanowski, M. (2012) *Health effects of black carbon*. RPRT. Denmark: World Health Organization Regional Office for Europe.

Javed, F., Correa, F. O. B., Chotai, M., Tappuni, A. R. and Almas, K. (2010) 'Systemic conditions associated with areca nut usage: A literature review', *Scandinavian Journal of Public Health* . doi: 10.1177/1403494810379291.

Jetter, J. J. and Kariher, P. (2009) 'Solid-fuel household cook stoves: Characterization of performance and emissions', *Biomass and Bioenergy*, 33(2), pp. 294–305. doi: 10.1016/j.biombioe.2008.05.014.

Jha, V., Garcia-Garcia, G., Iseki, K., Li, Z., Naicker, S., Plattner, B., Saran, R., Wang, A. Y.-M. and Yang, C.-W. (2013) 'Chronic kidney disease: global dimension and perspectives', *The Lancet*, 382(9888), pp. 260–272. doi: 10.1016/S0140-6736(13)60687-X.

Johnson, M. and Chiang, R. (2015) 'Quantitative guidance for stove usage and performance to achieve health and environmental targets', *Environmental Health Perspectives*, 123, p. 820. Available at:

http://go.galegroup.com/ps/i.do?id=GALE|A425460955&v=2.1&u=ubcolumbia&it=r&p=HRCA&sw=w&asid=104ca49117d403fb1d4cbf1e52efde26.

Johnson, M., Edwards, R., Alatorre Frenk, C. and Masera, O. (2008) ‘In-field greenhouse gas emissions from cookstoves in rural Mexican households’, *Atmospheric Environment*, 42(6), pp. 1206–1222. doi: 10.1016/j.atmosenv.2007.10.034.

Johnson, M., Edwards, R. and Masera, O. (2010) ‘Improved stove programs need robust methods to estimate carbon offsets’, *Climatic Change*, 102, pp. 641–49. doi: 10.1007/s10584-010-9802-0.

Johnson, N. G. and Bryden, K. M. (2012) ‘Factors affecting fuelwood consumption in household cookstoves in an isolated rural West African village’, *Energy and Exergy Modelling of Advance Energy Systems*, 46(1), pp. 310–321. doi: 10.1016/j.energy.2012.08.019.

Just, B., Rogak, S. and Kandlikar, M. (2013) ‘Characterization of ultrafine particulate matter from traditional and improved biomass cookstoves’, *Environmental Science & Technology*, 47(7), pp. 3506–3512.

Kar, A., Rehman, I. H., Burney, J., Puppala, S. P., Suresh, R., Singh, L., Singh, V. K., Ahmed, T., Ramanathan, N. and Ramanathan, V. (2012) ‘Real-time assessment of black cCarbon pollution in Indian households due to traditional and improved biomass cookstoves’, *Environmental Science & Technology*, 46(5), pp. 2993–3000.

Kerr, B. T. (2014) *First of its kind carbon finance loan fund launched to spur clean cookstove and fuel market*. Available at: http://carbonfinanceforcookstoves.org/first-carbon-finance-loan-fund-announced/ (Accessed: 20 January 2015).

Kes, A. and Swaminathan, H. (2006) *Gender, Time Use, and Poverty in Sub-Saharan Africa: Chapter 2 - Gender and Time Poverty in Sub-Saharan Africa*. Washington D.C.

Khushk, W. A., Fatmi, Z., White, F. and Kadir, M. M. (2005) ‘Health and social impacts of improved stoves on rural women: a pilot intervention in Sindh, Pakistan.’, *Indoor air*, 15(5), pp. 311–6. doi: 10.1111/j.1600-0668.2005.00367.x.

Kishore, V. V. N. and Ramana, P. V (2002) ‘Improved cookstoves in rural India: how improved are they?: A critique of the perceived benefits from the National Programme on Improved Chulhas (NPIC)’, *Energy*, 27(1), pp. 47–63. doi: 10.1016/S0360-5442(01)00056-1.

Kossoy, A. and Ambrosi, P. (2010) *State and trends of the carbon market 2010*. Washington D.C. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/13401/55419.pdf?sequence=1.

Lambe, F., Jürisoo, M., Lee, C. and Johnson, O. (2015) ‘Can carbon finance transform household energy markets? A review of cookstove projects and programs in Kenya’, *Energy Research & Social Science*, 5(0), pp. 55–66. doi: http://dx.doi.org/10.1016/j.erss.2014.12.012.

Lee, C. M., Chandler, C., Lazarus, M. and Johnson, F. X. (2013) *Assessing the climate impacts of cookstove projects: issues in emissions accounting (Working Paper No. 2013-01)*. Stockholm, Sweden.

Lewis, J. J. and Pattanayak, S. K. (2012) ‘Who Adopts Improved Fuels and Cookstoves? A Systematic Review’, *Environ Health Perspect*. National Institute of Environmental Health Sciences. doi: 10.1289/ehp.1104194.

Lin, H. H., Murray, M., Cohen, T., Colijn, C. and Ezzati, M. (2008) ‘Effects of smoking and solid-fuel use on COPD, lung cancer, and tuberculosis in China: a time-based, multiple risk factor, modelling study', *Lancet*, 372(9648), pp. 1473–1483. doi: 10.1016/S0140-6736(08)61345-8.

Liu, J., Mauzerall, D. L., Chen, Q., Zhang, Q., Song, Y., Peng, W., Klimont, Z., Qiu, X., Zhang, S., Hu, M., Lin, W., Smith, K. R. and Zhu, T. (2016) 'Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source', *Proceedings of the National Academy of Sciences* , 113(28), pp. 7756–7761. doi: 10.1073/pnas.1604537113.

MacCarty, N., Ogle, D., Still, D., Bond, T. and Roden, C. (2008) 'A laboratory comparison of the global warming impact of five major types of biomass cooking stoves', *Energy for Sustainable Development*, 12(2), pp. 56–65. doi: 10.1016/S0973-0826(08)60429-9.

MacCarty, N., Still, D. and Ogle, D. (2010) 'Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance', *Energy for Sustainable Development*, 14(3), pp. 161–171. doi: 10.1016/j.esd.2010.06.002.

MacCarty, N., Still, D., Ogle, D. and Drouin, T. (2008) *Assessing Cook Stove Performance: Field and Lab Studies of Three Rocket Stoves Comparing the Open Fire and Traditional Stoves in Tamil Nadu, India on Measures of Time to Cook, Fuel Use, Total Emissions, and Indoor Air Pollution*. RPRT. Oregon, CA, USA: Aprovecho Research Center. Available at: http://aprovecho.org/web-content/publications/assets/India CCT Paper_1.7.08.pdf.

Malla, M. B., Bruce, N., Bates, E. and Rehfuess, E. (2011) 'Applying global cost-benefit analysis methods to indoor air pollution mitigation interventions in Nepal, Kenya and Sudan: Insights and challenges', *Clean Cooking Fuels and Technologies in Developing Economies*, 39(12), pp. 7518–7529. doi: 10.1016/j.enpol.2011.06.031.

Manibog, F. R. (1984) 'Improved cooking stoves in developing countries: problems and opportunities', *Annual Review of Energy*, 9(1), pp. 199–227. doi: 10.1146/annurev.eg.09.110184.001215.

Manibog, F. R. (1984) 'Improved cooking stoves in developing countries: problems and opportunities', *Annual Review of Energy*, 9(1), pp. 199–227. doi: 10.1146/annurev.eg.09.110184.001215.

Masera, O. R., Saatkamp, B. D. and Kammen, D. M. (2000) 'From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model', *World Development*, 28(12), pp. 2083–2103. doi: 10.1016/S0305-750X(00)00076-0.

McCracken, J. P., Smith, K. R., Diaz, A., Mittleman, M. A. and Schwartz, J. (2007) 'Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women', *Environ Health Perspect*. National Institute of Environmental Health Sciences, 115(7). Available at: http://dx.doi.org/10.1289/ehp.9888.

Michaelowa, A., Petersen, T., Feige, S., Galante, A., Thorne, S. and Pedersen, M. (2014) *Suppressed demand: A new climate finance approach to avoid carbon lock-in and deliver clean development to the world's poorest communities*. Geneva, Switzerland. Available at: http://asialeds.org/sites/default/files/resource/file/Climate-policy-brief-FINAL-lo-res.pdf.

Miller, K. A., Siscovick, D. S., Sheppard, L., Shepherd, K., Sullivan, J. H., Anderson, G. L. and Kaufman, J. D. (2007) 'Long-Term Exposure to Air Pollution and Incidence of Cardiovascular Events in Women', *New England Journal of Medicine*. Massachusetts Medical Society, 356(5), pp. 447–458. doi: 10.1056/NEJMoa054409.

Ministry of New and Renewable Energy (2012) *National Biomass Cookstoves Initiative*. Available at:

http://www.mnre.gov.in/schemes/decentralized-systems/national-biomass-cookstoves-initiative/ (Accessed: 16 November 2014).

Misra, A., Chowbey, P., Makkar, B., Vikram, N., Wasir, J., Chadha, D., Joshi, S. R., Sadikot, S., Gupta, R., Gulati, S. and Munjal, Y. (2009) *Consensus Statement for Diagnosis of Obesity, Abdominal Obesity and the Metabolic Syndrome for Asian Indians and Recommendations for Physical Activity, Medical and Surgical Management*. Available at: http://www.japi.org/february_2009/R-1.html (Accessed: 1 February 2016).

Muralidharan, V., Sussan, T. E., Limaye, S., Koehler, K., Williams, D. L., Rule, A. M., Juvekar, S., Breysse, P. N., Salvi, S. and Biswal, S. (2015) 'Field testing of alternative cookstove performance in a rural setting of western India.', *International journal of environmental research and public health*. Multidisciplinary Digital Publishing Institute, 12(2), pp. 1773–87. doi: 10.3390/ijerph120201773.

Mustafic, H., Jabre, P., Caussin, C. and Murad, M. H. (2012) 'Main Air Pollutants and Myocardial Infarction: A Systematic Review and Meta-analysis', *JAMA: Journal of the American Medical Association (Abstracts)*, 307(7), pp. 713–721.

Naeher, L. P., Brauer, M., Lipsett, M., Zelikoff, J. T., Simpson, C. D., Koenig, J. Q. and Smith, K. R. (2007) 'Woodsmoke health effects: a review', *Inhalation toxicology*. Informa Healthcare, 19(1), pp. 67–106. doi: 10.1080/08958370600985875.

Naeher, L. P., Leaderer, B. P. and Smith, K. R. (2000) 'Particulate matter and carbon monoxide in highland Guatemala: indoor and outdoor levels from traditional and improved wood stoves and gas stoves', *Indoor air*, 10(3), pp. 200–205.

Neupane, M., Basnyat, B., Fischer, R., Froeschl, G., Wolbers, M. and Rehfuess, E. A. (2015) 'Sustained use of biogas fuel and blood pressure among women in rural Nepal', *Environmental Research*, 136, pp. 343–351. doi: 10.1016/j.envres.2014.10.031.

Newby, D. E., Newby, D. E., Mannucci, P. M., Tell, G. S. and Baccarelli, A. A. (2014) 'Expert position paper on air pollution and cardiovascular disease', *European heart journal*. Oxford University Press, 36(2), pp. 83–93. doi: 10.1093/eurheartj/ehu458.

Norris, C., Goldberg, M. S., Marshall, J. D., Valois, M.-F., Pradeep, T., Narayanswamy, M., Jain, G., Sethuraman, K. and Baumgartner, J. (2016) 'A panel study of the acute effects of personal exposure to household air pollution on ambulatory blood pressure in rural Indian women', *Environmental research*, 147, pp. 331–42. doi: 10.1016/j.envres.2016.02.024.

Northcross, A. L., Hwang, N., Balakrishnan, K. and Mehta, S. (2015) 'Assessing exposures to household air pollution in public health research and program evaluation', *EcoHealth*, 12(1), pp. 57–67. doi: 10.1007/s10393-014-0990-3.

Oberdörster, G., Oberdörster, E. and Oberdörster, J. (2005) 'Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles', *Environmental Health Perspectives*. National Institue of Environmental Health Sciences, 113(7), pp. 823–839. doi: 10.1289/ehp.7339.

Ochieng, C. A., Tonne, C. and Vardoulakis, S. (2013) 'A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya', *Biomass and Bioenergy*, 58, pp. 258–266. doi: 10.1016/j.biombioe.2013.07.017.

Pachauri, S., Brew-Hammond, A., Barnes, D. F., Bouille, D. H., Gitonga, S., Modi, V., Prasad, G., Rath, A. and Zerriffi, H. (2012) 'Chapter 19 - Energy Access for Development', in *Global Energy Assessment* -

*Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 1401–1458. Available at: www.globalenergyassessment.org.

Painschab, M. S., Davila-Roman, V. G., Gilman, R. H., Vasquez-Villar, A. D., Pollard, S. L., Wise, R. A., Miranda, J. J., Checkley, W. and Group, C. C. S. (2013) 'Chronic exposure to biomass fuel is associated with increased carotid artery intima-media thickness and a higher prevalence of atherosclerotic plaque', *Heart* , 99(14), pp. 984–991. doi: 10.1136/heartjnl-2012-303440.

Pandey, S. and Yadama, G. N. (1992) 'Community development programs in Nepal: a Ttest of diffusion of innovation theory', *Social Service Review*. The University of Chicago Press, 66(4), pp. 582–597. Available at: http://www.jstor.org.ezproxy.library.ubc.ca/stable/30012488.

Parikh, J. and Laxmi, V. (2000) 'Biofuels, pollution and health linkages: a Ssurvey of rural Tamil Nadu', *Economic and Political Weekly*. Economic and Political Weekly, 35(47), pp. 4125–4137. Available at: http://www.jstor.org.ezproxy.library.ubc.ca/stable/4409979.

Patange, O. S., Ramanathan, N., Rehman, I. H., Tripathi, S. N., Misra, A., Kar, A., Graham, E., Singh, L., Bahadur, R. and Ramanathan, V. (2015) 'Reductions in Indoor Black Carbon Concentrations from Improved Biomass Stoves in Rural India', *Environmental Science & Technology*. American Chemical Society, 49(7), pp. 4749–4756. doi: 10.1021/es506208x.

Pennise, D., Brant, S., Agbeve, S. M., Quaye, W., Mengesha, F., Tadele, W. and Wofchuck, T. (2009) 'Indoor air quality impacts of an improved wood stove in Ghana and an ethanol stove in Ethiopia', *Energy for Sustainable Development*, 13(2), pp. 71–76. doi: 10.1016/j.esd.2009.04.003.

Pennise, D. M., Smith, K. R., Kithinji, J. P., Rezende, M. E., Raad, T. J., Zhang, J. and Fan, C. (2001) 'Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil', *Journal of Geophysical Research: Atmospheres*, 106(D20), pp. 24143–24155. doi: 10.1029/2000JD000041.

Person, B., Loo, J. D., Owuor, M., Ogange, L., Jefferds, M. E. D. and Cohen, A. L. (2012) '"It is good for my family's health and cooks food in a way that my heart loves": qualitative findings and implications for scaling up an improved cookstove project in rural Kenya.', *International journal of environmental research and public health*. Molecular Diversity Preservation International, 9(5), pp. 1566–80. doi: 10.3390/ijerph9051566.

Pickering, T. G., Hall, J. E., Appel, L. J., Falkner, B. E., Graves, J., Hill, M. N., Jones, D. W., Kurtz, T., Sheps, S. G. and Roccella, E. J. (2005) 'Recommendations for Blood Pressure Measurement in Humans and Experimental Animals: Part 1: Blood Pressure Measurement in Humans: A Statement for Professionals From the Subcommittee of Professional and Public Education of the American Heart Association Cou', *Hypertension*, 45(1), pp. 142–161. doi: 10.1161/01.HYP.0000150859.47929.8e.

Pine, K., Edwards, R., Masera, O., Schilmann, A., Marrón-Mares, A. and Riojas-Rodríguez, H. (2011) 'Adoption and use of improved biomass stoves in Rural Mexico', *Energy for Sustainable Development*, 15(2), pp. 176–183. doi: 10.1016/j.esd.2011.04.001.

Pope, C. A., Burnett, R. T., Krewski, D., Jerrett, M., Shi, Y., Calle, E. E. and Thun, M. J. (2009) 'Cardiovascular Mortality and Exposure to Airborne Fine Particulate Matter and Cigarette Smoke: Shape of the Exposure-Response Relationship', *Circulation*, 120(11), pp. 941–948. doi: 10.1161/CIRCULATIONAHA.109.857888.

Pope, D. P., Mishra, V., Thompson, L., Siddiqui, A. R., Rehfuess, E. A., Weber, M. and Bruce, N. G.

(2010) ‘Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries’, *Epidemiologic Reviews*. doi: 10.1093/epirev/mxq005.

Pope III, C. A. and Dockery, D. W. (2006) ‘Health effects of fine particulate air pollution: lines that connect’, *Journal of the Air & Waste Management Association (Air & Waste Management Association)*. Air & Waste Management Association, 56(6), pp. 709–742. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=21559476&site=ehost-live&scope=site.

Preble, C. V, Hadley, O. L., Gadgil, A. J. and Kirchstetter, T. W. (2014) ‘Emissions and Climate-Relevant Optical Properties of Pollutants Emitted from a Three-Stone Fire and the Berkeley-Darfur Stove Tested under Laboratory Conditions’, *Environmental Science & Technology*. American Chemical Society, 48(11), pp. 6484–6491. doi: 10.1021/es5002715.

Putti, V. R., Tsan, M., Mehta, S. and Kammila, S. (2015) *Technical Report 007/15: The State of the Global Clean and Improved Cooking Sector*. Washington, D.C.

Quincey, P. (2007) ‘A relationship between Black Smoke Index and Black Carbon concentration’, *Atmospheric Environment*, 41(36), pp. 7964–7968. doi: http://dx.doi.org/10.1016/j.atmosenv.2007.09.033.

Quinn, A. K., Ae-Ngibise, K. A., Jack, D. W., Boamah, E. A., Enuameh, Y., Mujtaba, M. N., Chillrud, S. N., Wylie, B. J., Owusu-Agyei, S., Kinney, P. L. and Asante, K. P. (2016) ‘Association of carbon monoxide exposure with blood pressure among pregnant women in rural Ghana: Evidence from GRAPHS.’, *International journal of hygiene and environmental health*, 219(2), pp. 176–83. doi: 10.1016/j.ijheh.2015.10.004.

R Core Team (2014) ‘R: A language and environment for statistical computing’. Vienna, Austria: R Foundation for Statistical Computing. Available at: http://www.r-project.org/.

Ramanathan, N., Lukac, M., Ahmed, T., Kar, A., Praveen, P. S., Honles, T., Leong, I., Rehman, I. H., Schauer, J. J. and Ramanathan, V. (2011) ‘A cellphone based system for large-scale monitoring of black carbon’, *Atmospheric Environment*, 45(26), pp. 4481–4487. doi: 10.1016/j.atmosenv.2011.05.030.

Ramanathan, V. and Carmichael, G. (2008) ‘Global and regional climate changes due to black carbon’, *Nature Geosci*. Nature Publishing Group, 1(4), pp. 221–227. Available at: http://dx.doi.org/10.1038/ngeo156.

Rehfuess, E., Mehta, S. and Prüss-Üstün, A. (2006) ‘Assessing household solid fuel use: multiple implications for the Millennium Development Goals’, *Environmental Health Perspectives*, 114(3), pp. 373–378. doi: 10.1289/ehp.8603.

Rehfuess, E., Puzzolo, E., Stanistreet, D., Pope, D. and Bruce, N. G. (2014) ‘Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review’, *Environmental Health Perspectives (Online)*. Research Triangle Park: National Institute of Environmental Health Sciences, 122(2), p. 120. doi: http://dx.doi.org/10.1289/ehp.1306639.

Rehman, I. H., Ahmed, T., Praveen, P. S., Kar, A. and Ramanathan, V. (2011) ‘Black carbon emissions from biomass and fossil fuels in rural India’, *Atmos. Chem. Phys.*, 11, pp. 7289–7299.

Roden, C. A., Bond, T. C., Conway, S., Osorto Pinel, A. B., MacCarty, N. and Still, D. (2009) ‘Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves’, *Atmospheric Environment*, 43(6), pp. 1170–1181. doi:

10.1016/j.atmosenv.2008.05.041.

Romieu, I., Riojas-Rodríguez, H., Marrón-Mares, A. ., Schilmann, A., Perez-Padilla, R. and Masera, O. (2009) ‘Improved Biomass Stove Intervention in Rural Mexico’, *American Journal of Respiratory and Critical Care Medicine*, 180(7), pp. 649–656.

Roth, C. (2014) *Micro-gasification: cooking with gas from dry biomass: An introduction to concepts and applications of wood-gas burning technologies for cooking*. Berlin, Germany, Germany. Available at: https://cleancookstoves.org/binary-data/RESOURCE/file/000/000/286-1.pdf.

Roth, G. A., Huffman, M. D., Moran, A. E., Feigin, V., Mensah, G. A., Naghavi, M. and Murray, C. J. L. (2015) ‘Global and Regional Patterns in Cardiovascular Mortality From 1990 to 2013’, *Circulation (New York, N.Y.)*. American Heart Association, etc, 132(17), pp. 1667–1678. doi: 10.1161/CIRCULATIONAHA.114.008720.

Ruiz-Mercado, I., Canuz, E., Walker, J. L. and Smith, K. R. (2013) ‘Quantitative metrics of stove adoption using Stove Use Monitors (SUMs)’, *Biomass & bioenergy*, 57, pp. 136–148. doi: 10.1016/j.biombioe.2013.07.002.

Ruiz-Mercado, I. and Masera, O. (2015) ‘Patterns of stove use in the context of fuel-device stacking: rationale and implications’, *EcoHealth*, 12(1), pp. 42–56. doi: 10.1007/s10393-015-1009-4.

Ruiz-Mercado, I., Masera, O., Zamora, H. and Smith, K. R. (2011) ‘Adoption and sustained use of improved cookstoves’, *Clean Cooking Fuels and Technologies in Developing Economies*, 39(12), pp. 7557–7566. doi: 10.1016/j.enpol.2011.03.028.

Ruiz-Vera, T., Pruneda-Álvarez, L. G., Ochoa-Martínez, Á. C., Ramírez-GarcíaLuna, J. L., Pierdant-Pérez, M., Gordillo-Moscoso, A. A., Pérez-Vázquez, F. J. and Pérez-Maldonado, I. N. (2015) ‘Assessment of vascular function in Mexican women exposed to polycyclic aromatic hydrocarbons from wood smoke’, *Environmental Toxicology and Pharmacology*, 40(2), pp. 423–429. doi: http://dx.doi.org/10.1016/j.etap.2015.07.014.

Saha, A., Kulkarni, P. K., Shah, A., Patel, M. and Saiyed, H. N. (2005) ‘Ocular morbidity and fuel use: an experience from India’, *Occupational and Environmental Medicine* , 62(1), pp. 66–69. doi: 10.1136/oem.2004.015636.

Salvi, S. S. and Barnes, P. J. (2009) ‘Chronic obstructive pulmonary disease in non-smokers’, *Lancet*, 374(9691), pp. 733–43. doi: 10.1016/S0140-6736(09)61303-9.

Sambandam, S., Balakrishnan, K., Ghosh, S., Sadasivam, A., Madhav, S., Ramasamy, R., Samanta, M., Mukhopadhyay, K., Rehman, H. and Ramanathan, V. (2015) ‘Can currently available advanced combustion biomass cook-stoves provide health relevant exposure reductions? Results from initial assessment of select commercial models in India’, *EcoHealth*. Springer US, 12(1), pp. 25–41. doi: 10.1007/s10393-014-0976-1.

Sanford, L. and Burney, J. (2015) ‘Cookstoves illustrate the need for a comprehensive carbon market’, *Environmental Research Letters*, 10(8), p. 84026. Available at: http://stacks.iop.org/1748-9326/10/i=8/a=084026.

Schilmann, A., Riojas-Rodríguez, H., Ramírez-Sedeño, K., Berrueta, V., Pérez-Padilla, R. and Romieu, I. (2015) ‘Children’s respiratory health after an efficient biomass stove (Patsari) intervention’, *EcoHealth*. Springer US, 12(1), pp. 68–76. doi: 10.1007/s10393-014-0965-4.

Shah, A. S. V, Langrish, J. P., Nair, H., McAllister, D. A., Hunter, A. L., Donaldson, K., Newby, D. E. and Mills, N. L. (2013) 'Global association of air pollution and heart failure: a systematic review and meta-analysis.', *Lancet (London, England)*, 382(9897), pp. 1039–48. doi: 10.1016/S0140-6736(13)60898-3.

Shah, A. S. V, Lee, K. K., McAllister, D. A., Hunter, A., Nair, H., Whiteley, W., Langrish, J. P., Newby, D. E. and Mills, N. L. (2015) 'Short term exposure to air pollution and stroke: systematic review and meta-analysis', *BMJ*, 350. Available at: http://www.bmj.com/content/350/bmj.h1295.abstract.

Shailaja, R. (2000) 'Women, energy and sustainable development', *Energy for Sustainable Development*. Elsevier, 4(1), pp. 45–64. doi: 10.1016/S0973-0826(08)60231-8.

Shan, M., Yang, X., Ezzati, M., Chaturvedi, N., Coady, E., Hughes, A., Shi, Y., Yang, M., Zhang, Y. and Baumgartner, J. (2014) 'A feasibility study of the association of exposure to biomass smoke with vascular function, inflammation, and cellular aging', *Environmental Research*, 135, pp. 165–172. doi: 10.1016/j.envres.2014.09.006.

Shanthirani, C. S., Pradeepa, R., Deepa, R., Premalatha, G., Saroja, R. and Mohan, V. (2003) 'Prevalence and risk factors of hypertension in a selected South Indian population--the Chennai Urban Population Study', *The Journal of the Association of Physicians of India*, 51, pp. 20–7.

Siddiqui, A. R., Lee, K., Gold, E. B. and Bhutta, Z. A. (2005) 'Eye and respiratory symptoms among women exposed to wood smoke emitted from indoor cooking: a study from southern Pakistan', *Energy for Sustainable Development*, 9(3), pp. 58–66. doi: 10.1016/S0973-0826(08)60524-4.

Simon, G. L., Bailis, R., Baumgartner, J. and Hyman, J. (2014) 'Current debates and future research needs in the clean cookstove sector', *Energy for sustainable development*. International Energy Initiative, 20, pp. 49–57. doi: 10.1016/j.esd.2014.02.006.

Smith, K. R., Bruce, N., Balakrishnan, K. and Adair-Rohani, H. (2014) 'Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution', *Annual review of public health*. Annual Reviews, 35(1), pp. 185–206. doi: 10.1146/annurev-publhealth-032013-182356.

Smith, K. R., Dutta, K., Chengappa, C., Gusain, P. P. S., Berrueta, V., Masera, O., Edwards, R., Bailis, R. and Shields, K. N. (2007) 'Monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance: conclusions from the Household Energy and Health Project', *Energy for Sustainable Development*, 11(2), pp. 5–18. doi: 10.1016/S0973-0826(08)60396-8.

Smith, K. R. and Keyun, D. (2010) 'Chinese national improved stove program for the 21st century to promote rural social and economic development (English translation of article in Chinese)', *Energy Policy Research*, 1, p. 24−25. Available at: http://cleancookstoves.org/binary-data/RESOURCE/file/000/000/6-1.pdf.

Smith, K. R., Mccracken, J. P., Thompson, L., Edwards, R., Shields, K. N., Canuz, E. and Bruce, N. (2010) '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 Expos Sci Environ Epidemiol*. Nature America, Inc., 20(5), pp. 406–416. Available at: http://dx.doi.org/10.1038/jes.2009.30.

Smith, K. R., McCracken, J. P., Weber, M., Hubbard, A., Jenny, A., Thompson, L. M., Balmes, J., Diaz, A., Arana, B. and Bruce, N. (2011) 'Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial', *The Lancet*, 378(9804), pp. 1717–

1726. doi: 10.1016/S0140-6736(11)60921-5.

Smith, K. R., Mehta, S. and Maeusezahl-Feuz, M. (2004) *Indoor air pollution from household use of solid fuels. In: Ezzati M, Lopez A, Roders A et al. Comparative Quantification of Health Risks, Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. RPRT. Geneva: World Health Organization. Available at: http://www.who.int/publications/cra/chapters/volume2/1435-1494.pdf.

Smith, K. R. and Peel, J. L. (2010) 'Mind the Gap', *Environ Health Perspect*. National Institute of Environmental Health Sciences, 118(12). doi: 10.1289/ehp.1002517.

Smith, K. R., Uma, R., Kishore, V. V. N., Zhang, J. F., Joshi, V. and Khalil, M. A. K. (2000) 'Greenhouse implications of household stoves: An analysis for India', *Annual Review of Energy and the Environment*. ANNUAL REVIEWS, 25, pp. 741–763. doi: 10.1146/annurev.energy.25.1.741.

Smith-Sivertsen, T., Díaz, E., Bruce, N., Díaz, A., Khalakdina, A., Schei, M. A., McCracken, J., Arana, B., Klein, R., Thompson, L. and Smith, K. R. (2004) 'Reducing indoor air pollution with a randomised intervention design - a presentation of the stove intervention study in the Guatemalan Highlands', *Nor J Epidemioli*, 14(2), pp. 137–43.

Smith-Sivertsen, T., Díaz, E., Pope, D., Lie, R. T., Díaz, A., McCracken, J., Bakke, P., Arana, B., Smith, K. R. and Bruce, N. (2009) 'Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE randomized trial, Guatemala', *American Journal of Epidemiology*, pp. 211–220. doi: 10.1093/aje/kwp100.

Soneja, S. I., Tielsch, J. M., Curriero, F. C., Zaitchik, B., Khatry, S. K., Yan, B., Chillrud, S. N. and Breysse, P. N. (2015) 'Determining particulate matter and black carbon exfiltration estimates for traditional cookstove use in rural Nepalese village households', *Environmental Science & Technology*, 49(9), pp. 5555–5562. doi: 10.1021/es505565d.

Still, D., Bentson, S. and Li, H. (2015) 'Results of Laboratory Testing of 15 Cookstove Designs in Accordance with the ISO/IWA Tiers of Performance', *EcoHealth*. Springer US, 12(1), pp. 12–24. doi: 10.1007/s10393-014-0955-6.

Tesfaye, F., Nawi, N. G., Van Minh, H., Byass, P., Berhane, Y., Bonita, R. and Wall, S. (2006) 'Association between body mass index and blood pressure across three populations in Africa and Asia', *J Hum Hypertens*, 21(1), pp. 28–37. Available at: http://dx.doi.org/10.1038/sj.jhh.1002104.

The Gold Standard (no date) *Pioneering methodology for tackling Black Carbon*. Available at: http://www.goldstandard.org/pioneering-methodology-for-tackling-black-carbon (Accessed: 30 April 2015).

The United Nations Framework Convention on Climate Change (no date) *CDM Rulebook: Clean Development Mechanism Rules, Practice and Procedures. What is a baseline?* Available at: http://www.cdmrulebook.org/465.html (Accessed: 15 June 2015).

The World Bank (2008) *The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits (An IEG Impact Evaluation)*. Washington D.C. doi: 10.1596/978-0-8213-7367-5.

The World Bank (no date) *Living Standards Measurement Study: India - Uttar Pradesh and Bihar 1997/98*. Available at: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:21485765~menuPK:4196952~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html#India-Uttar_Pradesh_and_Bihar (Accessed: 11 June 2015).

The World Bank (Carbon Finance Unit) (2016a) *The role of the World Bank in carbon finance: an Aapproach for further engagement*. Available at: https://wbcarbonfinance.org/docs/Role_of_the_WorkBank.pdf (Accessed: 12 July 2016).

The World Bank (Carbon Finance Unit) (2016b) *The Role of the World Bank in Carbon Finance: An Approach for Further Engagement*.

Timko, J. A. and Kozak, R. A. (2016) 'The influence of an improved firewood cookstove, Chitetzo mbaula, on tree species preference in Malawi', *Energy for Sustainable Development*, 33, pp. 53–60. doi: http://dx.doi.org/10.1016/j.esd.2016.04.002.

Tseng, C.-H. (2008) 'Betel Nut Chewing Is Associated with Hypertension in Taiwanese Type 2 Diabetic Patients', *Hypertens Res*. The Japanese Society of Hypertension, 31(3), pp. 417–423. Available at: http://dx.doi.org/10.1291/hypres.31.417.

United Nations Framework Convention on Climate Change (2015) *AMS-II.G.: Energy efficiency measures in thermal applications of non-renewable biomass --- Version 7.0, Valid from 24 Jul 15 onwards*. Available at: http://cdm.unfccc.int/methodologies/DB/KZ6FQOCEEHD1V02ARWTW1W2R9G45BX (Accessed: 3 March 2016).

United Nations Framework Convention on Climate Change (no date) *Small-scale Methodology: Energy efficiency measures in thermal applications of non-renewable biomass (Version 5.0)*. Available at: http://cdm.unfccc.int/filestorage/7/m/24G3EKN6PT0QJ1BHRICMYDX97OW8UF.pdf/EB70_repan30_AMS-II.G_ver05.0.pdf?t=cHV8bnZycTA0fDB667AE6C3U8A7tz42nO-tF (Accessed: 20 August 2015).

Venkataraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A. H. and Friedlander, S. K. (2005) 'Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts', *Science*. American Association for the Advancement of Science, 307(5714), pp. 1454–1456. Available at: http://www.jstor.org/stable/3841722.

Venkataraman, C., Sagar, A. D., Habib, G., Lam, N. and Smith, K. R. (2010) 'The Indian National Initiative for Advanced Biomass Cookstoves: The benefits of clean combustion', *Energy for Sustainable Development*, (14), pp. 63–72. Available at: http://ehs.sph.berkeley.edu/krsmith/publications/2010/ESD_60final_3.pdf.

Warburton, D. E. R., Nicol, C. W. and Bredin, S. S. D. (2006) 'Health benefits of physical activity: the evidence', *Canadian Medical Association Journal* , 174(6), pp. 801–809. doi: 10.1503/cmaj.051351.

West, S. K., Bates, M. N., Lee, J. S., Schaumberg, D. A., Lee, D. J., Adair-Rohani, H., Chen, D. F. and Araj, H. (2013) 'Is household air pollution a risk factor for eye disease?', *International journal of environmental research and public health*. Multidisciplinary Digital Publishing Institute, 10(11), pp. 5378–98. doi: 10.3390/ijerph10115378.

Whelton, P., J, H., Appel, L., Cutler, J., Havas, S., Kotchen, T., Roccella, E., Stout, R., Vallbona, C., Winston, M. and Karimbakas, J. (2002) 'Primary prevention of hypertension: Clinical and public health advisory from the national high blood pressure education program', *JAMA*, 288(15), pp. 1882–1888. Available at: http://dx.doi.org/10.1001/jama.288.15.1882.

Whelton, S. P., Chin, A., Xin, X. and He, J. (2002) 'Effect of Aerobic Exercise on Blood Pressure: A Meta-Analysis of Randomized, Controlled Trials', *Annals of Internal Medicine*, 136(7), pp. 493–503. Available at: http://dx.doi.org/10.7326/0003-4819-136-7-200204020-00006.

Whitley, E. and Ball, J. (2002) 'Statistics review 6: Nonparametric methods', *Critical Care*, 6(6), p. 509. doi: 10.1186/cc1820.

World Bank (2004) *The Impact of Energy on Women's Lives in Rural India*. RPRT. Washington DC: Joint UNDP/World Bank.

World Energy Outlook/International Energy Agency (2015) *World Energy Outlook 2015 Biomass database*. Available at: http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/ (Accessed: 17 June 2016).

World Health Organization (2006a) *Fuel for Life: Household Energy and Health*. France.

World Health Organization (2006b) *Indoor air pollution and health*. RPRT. Geneva, Switzerland: World Health Organization.

World Health Organization (2014) *Indoor air quality guidelines: household fuel combustion*. Geneva, Switzerland. Available at: http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf?ua=1.

Zerriffi, H. (2011) 'Innovative business models for the scale-up of energy access efforts for the poorest', *Current Opinion in Environmental Sustainability*, 3(4), pp. 272–278. doi: 10.1016/j.cosust.2011.05.002.

Zhang, J., Smith, K. R., Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M. A. K., Rasmussen, R. A. and Thorneloe, S. A. (2000) 'Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors', *Atmospheric Environment*, 34(26), pp. 4537–4549. doi: 10.1016/S1352-2310(99)00450-1.

Zhou, Z., Dionisio, K. L., Arku, R. E., Quaye, A., Hughes, A. F., Vallarino, J., Spengler, J. D., Hill, A., Agyei-Mensah, S. and Ezzati, M. (2011) 'Household and community poverty, biomass use, and air pollution in Accra, Ghana', *Proceedings of the National Academy of Sciences of the United States of America*. National Academy of Sciences, 108(27), pp. 11028–11033. doi: 10.1073/pnas.1019183108.

Zube, D. J. (2010) *Heat transfer efficiency of biomass cookstoves*. Colorado State University. Available at: https://dspace.library.colostate.edu/bitstream/handle/10217/39344/2010_Summer_Zube_Daniel.pdf?sequence=1&isAllowed=y.

# Appendices

## Appendix A

**Figure A-1: Typical Two Traditional Stoves used in Study Area**

**Figure A-2: Three Traditional Stoves in a Study Home (stove on left is not lit)**

**Figure A-3: Intervention Stove approved for CDM Stove Intervention Program**

*White lines on the stoves are draw by user as part of the local cultural and religious practice*

**Figure A-4: A Woman Making Roti with CDM-approved Intervention Stove**

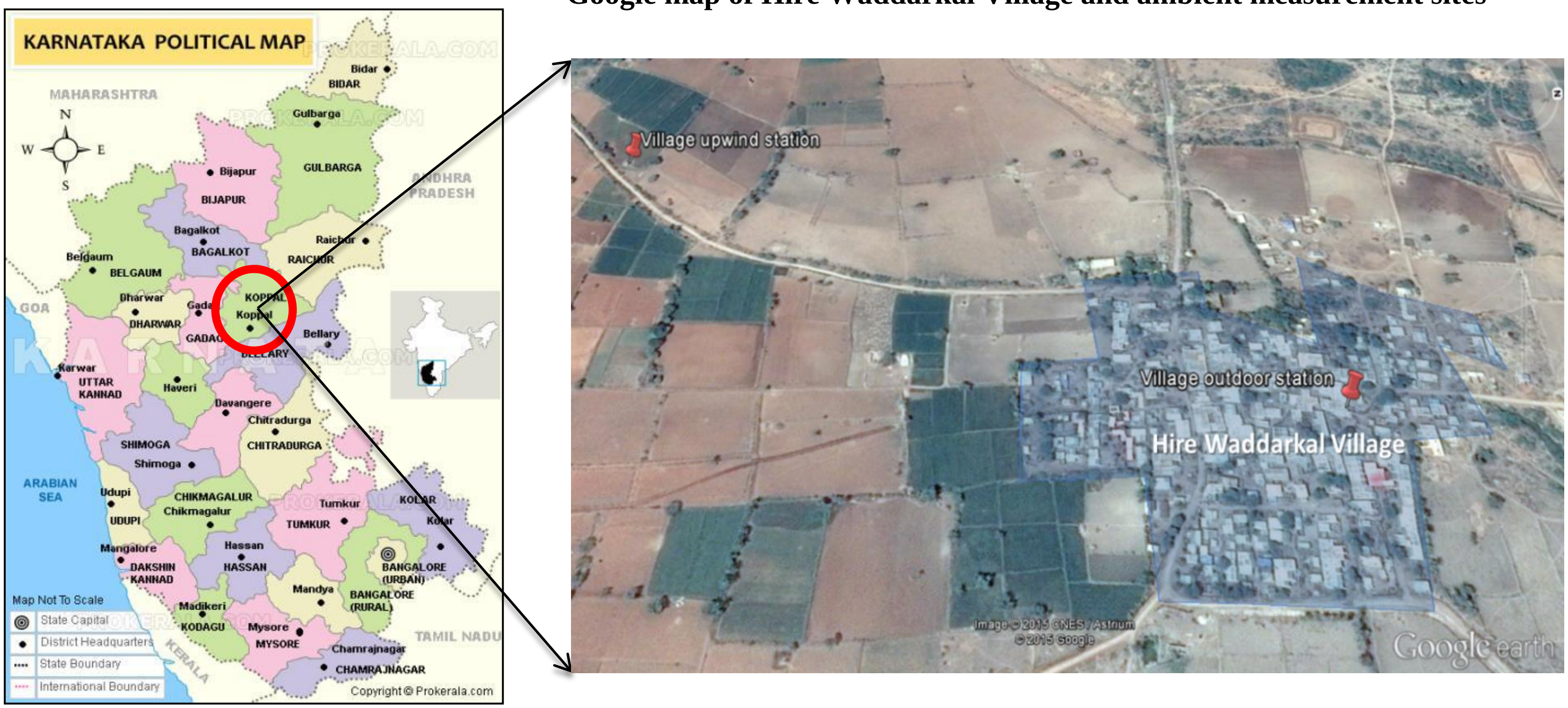
**Figure A-5: CDM-approved Intervention Stove in Outdoor Cooking Area**

## Appendix A.1: Carbon Crediting Methodology for the Karnataka Project

According to the CDM methodology carbon credits are calculated from multiplying four key variables: 1) default value for net calorific value of the non-renewable woody biomass that is substituted (0.015 TJ/ton); 2) default value for emissions for the substitution of non-renewable woody biomass (81.6 tCO2/TJ); 3) quantity of woody biomass saved; and 4) fraction of the wood savings which is non-renewable (United Nations Framework Convention on Climate Change, 2015). Quantity of wood biomass saved was determined from a default efficiency value (0.1) and wood consumption of traditional stove versus efficiency of the intervention stove determined from laboratory-based Water Boiling Tests; wood savings were estimated to be 1.98t/household/year. Fraction of the wood savings that is non-renewable was determined from surveys, including Forest Survey of India, national and local statistics, maps, and remote sensing data resulting in a regional estimate of 0.953. Values of the four variables above were multiplied to obtain project estimated emission reductions (carbon credits) of 2.31 tons of $CO_2$-equivalent/household/year (CDM Executive Board, 2006).

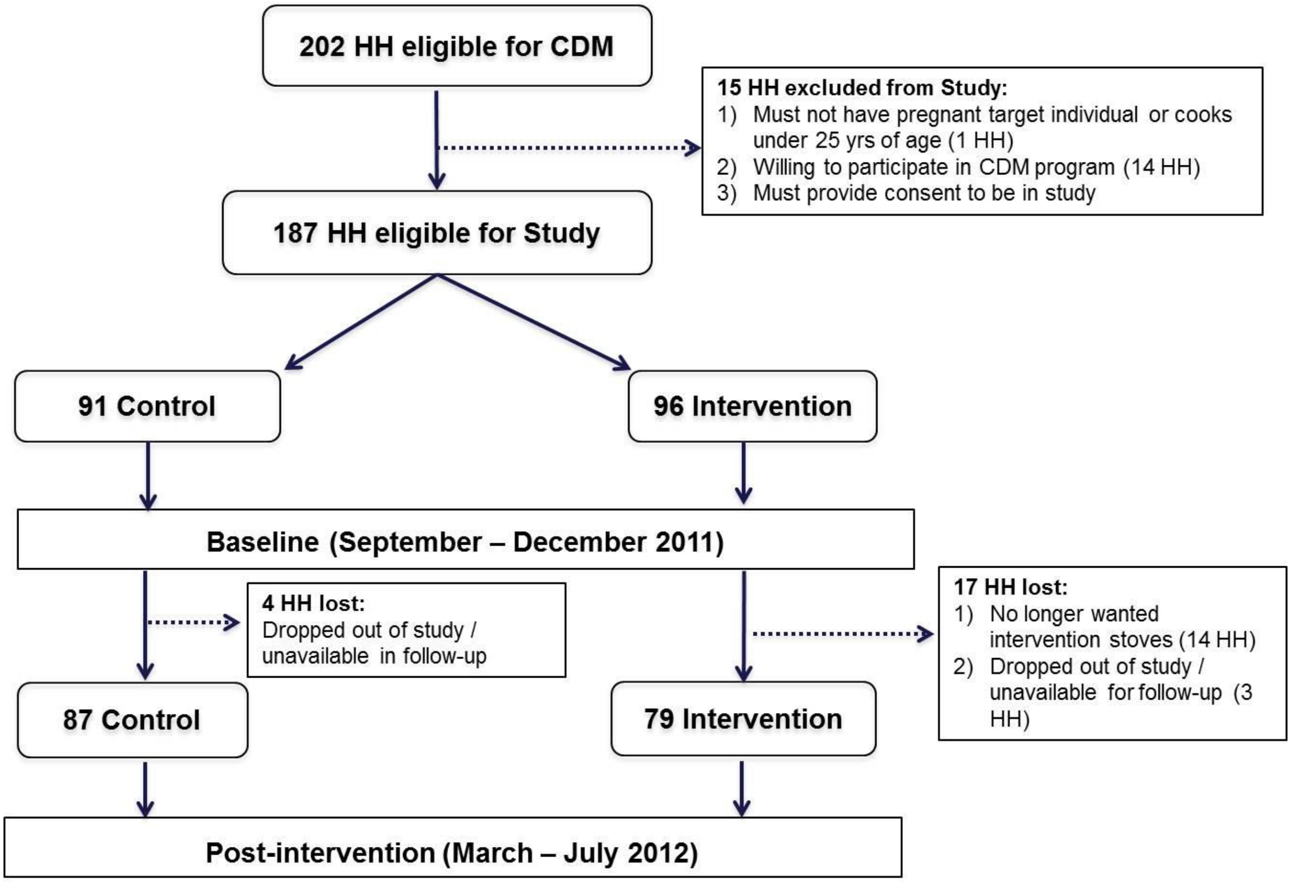
**Figure A-6: Map of Karnataka State in southwest India and Koppal District (in red circle) where Hire Waddarkal study village (see Google Map insert) and ambient measurements sites are located**

**Google map of Hire Waddarkal Village and ambient measurement sites**




Source: http://www.prokerala.com/maps/karnataka-map.html

**Figure A-7: Study Design - Randomized Treatment with Control Population**




## Appendix A.2: $PM_{2.5}$ sampling

$PM_{2.5}$ samples were collected on 37 mm Teflon filters (EMD Millipore, MA, USA) placed downstream of a cyclone (GK2.05 (KTL) or GK2.05SH (KTL) (BGI Inc., Waltham, MA, USA)) with a 2.5 µm aerodynamic-diameter cut point connected to a battery-operated pump (Apex Pro, Casella CEL, UK) running at 4.0±0.4 L min$^{-1}$ for the GK2.05 cyclone and 3.5±0.35 L min$^{-1}$ for the GK2.05SH cyclone. To prolong battery life, pumps were operated on duty cycles (1-min on, 1-min off [pre, early post phase]; 1-min on, 9-min off [remaining post]).

## Appendix A.3: Filter correction for shortened sampling durations

In the post-intervention season, the indoor air pollution measurement period was shortened from 24 hours to 22 hours. The measurements were repeated in households where we failed to reach the 22-hr target measurement period because of equipment failure, and re-measured to ensure that at least two consecutive main meals or a minimum 16 hours in a day were captured. We assessed if there were statistically significant differences between PM measurements that ran for a full 24 hours and for shorter durations. To do this, 24-hour real-time data from DustTrak ($PM_{2.5}$) and microAeth (BC) was used; the real-time monitoring was conducted in a subset of households (n=30) co-located with the gravimetric measurements in both evaluation phases.

Of the total of 60 real-time measurements conducted during pre- and post-intervention seasons, 37 $PM_{2.5}$ and 46 BC measurements completed a full 24- hour sampling period. These 24-hour sampling data were "shortened" and stratified into two types of measurement periods by taking either the first >18-22 hours ("short tail"; captured a brief non-cooking period after 2 main meals were cooked but did not complete 24-hours), or the first 16-18 hours ("cooking periods only"; captured 2 main meals but not the non-cooking period following the last meal) to simulate differences between filter measurements < 24 hours, and evaluate the impact of losing data. Median air pollutant concentrations of the shortened measurement periods and the 24-hour measurement period were compared to test for differences. The short-tail samples (>18-22-hour) were statistically significantly different ($p<0.05$) from the 24-hour samples in 14 $PM_{2.5}$ and 5 BC measurements. All of the two-peak samples (16-18 hour) were also statistically significantly different from the 24-hour sampling period. As a result, measurement periods where sampling captured a minimum of 2 consecutive main meals but did not meet the 24-hr target were adjusted to make them comparable to the 24-hour samples. Specifically, we applied correction factors drawn from distributions developed from co-located time-integrated and real-time $PM_{2.5}$ (DustTrak) and BC (microAeth) indoor measurements. The number of measurement samples that were 22 hours or less was similar between control and intervention groups (Table A-1).

<u>Two types of "shortened" measurements:</u>

1) "Short tail" - measurements captured two consecutive meals as well as a non-cooking period following the second meal, but did not complete the full 24-hour sampling period. Reasons for short-tail samples are either a result of an intended change from 24-hour to 22-hour sampling period in the latter half of the post-intervention season or because of equipment failure.

2) "Cooking periods only" - measurements that caught 2 consecutive main meals (16 hours - 18 hours) but did not sample non-cooking period following the second meal. The 16-18 hour division is based on real-time measurements in a subset of homes which showed that a range between 16 to 18 hours caught at least 2 consecutive meals (shown by two high peaks in air pollution concentrations) in households.

Of the 381 filter-based measurements, 43% completed a full 24-hour target, 54% completed >18-23 hours ("short-tail"), and 4% captured 16-18 hours ("cooking periods only") (Table A-1).

**Table A-1: Filter Counts and Sampling Duration by Measurement Season and Randomized Groups**

| | Cooking periods only (16 hrs - 18 hrs) | Short tail >18 - 23 hrs | Full cycle 24 hrs | TOTAL |
|---|---|---|---|---|
| **By Season** | | | | |
| **Season 1 (1:1 min on/off)** | 6 | 35 | 148 | 189 |
| **Season 2 (1:1 min on/off)**<br>**Season 2.1 (1:9 min on/off)** | 8 | 169 | 15 | 192 |
| **TOTAL** | **14 (4%)** | **204 (54%)** | **163 (43%)** | **381** |
| **By randomized groups** | | | | |
| **Control (percent of total filters)** | 6 (3%) | 108 (57%) | 75 (40%) | 189 |
| **Intervention (percent of total filters)** | 8 (4%) | 96 (50%) | 88 (46%) | 192 |

**Method:**

Linear-regression fits based on the 24-hour average filter concentrations with paired and co-located real-time monitors for $PM_{2.5}$ (DustTrak (DT)) and black carbon (MicroAeth) were used to correct ‘short’ filter-based concentrations grouped under those that had a "short tail" (>18 - 23 hours), and those that stopped immediately after sampling 2 main consecutive meals, "cooking periods only" (16-18 hours). The raw DT concentrations were not normalized because in this case, we were only interested in the relationship between DT and filter concentration and not the absolute values.

***Step 1:*** Samples where filters and real-time monitors (DT and microAeth) ran the same sampling duration were matched to develop a regression between gravimetric concentrations and real-time measurements. Linear regression fits between 24-hour filter and real-time DT (PM) and microAeth (BC) concentrations provided $R^2$ values of ~0.8-0.9 (Figure A-8, Figure A-9, Figure A-10, Figure A-11).

***Step 2*:** The regression equations were applied to co-located air sampling measurements where filters run short of the 24-hour sampling duration but where real-time (DT and microAeth) 24-hour sampling was completed.

For example, the regressions equation for $PM_{2.5}$ (between shortened filter-based and 24-hour DustTrak concentrations) in Season 1 (Baseline) is:

$$y = 0.1976x - 37.756$$

where $x$ is 24-hour mean concentration of $PM_{2.5}$ from real-time DT monitor, and $y$ is expected filter concentration from a 24-hour sampling.

A concentration value from the "shortened" filter concentration (either "short-tail" or "cooking periods only" samples) was divided by the expected filter concentration to obtain an adjustment ratio as summarized in Table S2 for $PM_{2.5}$ and absorbance (for breakdown by season and more details see Table A-3, Table A-4).

***Step 3*:** To adjust the shortened filters and propagate uncertainty throughout the correction process, a value was drawn from a normal distribution represented by the ratios as the mean and SD was applied to the "shortened" filters that run less than 24 hours.

**Table A-2: Summary of Filter versus Real-time Linear Regression Fits and Adjustment ratios Shortened Sampling Durations**

| Comparison | Linear-Regression Fits | | Mean (SD) ratios for >18-23 hour sampling filters | Mean (SD) ratios for 16-18 hour sampling filters |
|---|---|---|---|---|
| | Season 1 | Season 2 | | |
| Filter mass and Real-time $PM_{2.5}$ | *y = 0.1976x - 37.756* ($R^2 = 0.8762$) | y = 0.3445x + 28.044 ($R^2 = 0.8159$) | 1.02 (0.15) | 1.37 (0.58) |
| Filter absorbance and real-time BC | y = 0.6258x + 4.0264 ($R^2 = 0.6537$) | y = 7.912x + 7.2733 ($R^2 = 0.7425$) | 0.94 (0.22) | 0.43 (0.11) |

**Figure A-8: 24-hr Filter vs. Real-Time PM (Baseline 1)**

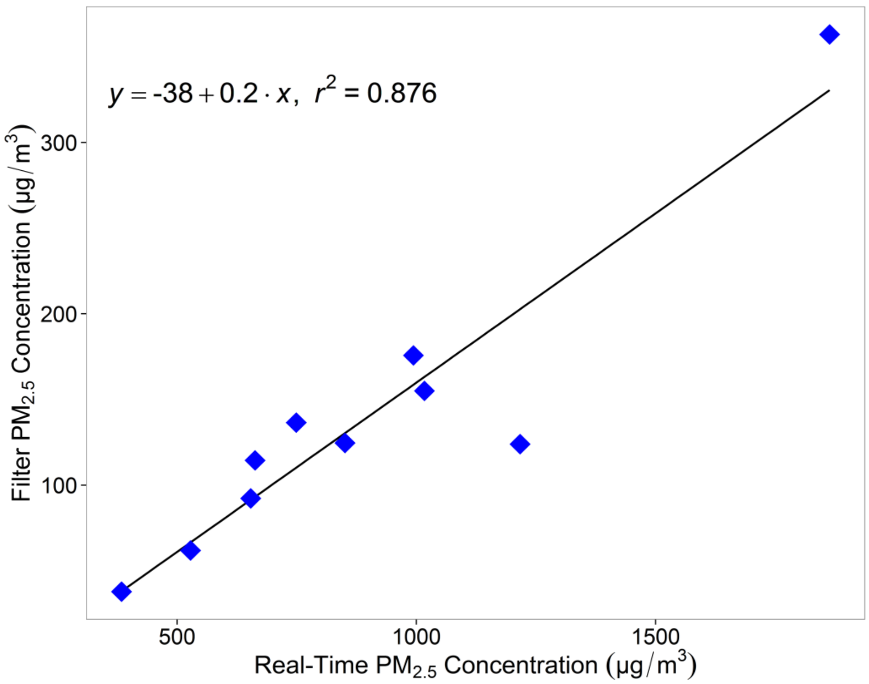



**Figure A-9: 24-hr Filter vs. Real-Time BC (Baseline)**

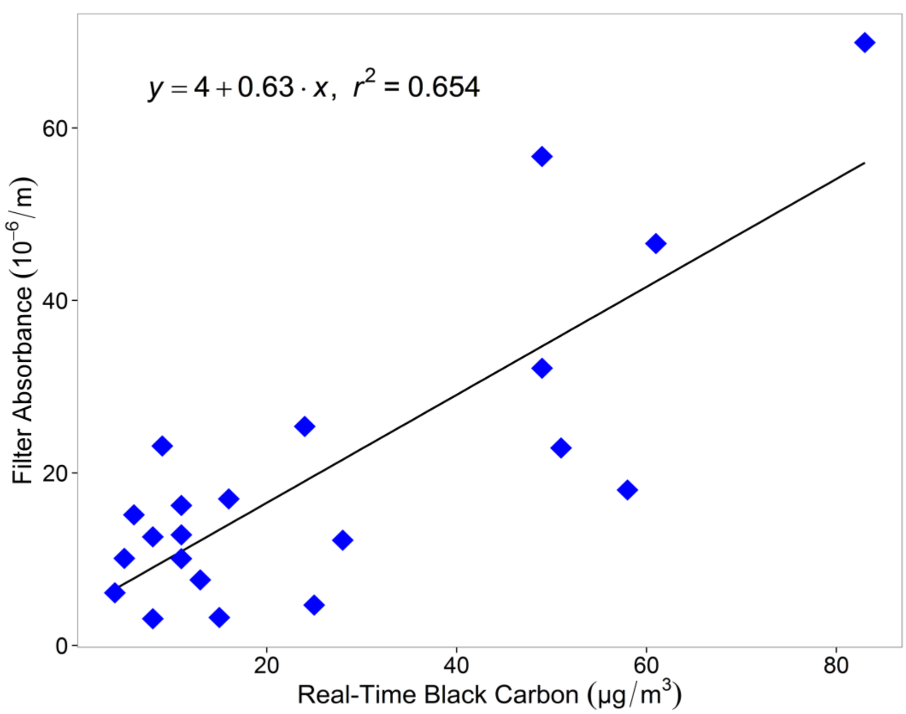


**Figure A-10: 24-hr Filter vs. Real-Time PM (Post-Intervention)**

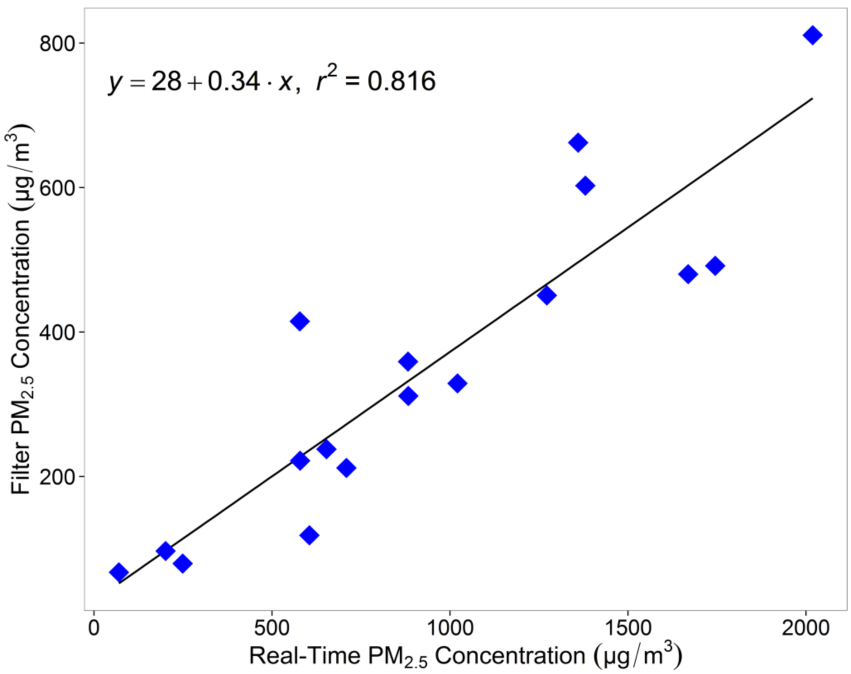
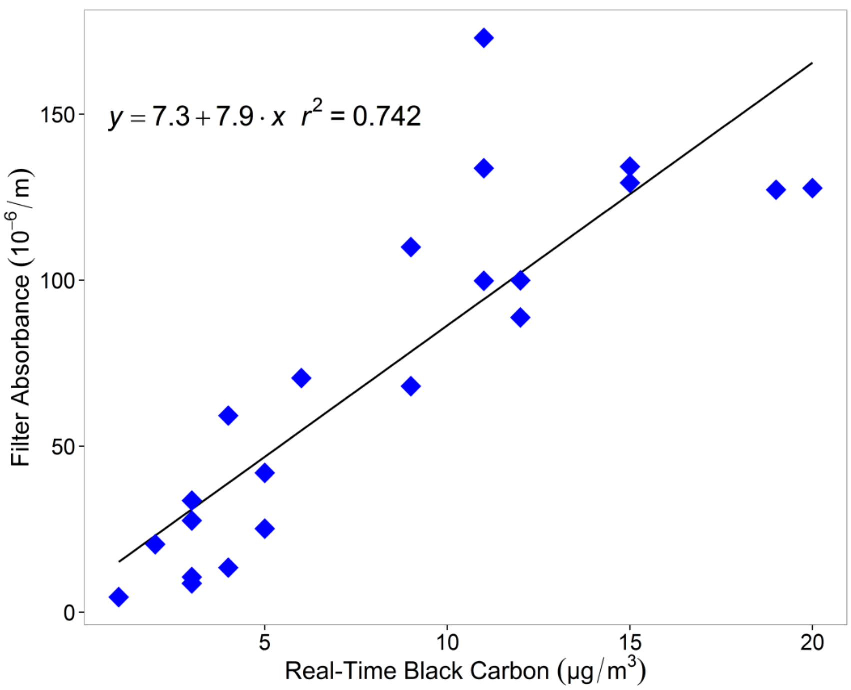



**Figure A-11: 24-hr Filter vs. Real-Time BC (Post-Intervention)**



## Table A-3: $PM_{2.5}$ adjustment ratios

**Baseline (Season 1)**

y = 0.1976x - 37.756 ($R^2$ = 0.8762)

**Post-Intervention (Season 2)**

y = 0.3445x + 28.044 ($R^2$ = 0.8159)

| Season | Sample duration | X (DustTrak PM) | Slope | Intercept | Y (Expected concentration) | Actual filter concentration (ug/m3) | Ratio (Actual/Expected) reading | Mean Ratios (Season 1 and 2) | SD |
|---|---|---|---|---|---|---|---|---|---|
| **Filters >18-22 hours ("short-tail")** | | | | | | | | | |
| 1 | 18-22 hrs | 384 | 0.1976 | 37.756 | 38 | 37.83 | 0.99 | | |
| 1 | 18-22 hrs | 1390 | 0.1976 | 37.756 | 237 | 290.57 | 1.23 | | |
| 1 | 18-22 hrs | 1269 | 0.1976 | 37.756 | 213 | 206.51 | 0.97 | | |
| 2 | 18-22 hrs | 934 | 0.3445 | 28.044 | 350 | 308.46 | 0.88 | | |
| | | | | | | | | **1.02** | **0.15** |
| **Filters 16-18 hours ("cooking periods only")** | | | | | | | | | |
| 1 | 2 meals | 580 | 0.1976 | 37.756 | 77 | 134.64 | 1.75 | | |
| 1 | 2 meals | 1133 | 0.1976 | 37.756 | 186 | 288.44 | 1.55 | | |
| 1 | 2 meals | 605 | 0.1976 | 37.756 | 82 | 42.20 | 0.52 | | |
| 1 | 2 meals | 399 | 0.1976 | 37.756 | 41 | 68.52 | 1.67 | | |
| | | | | | | | | **1.37** | **0.58** |

## Table A-4: Absorbance adjustment ratios

**Baseline (Season 1)**

$y = 0.6258x + 4.0264$ ($R^2 = 0.6537$)

**Post-Intervention (Season 2)**

$y = 7.912x + 7.2733$ ($R^2 = 0.7425$)

| Season | Sample duration | AET H BC | Slope | Intercept | Y (Expected absorbance) | Actual filter Abs (10^-6 /m) | Ratio (Actual/ Expected) reading | Mean ratios (Season 1 and 2) | SD |
|---|---|---|---|---|---|---|---|---|---|
| **Filters >18-22 hours ("short-tail")** | | | | | | | | | |
| 1 | 18-22 hrs | 41 | 0.6258 | 4.0264 | 30 | 32.14 | 1.08 | | |
| 1 | 18-22 hrs | 22 | 0.6258 | 4.0264 | 18 | 12.2 | 0.69 | | |
| 2 | 18-22 hrs | 15 | 7.912 | 7.2733 | 126 | 134.22 | 1.07 | | |
| | | | | | | | | **0.94** | **0.22** |
| **Filters 16-18 hours ("cooking periods only")** | | | | | | | | | |
| 1 | 2 meals | 46 | 0.6258 | 4.0264 | 33 | 18.02 | 0.55 | | |
| 1 | 2 meals | 9 | 0.6258 | 4.0264 | 10 | 3.1 | 0.32 | | |
| 2 | 2 meals | 3 | 7.912 | 7.2733 | 31 | 13.43 | 0.43 | | |
| | | | | | | | | **0.43** | **0.11** |

## Appendix A.4: Teflon Filter Laboratory Analysis

The 37 mm Teflon filters were pre- and post-weighed in triplicate on a microbalance (Sartorius M3P) at the University of Minnesota (7% of study filters) and the School of Population and Public Health at the University of British Columbia (93% of filters). To ensure consistency in quality of balances and environment between the two laboratories, five filters were weighed at both labs; differences were less than or equal to 0.02 mg for each filter.

Prior to weighing, filters were allowed to equilibrate in a temperature and humidity controlled room for at least 48 hours (21°C ± 2°C; 40 ± 5%). A radioactive neutralizer was used to remove static charge and filters were reweighed if three consecutive weights of the same filter were not within 0.01 mg of one another.

Three laboratory blanks were kept in the balance room for use as quality control, and were weighed at the beginning and end of each weighing session. A total of 49 field blanks were deployed in the field with a mean (SD) mass gain of 0.004 mg (0.009) over the two measurement phases. Blank correction was performed by subtracting the mean mass of field blanks from the mass of the $PM_{2.5}$ filter samples. The $PM_{2.5}$ mass concentration was obtained by dividing the blank-corrected mass by the sampled air volume.

## Table A-5: Baseline characteristics of participating and drop-out households

| Characteristics | Control (n=91) | Intervention (n=96) | p-value[a] | Drop out (n=21) | p-value[b] | Control-after drop out (n=87) | Intervention-after drop out (n=79) | p-value[c] |
|---|---|---|---|---|---|---|---|---|
| Number of rooms in house | 2.0 ± 1.0 | 2.2 ± 1.1 | 0.19 | 2.0 ± 0.8 | 0.82 | 2.0 ± 1.0 | 2.3 ± 1.2 | 0.14 |
| Family size | 6.1 ± 1.9 | 5.8 ± 2.0 | 0.35 | 5.7 ± 1.6 | 0.43 | 6.1 ± 2.0 | 5.8 ± 2.0 | 0.30 |
| House type (shared wall with neighbor) (%) | 83 | 84 | 0.95 | 95 | 0.22 | 82 | 82 | 1.00 |
| Roof Material (*improved, i.e. corrugated iron, zinc, metal sheets, cement, concrete, tiles*) (%) | 53 | 52 | 1.00 | 57 | 0.82 | 52 | 52 | 1.00 |
| Floor Material (*finished floor, i.e. ceramic, marble tiles, cement/concrete, stone) (%)* | 67 | 75 | 0.30 | 71 | 1.00 | 68 | 75 | 0.42 |
| Area of irrigated land owned | 1.8 ± 2.8 | 1.6 ± 2.8 | 0.42 | 1.7 ± 2.6 | 0.85 | 1.9 ± 2.8 | 1.5 ± 2.8 | 0.17 |
| Radio (%) | 12 | 5 | 0.16 | 5 | 0.81 | 13 | 5 | 0.15 |
| TV (%) | 20 | 28 | 0.24 | 24 | 1.00 | 21 | 28 | 0.37 |
| Bicycle (%) | 16 | 20 | 0.71 | 10 | 0.36 | 18 | 23 | 0.61 |
| Motorcycle (%) | 12 | 9 | 0.72 | 14 | 0.86 | 13 | 8 | 0.42 |
| Electric mixer (%) | 8 | 9 | 0.88 | 10 | 1.00 | 8 | 9 | 1.00 |
| Cow ownership (%) | 36 | 45 | 0.30 | 57 | 0.16 | 37 | 41 | 0.74 |
| Buffalo ownership (%) | 18 | 11 | 0.33 | 14 | 1.00 | 18 | 10 | 0.20 |
| Chimney above stove (%) | 36 | 39 | 0.79 | 43 | 0.80 | 37 | 38 | 1.00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Smokers in home (%) | 36 | 36 | 1.00 | 35 | 1.00 | 35 | 37 | 0.93 |
| No windows (%) | 27 | 26 | 0.95 | 16 | 0.40 | 28 | 27 | 1.00 |

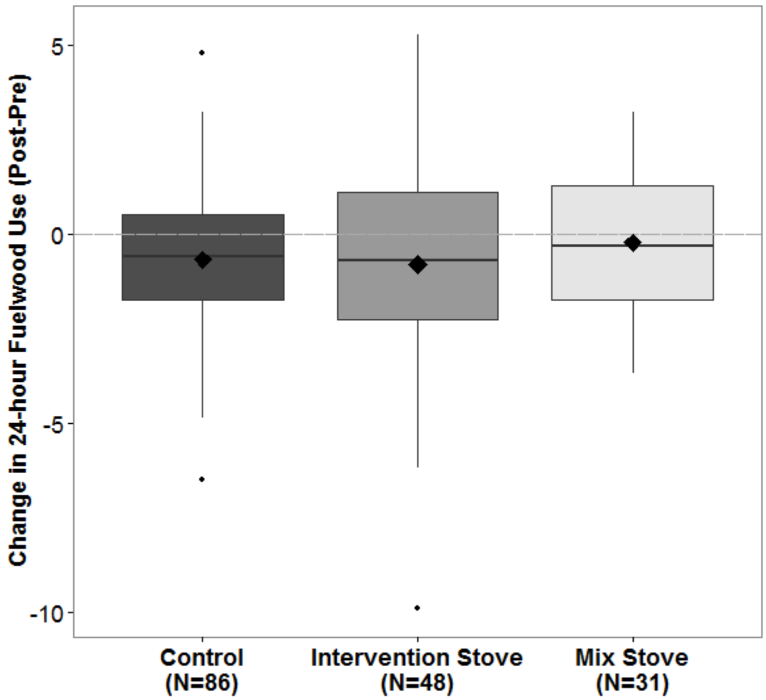
*Data are mean ± SD or number (%). p-Values are two-tailed t-tests for continuous variables; chi-square tests for categorical variables.*
[a] *Between control and intervention groups as randomized.*
[b] *Between drop out group and study population that remained in the study.*
[c] *Between control and intervention groups that remained until end of the study.*

**Table A-6: Change in fuelwood use by season and stove use groups**

| Analysis Type and Groups | Pre-intervention[1] | | Post-intervention[1] | | Median difference[2] [95% CI] (N) | p-value[3] |
|---|---|---|---|---|---|---|
| | Median (kg/day) (N) | Range | Median (kg/day) (N) | Range | | |
| **Intent-to-Treat Analysis** | | | | | | |
| Control | 4.1 (87) | 1.5-10.4 | 3.6 (86) | 0.2-11.0 | -0.60 [-1.02, -0.22] (86) | - |
| Intervention | 4.3 (79) | 0.5-12.5 | 3.8 (79) | 1.3-10.4 | -0.52 [-1.07, 0.00] (79) | 0.74 |
| **Per-protocol Analysis** | | | | | | |
| Intervention | 4.5 (48) | 0.5-12.5 | 3.6 (48) | 1.5-9.1 | -0.72 [-1.50, 0.05] (48) | 0.95 |
| Mix stove | 4.1 (31) | 1.5-10.6 | 4.0 (31) | 1.3-10.4 | -0.20 [-1.03, 0.55] (31) | 0.48 |

*N=sample size; CI=confidence interval*
[1]*Values from unpaired data*
[2] *Seasonal difference (post minus pre) from paired households*
**3** *Wilcoxon rank-sum test of paired seasonal differences between randomized or stove us groups using control as reference*

**Figure A-12: Change in 24-hour fuelwood consumption by stove use**




*Median and mean are represented by black horizontal line and diamond symbol, respectively.*

## Appendix A.5: Fuelwood Moisture

The moisture content of weighed fuelwood corresponded with seasonal conditions, and was moderately higher ($p<0.01$) pre-intervention (post-monsoon/winter) compared to post-intervention (summer) (mean (SD) among all households: 15% (5%) [pre] and 11% (3%) [post]. The decrease in fuelwood moisture in the post-intervention season may be responsible for the reduced fuelwood consumption in that season, owing to more efficient burning of drier wood. The seasonal decrease (post - pre) in median fuelwood moisture content did not differ between control (-4.0%) and exclusive intervention stove (-3.8%) homes, but decreases for mixed stove homes (-4.8%) were marginally greater ($p=0.10$) than the control group.

**Table A-7: Weather conditions, and 24-hour $PM_{2.5}$ and absorbance concentrations upwind and center of village during pre- and post-intervention seasons**

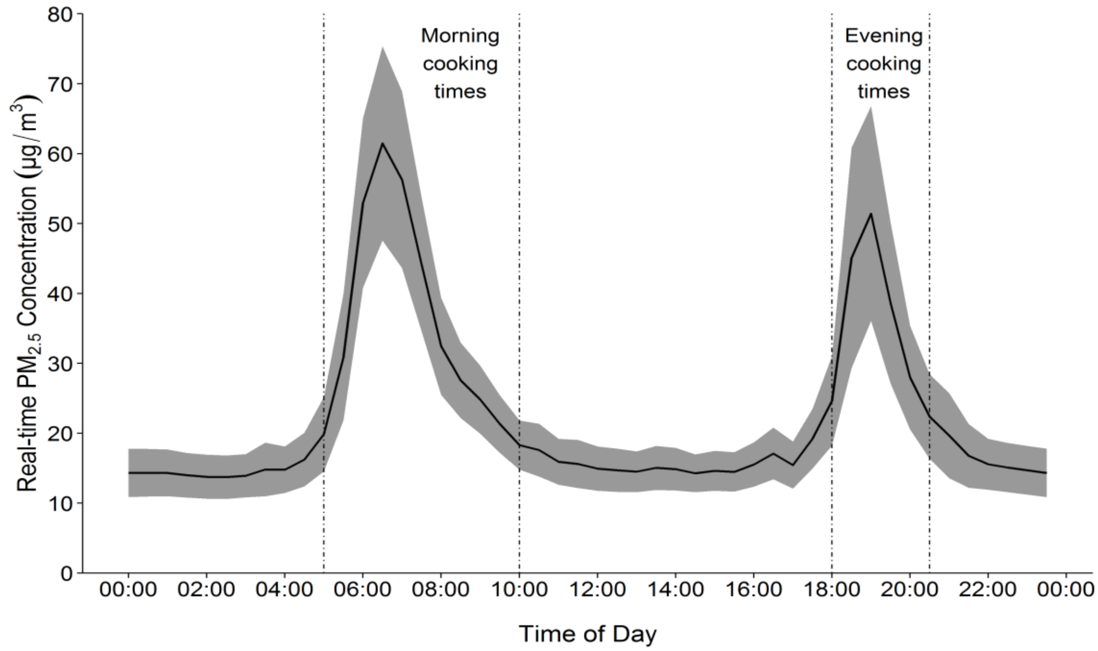
| Season | Mean (SD) Tempera-ture (°C) | Mean (SD) Humidity (%) | Upwind Village Mean (SD) | | Center Village Mean (SD) | | Upwind & Center Village Difference[b] (95% CI) $PM_{2.5}$ ($\mu g/m^3$) | Upwind & Center Village Difference[b] (95% CI) Abs ($10^{-6}/m$) |
|---|---|---|---|---|---|---|---|---|
| | | | $PM_{2.5}$ ($\mu g/m^3$) | Abs ($10^{-6}/m$) | $PM_{2.5}$ ($\mu g/m^3$) | Abs ($10^{-6}/m$) | | |
| **Pre-intvn**[a] | 26 (2) | 63 (11) | 4 (3.1) (n=8) | 0.3 (0.3) (n=7) | 23 (15) (n=38) | 3.3 (2.1) (n=38) | 13 (8, 24) | 2.7 (1.4, 3.9) |
| **Post-intvn**[a] | 30 (3) | 52 (17) | 5 (0.5) (n=2) | 1.2 (0.9) (n=8) | 29 (23) (n=36) | 3.2 (2.2) (n=35) | 18 (-1, 62) | 1.6 (0.5, 2.9) |

*SD = Standard Deviation; n=sample size; CI = confidence interval*
*[a] Pre-intervention (September 2-28, 2011); Post-intervention (July 14 - August 4)*
*[b] Wilcoxon rank-sum test for difference and 95% CI between upwind and center of village concentrations*

## Appendix A.6: Regional and Village-Level Ambient Concentrations

Of the 88 $PM_{2.5}$ samples collected in the village center, 73 were analyzed for mass and absorbance upon meeting minimum flow rate and volume criteria, and having non-negative filter mass. Of the 27 PM samples collected upwind of the village, 10 were analyzed for mass and 15 were analyzed for absorbance; the remaining samples were excluded owing to unstable flow rate and negative measurement of filter mass. Negative filter masses were presumably a result of low ambient concentrations and low pump flow rates, particularly in the post-intervention season, because of the reduced sampling duty cycle. Results of these filter analyses are presented in Table A-7.

**Figure A-13: Ambient 30-min average $PM_{2.5}$ concentrations at center of village**




*From DustTrak $PM_{2.5}$ measurements located at center of village during baseline season (September 10, 2011 - December 10, 2011) over 37 measurement days. Shaded areas represent 95% confidence intervals.*

Figure A-13 is derived from DustTrak (DT) data adjusted with co-located integrated filter measurement. We normalized the DT data by first obtaining a ratio by dividing co-located 24-hour filter concentration by mean of the 24-hour DT concentration. The ratio was then multiplied with the 30-minute average DT data. Similar to Rehman et al. (Rehman *et al.*, 2011), our study found significant contributions of indoor biomass combustion activities to ambient village concentrations particularly during morning and evening cooking times.

## Appendix A.7*:* Repeated Household Measures to Assess Day-to-Day Variability

Of the total 40 households that had repeated indoor air pollution measurements in baseline and post-intervention seasons to assess day-to-day variability, 16 completed three consecutive sampling days and 13 completed two consecutive sampling days; the remaining households were excluded from analysis because follow-up measurements did not meet minimum sampling duration or flow requirements. The mean relative standard deviation (RSD) (range) for indoor $PM_{2.5}$ across the households with the repeated measurements was 37% (range: 0 - 86% [pre]) and 37% (range: 7 - 79%; [post]). The mean RSD (range) for indoor Abs across the same households was 31% (range: 0 - 80% [pre]) and 36% (range: 2 - 65%; [post]).

In addition, we used these repeated-measure samples to test the effect of sampling duration (24-hour versus longer duration) on indoor air pollution concentrations. For the 13 households that completed two consecutive sampling days there were no statistically significant differences in $PM_{2.5}$ and Abs levels between the two days in either the baseline ($PM_{2.5}$ p=0.32; Abs p=0.74) or post-intervention seasons ($PM_{2.5}$ p=1; Abs p=0.32). Similarly, in the 16 households with three consecutive day samples there were not statistically significant differences in air pollution levels between the sampled days in baseline ($PM_{2.5}$ p=0.61; Abs p=0.88) or post-intervention seasons ($PM_{2.5}$ p=0.72; Abs p=0.21).

**Figure A-14: Comparison of indoor 24-hour $PM_{2.5}$ sampling vs. 72-hour sampling**

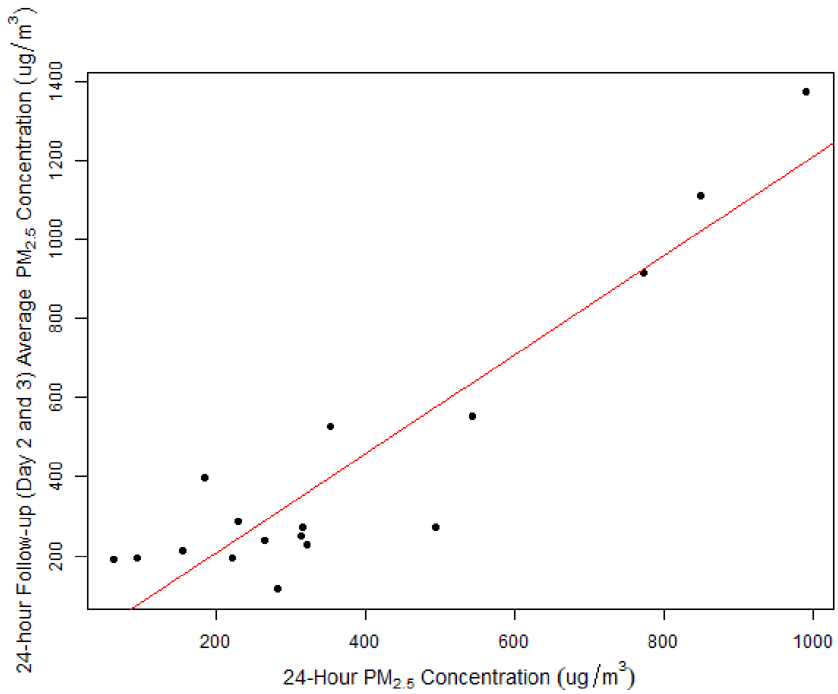



**Figure A-15: Comparison of indoor 24-hour $PM_{2.5}$ sampling vs. 48-hour sampling**

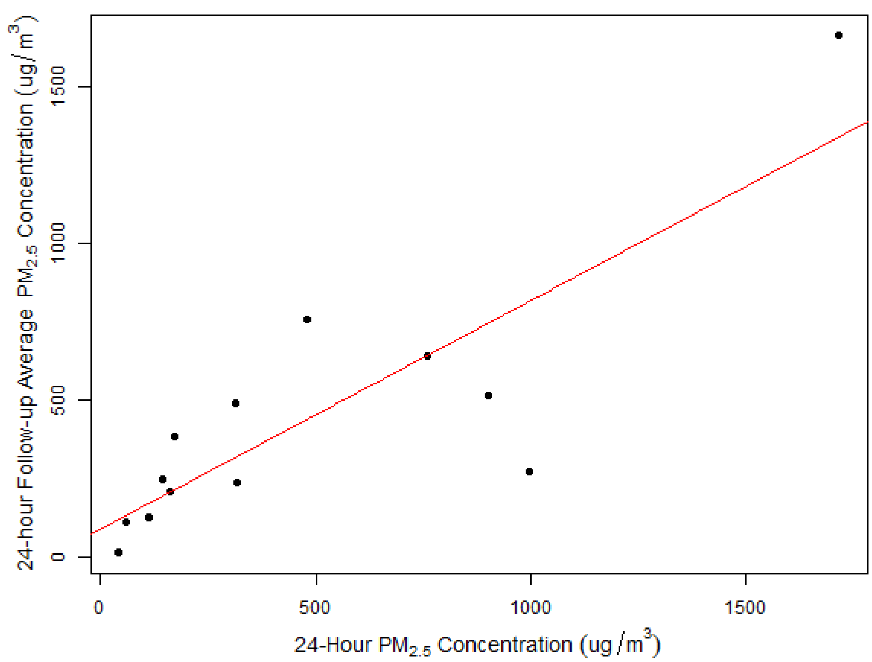
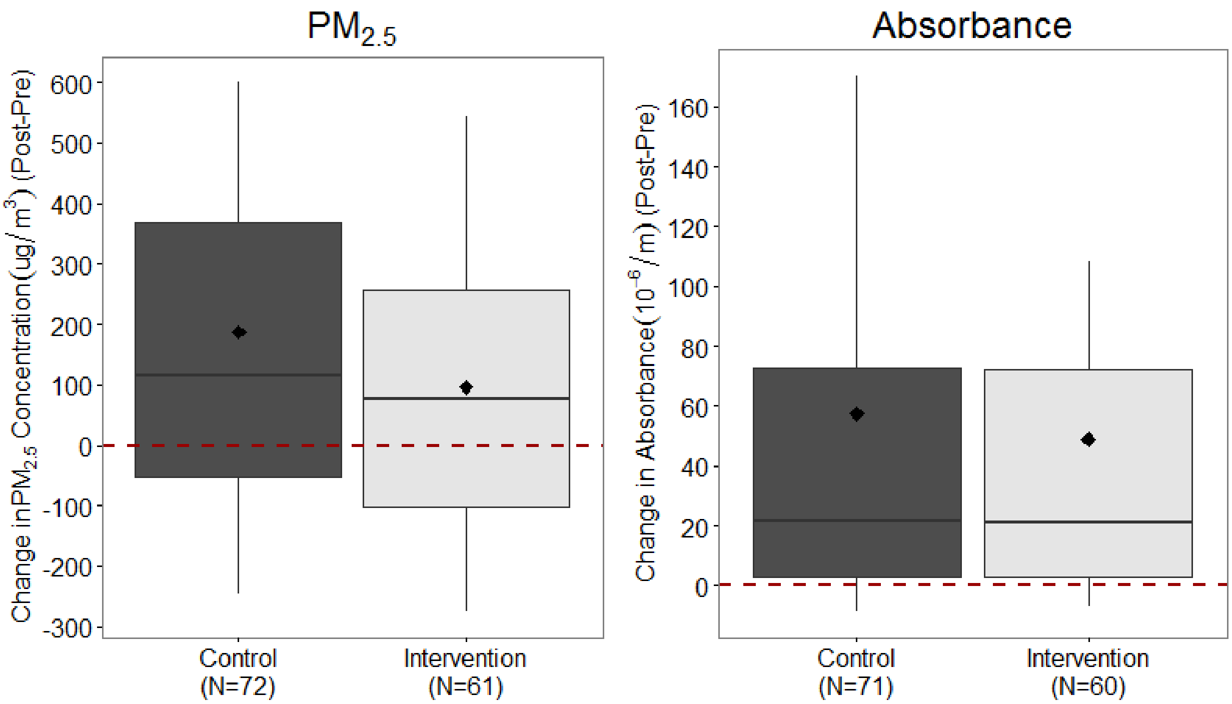


**Figure A-16: Change in air pollutant concentrations by randomized groups**




*Note: lower and upper hinges represents the 25th and 75th percentiles, respectively; black line inside the box represents the 50th percentile; lower and upper whiskers represent the 10th and 90th percentiles, respectively; and diamond represents the mean.*

Figure A-16 demonstrates seasonal change (post-intervention minus pre-intervention) in $PM_{2.5}$ and Abs by control and intervention groups as randomized (ITT). A majority of homes in all groups experienced higher $PM_{2.5}$ concentrations and Abs in the post-intervention season with median change for both pollutants above zero. The magnitude of the $PM_{2.5}$ increase was smaller for the intervention group compared to the control. Median (SD) of seasonal difference for $PM_{2.5}$ between control and exclusive stove groups are 114 (602) and 75 (407) μg/m$^3$, respectively. This difference is borderline statistically significant for a one-tailed test (p=0.14). The one-tailed test checks whether concentrations are statistically lower for the intervention than the control. For Abs, the seasonal change was similar between the control and intervention groups.

## Appendix A.8: Log-Linear Mixed-Effect Model

We assigned household as the random effect because of repeated measures per household. We log-transformed $PM_{2.5}$ and Abs concentrations to normalize skewed distributions. We controlled for the following covariates: ambient conditions (temperature, humidity, and outdoor $PM_{2.5}$ or Abs concentrations), presence of chimney, and wood quantity and wood moisture.

Visual inspections of normal quantile plots of the random effect (household), and residuals of the mixed effect model suggest assumptions of normality were not violated.

### $PM_{2.5}$

$$\log(PM_{2.5}) \sim \beta_1 \text{ chimney} + \beta_2 \text{ wood use} + \beta_3 \text{ wood moisture} + \beta_3 \text{ outdoor } PM_{2.5} + \beta_4 \text{ humidity} + \beta_5 \text{ outdoor temperature} + \beta_6 \text{ Stove use group*Season} + (1 \mid \text{household}) + \varepsilon$$

**Table A-8: Multivariate adjusted effects for indoor $PM_{2.5}$ concentrations**

| Fixed effects | Estimate[1] | Std. Error | df | t value | Pr(>\|t\|) |
|---|---|---|---|---|---|
| (Intercept) | 5.325916 | 1.042894 | 189.8684 | 5.106862 | 7.93E-07 *** |
| Chimney | -0.86441 | 0.148079 | 123.6953 | -5.8375 | 4.37E-08 *** |
| 24-hour Wood Use | 0.035865 | 0.030259 | 225.3189 | 1.185273 | 0.237158 |
| Wood Moisture | -0.01119 | 0.012543 | 192.6042 | -0.89202 | 0.373493 |
| Outdoor $PM_{2.5}$ concentration | -0.0025 | 0.003594 | 215.1755 | -0.69415 | 0.488336 |
| Humidity | -0.00287 | 0.005781 | 185.21 | -0.4972 | 0.619635 |
| Temperature | 0.023168 | 0.029508 | 199.4677 | 0.78514 | 0.433303 |
| Exclusive Intv Stove Group | 0.090043 | 0.194512 | 203.5574 | 0.462914 | 0.64392 |
| Mixed Stove Group | 0.163337 | 0.231744 | 204.0722 | 0.704816 | 0.481728 |
| Post-intv season | 0.434534 | 0.14538 | 136.0232 | 2.988949 | 0.003323 ** |
| Exclusive intv stove:post-intv season | -0.38729 | 0.212911 | 120.0261 | -1.81901 | 0.071404 . |
| Mixed Stove: post-intv season | -0.09046 | 0.249593 | 119.2742 | -0.36241 | 0.717685 |

*Intv = Intervention*
*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*
[1] *Unexponentiated estimates*

## Absorbance

$$\log(\text{Abs}) \sim \beta_1 \text{ chimney} + \beta_2 \text{ wood use} + \beta_3 \text{ wood moisture} + \beta_3 \text{ outdoor Abs} + \beta_4 \text{ humidity} + \beta_5 \text{ outdoor temperature} + \beta_6 \text{ Stove use group*Season} + (1 \mid \text{household}) + \varepsilon$$

**Table A-9: Multivariate adjusted effects for indoor absorbance concentrations**

| Fixed effects | Estimate[1] | Std. Error | df | t value | Pr(>\|t\|) |
|---|---|---|---|---|---|
| (Intercept) | 2.469897 | 0.961027 | 208.9278 | 2.57006 | 0.010864 * |
| Chimney | -0.47095 | 0.117127 | 115.5104 | -4.02084 | 0.000104 *** |
| 24-hour Wood Use | 0.023672 | 0.026747 | 224.2119 | 0.88503 | 0.377089 |
| Wood Moisture | -0.00115 | 0.01152 | 218.3425 | -0.0997 | 0.920672 |
| Outdoor $PM_{2.5}$ concentration | 0.004065 | 0.003243 | 226.4036 | 1.253362 | 0.211367 |
| Humidity | 0.010857 | 0.005387 | 205.6134 | 2.015567 | 0.045147 * |
| Temperature | 0.003316 | 0.026813 | 217.2865 | 0.123681 | 0.901682 |
| Exclusive Intv Stove Group | -0.0544 | 0.16531 | 218.3977 | -0.32907 | 0.742414 |
| Mixed Stove Group | 0.090756 | 0.196958 | 217.7616 | 0.460789 | 0.64541 |
| Post-intv Season | 0.769263 | 0.140399 | 136.1285 | 5.479127 | 2.00E-07 *** |
| Exclusive Intv Stove:post-intv season | -0.03706 | 0.210306 | 117.4392 | -0.17623 | 0.860418 |
| Mixed Stove: post-intv season | 0.173519 | 0.247787 | 117.7501 | 0.700277 | 0.485136 |

*Intv = Intervention*
*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*
[1] *Unexponentiated estimates*

**Table A-10: Seasonal percent change in HAP concentrations by stove use groups (within-group analysis)**

| Stove Use Groups | Ratio | 95% CI | *p*-Value |
|---|---|---|---|
| **$PM_{2.5}$** | | | |
| Control | 1.54 | 1.16, 2.06 | 0.003 |
| Exclusive Intvn Stove | 1.05 | 0.72, 1.54 | 0.81 |
| Mixed Stove | 1.41 | 0.87, 2.28 | 0.16 |
| **Abs** | | | |
| Control | 2.16 | 1.63, 2.85 | <.0001 |
| Exclusive Intvn Stove | 2.08 | 1.43, 3.02 | 0.0002 |
| Mixed Stove | 2.57 | 1.61, 4.10 | 0.0001 |

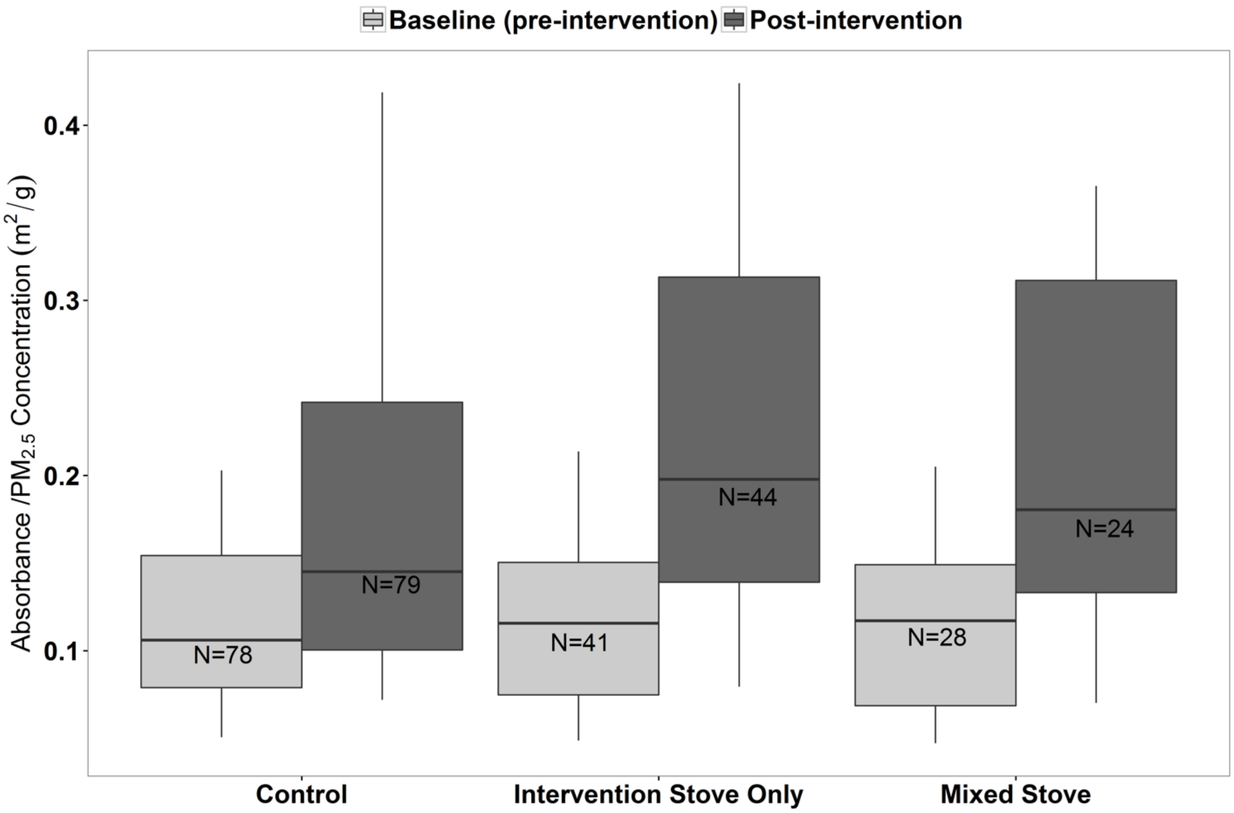
**Table A-11: Percent difference in HAP concentrations between stove use groups in post-intervention season (between-group analysis)**

| | Ratio | 95% CI | *P*-Value |
|---|---|---|---|
| **$PM_{2.5}$** | | | |
| Control | *Ref* | - | - |
| Exclusive intvn stove | 0.74 | 0.47, 1.18 | 0.29 |
| Mixed stove user | 1.08 | 0.62, 1.85 | 0.95 |
| **Abs** | | | |
| Control | *Ref* | - | - |
| Exclusive intvn stove | 0.91 | 0.61, 1.36 | 0.85 |
| Mixed stove user | 1.30 | 0.81, 2.09 | 0.39 |

Chimney homes had 58% and 38% lower $PM_{2.5}$ and Abs, respectively, compared to non-chimney homes, and these effects were significant for both pollutants (Table S8; Table S9). Multivariate adjusted regression model showed the control group experienced a statistically significant $PM_{2.5}$ increase of 54% [95% CI: 16%, 106%] compared to pre-intervention season, whereas the $PM_{2.5}$ increase in exclusive interventions stove (5% [-28%, 54%]) and mixed stove (41% [-13%,128%) groups were not statistically significant (Table S10). For Abs, all groups experienced statistically significant increases in post-intervention season compared to pre-intervention season. The Abs increases were 116% [63%, 185%] for control; 108% [43%, 202%] for exclusive intervention stove; and 157% [61%, 310%] for mixed stove groups (Table S10).

Differences between stove use groups in the post-intervention season are provided in Table S11. The exclusive intervention stove group had lower $PM_{2.5}$ (-26% [-53%, 18%]) and Abs (-9% [-39%, 36%]), respectively, compared to control group. Mixed stove homes had higher $PM_{2.5}$ (8% [-38%, 85%]) and Abs (30% [-19%, 109%]) compared to control group. These effects were not statistically significant.

**Figure A-17: Absorbance/$PM_{2.5}$ mass ratio between pre- and post-intervention seasons (per-protocol analysis)**




*Note: lower and upper hinges represents the 25th and 75th percentiles, respectively; black line inside the box represents the 50th percentile; lower and upper whiskers represent the 10th and 90th percentiles, respectively.*

Figure A-17 is Absorbance:$PM_{2.5}$ ratios between pre- and post-intervention seasons by stove use groups. The Absorbance:$PM_{2.5}$ ratios were higher in the post-intervention season (darker boxes) in all stove use groups. The two intervention groups (intervention stove only and mixed stove groups) experienced higher Abs:$PM_{2.5}$ ratios compared to control group.

**Figure A-18: Change in $PM_{2.5}$ by stove use and chimney**

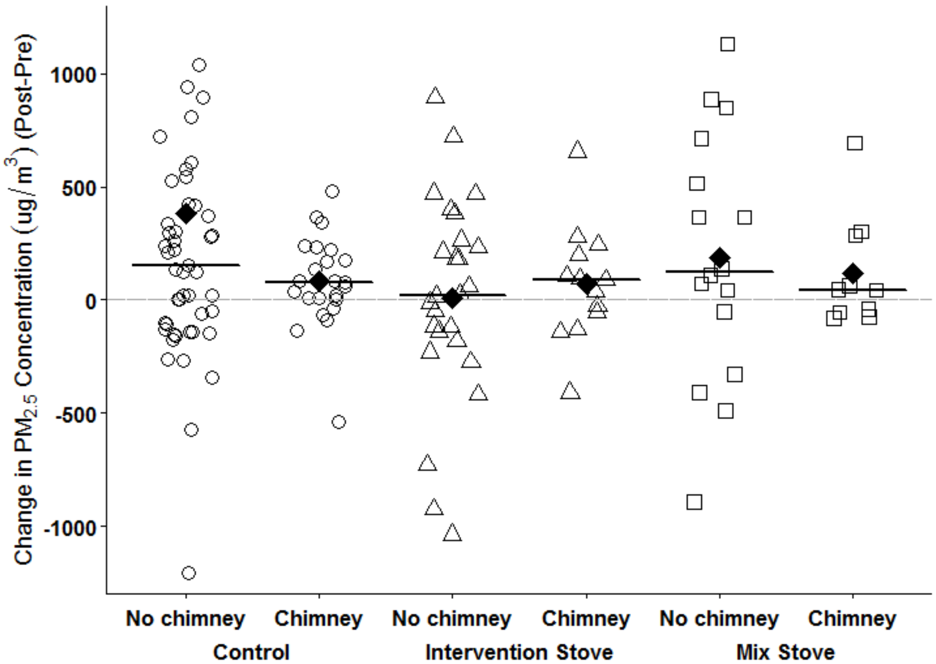
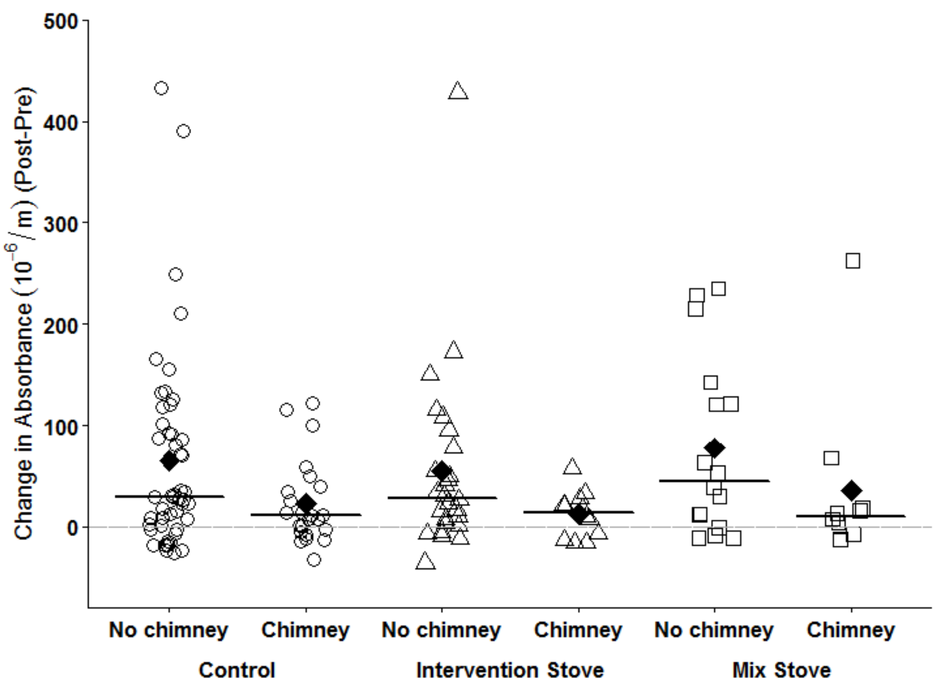



**Figure A-19: Change in absorbance by stove use and chimney**




*Median and mean are represented by black horizontal line and diamond symbols, respectively. Because of outliers, y-axis for $PM_{2.5}$ graph zoomed in to show median and mean around zero; data from 3 households (2% of data) not shown as a result since change in $PM_{2.5}$ concentration was above 2,000 $\mu g/m^3$.*

## Appendix A.9: Time-weighted total exposure

A rough estimation of time-weighted total exposure from time use data is 225 μg/m$^3$. We derived this number from an estimated amount of time a typical woman in the study village spends outdoor (~10 hours) either working in a farm or outside her house, with an average outdoor village PM concentration of 23 μg/m$^3$. The rest of the 14 hours is spent indoor (cooking, cleaning, childcare, etc.) where mean indoor concentration is 370 μg/m$^3$.

Weighed total exposure:

a. [(10 hrs * 23 μg/m$^3$) + (14 hrs * 370 μg/m$^3$)]/24 hours = 225 μg/m$^3$

Indoor exposure accounted for 96% of the total time-weighted average exposure in the study population.

## Cited literature for Appendix A


(1) United Nations Framework Convention on Climate Change. AMS-II.G.: Energy efficiency measures in thermal applications of non-renewable biomass --- Version 7.0, Valid from 24 Jul 15 onwards http://cdm.unfccc.int/methodologies/DB/KZ6FQOCEEHD1V02ARWTW1W2R9G45BX (accessed Mar 3, 2016).

(2) CDM Executive Board. *Project Design Document Form (CDM-SSC-PDD) - Version 03*; UNFCCC, 2006.

(3) Rehman, I. H.; Ahmed, T.; Praveen, P. S.; Kar, A.; Ramanathan, V. Black carbon emissions from biomass and fossil fuels in rural India. *Atmos. Chem. Phys.* **2011**, *11*, 7289–7299.

## Appendix B

### Table B-1: Between-group BP in post-intervention season by age and BMI groups

| | Systolic | | Diastolic | |
|---|---|---|---|---|
| | Exclusive stove | Mixed stove | Exclusive stove | Mixed stove |
| | Estimate (95% CI) | | | |
| **Age** | | | | |
| Old vs. young | -0.1 (-10.8, 10.6) | **18.2 (4.4, 32.0)** | 3.7 (-2.5, 9.9) | **10.8 (2.9, 18.8)** |
| **BMI** | | | | |
| Underweight vs. normal | 1.8 (-8.8, 12.4) | 14.6 (-0.1, 29.3) | 2.8 (-3.7, 9.4) | **9.3 (0.2, 18.4)** |
| Overweight vs. normal | -3.9 (-21.7, 13.8) | **24.8 (4.6, 45.0)** | -4.6 (-15.6, 6.4) | 9.6 (-2.9, 22.1) |
| Underweight vs. overweight | 5.7 (-12.4, 23.9) | -10.2 (-28.2, 7.8) | 7.4 (-3.8, 18.7) | -0.3 (-11.5, 10.8) |

*Reference group: control (traditional stove user); old (≥40 years of age); young (<40 years of age); BMI=body-mass index; underweight (BMI < 18.5 kg/m2); normal (18.5 kg/m2 ≥ BMI < 23 kg/m2); overweight (BMI ≥ 23 kg/m2);adjusted for BMI, age, temperature, betel use, self-rating of own health, and irrigated land ownership.*

**Table B-2: Seasonal change (post - pre-intervention) in BP for stove use groups by age and BMI groups**

| | Systolic BP | | | Diastolic BP | | |
|---|---|---|---|---|---|---|
| | Control | Exclusive intervention stove | Mixed stove | Control | Exclusive intervention stove | Mixed stove |
| | Estimate [95% CI] | | | | | |
| **Age** | | | | | | |
| Young (<40 years) | 0.8 [-2.1, 3.7] | -2.1 [-6.2, 1.9] | -1.0 [-6.8, 4.7] | 0.7 [-1.4, 2.8] | -1.8 [-4.7, 1.2] | -3.0 [-7.2, 1.1] |
| Old ( $\geq$ 40 years) | 1.1 [-1.6, 3.8] | -1.1 [-4.3, 2.1] | **7.4 [2.8, 12.0]** | **2.7 [0.8, 4.7]** | 0.6 [-1.7, 3.0] | 2.0 [-1.4, 5.3] |
| **BMI** | | | | | | |
| Underweight | 2.2 [-0.5, 5.0] | -1.4 [-5.7, 2.9] | 4.0 [-1.0, 9.1] | **2.4 [0.4, 4.4]** | -0.8 [-3.9, 2.3] | 0.8 [-2.8, 4.4] |
| Normal | -1.6 [-5.4, 2.2] | -0.3 [-4.3, 3.7] | 1.5 [-6.8, 9.8] | -0.2 [-2.9, 2.5] | 1.1 [-1.7, 4.0] | 1.0 [-4.9, 6.9] |
| Overweight | -0.2 [-6.1, 5.6] | -5.6 [-15.1, 3.9] | 5.0 [-3.7, 13.7] | 3.3 [-0.9, 7.6] | -3.7 [-10.5, 3.1] | -5.8 [-12.1, 0.4] |

*BMI=body-mass index; underweight (BMI < 18.5 kg/m2); normal (18.5 kg/m2 ≥ BMI < 23 kg/m2); overweight (BMI ≥ 23 kg/m2); adjusted for BMI, age, temperature, betel use, self-rating of own health, and irrigated land ownership*

**Table B-3:** **Seasonal differences (post-pre) for air pollutants by stove groups**

| | Sample size (households) | | | Control | | | Exclusive intervention stove | | | Mixed stove | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Control** | **Exclusive** | **Mixed** | **Baseline mean ± SD** | **Median difference** | **95% CI for the median difference** | **Baseline mean ± SD** | **Median difference** | **95% CI for the median difference** | **Baseline mean ± SD** | **Median difference** | **95% CI for the median difference** |
| **$PM_{2.5}$** (μg/m3) | 72 | 39 | 25 | 358 ± 394 | 160 | 85, 237 | 372 ± 367 | 44 | -57, 144 | 446 ± 455 | 65 | -67, 198 |
| **Abs** ($10^{-6}$/m) | 71 | 38 | 25 | 28 ± 17 | 34 | 20, 54 | 29 ± 15 | 29 | 14, 42 | 32 ± 17 | 40 | 18, 64 |
| **Abs/$PM_{2.5}$** ($m^2$/g) | 71 | 38 | 24 | 0.12 ± 0.06 | 0.04 | 0.01, 0.07 | 0.12 ± 0.07 | 0.07 | 0.03, 0.12 | 0.12 ± 0.08 | 0.10 | 0.06, 0.15 |

*Exclusive=exclusive intervention stove group; mixed=mixed stove group; CI=confidence interval. Median and 95% CI obtained from paired Wilcoxon test.*

## Appendix C

## Appendix C.1: Interview question guides

Appendix C.1.1: Interview questions for cooks and fuelwood collectors

**SEMI-STRUCTURED INTERVIEW GUIDE**
**(for main cook and fuelwood collector)**

Household ID: ___________
Interviewee subject ID: _______________
Interviewer initials: _______________
Date of interview: _______________ Location of interview: _______________
Interview Start Time: __________ End Time: ____________
Voice Recorder File ID: ________________

We'll be talking today about your experiences with activities relating to cookstoves, fuelwood collection and livelihoods. The interview will take about 45 minutes to 1 hour of your time. You can stop the interview at any time, or if you do not want to answer any of the questions, please let me know and we can skip it.

**I. Cooking**

1. What type of cookstoves do you use at home? If more than one, how many of each stove type are there?
2. How long have you been using each type of stove?
3. For what purposes do you use each type of stove?
   - PROBE: Specify by type of food, i.e. curries, roti, tea, as well as other uses aside from cooking, i.e. room heating, drying clothes, and any other cultural practices/significances.
4. How often do you use each type of stove, i.e. once a week, everyday?
   - PROBE: Which type of stove do you use the most?
5. Do you do any other activities during cooking period, i.e. when the cookstove is burning? If so, can you tell me what they are?
   - PROBE: floor sweeping, clothes washing, child care, livestock feeding, etc.
6. Is there anyone else in the family who help you while you cook? What do they do?
7. Have you ever used the intervention stoves? If yes, what was your experience like?
   a. If you are no longer using intervention stoves, can you tell me why you no longer use/need them?
   - PROBE: Do you use the intervention stoves with other stoves?

**II. Fuelwood Collection**

8. Do you make separate trips to collect fuelwood or combine with other work tasks?
   - PROBE: Why do you combine or make separate trips? Does it depend on season, labor availability, harvest/planting time, etc.?
9. Do you collect fuelwood by yourself, with your family members, or friends and neighbors from your community?
   - PROBE: Why do you collect fuelwood by yourself/with family members/friends/neighbors?

Semi-structured Interview Guide, 5/8/2014 Page 1 of 3

10. Over the past 10 years, have there been any changes experienced by you and your family members in collecting fuelwood, such as distances travelled, fuel wood load carried/trip or wood type? How have these changes affected the quality of life for you and your family members?

**III. Livelihood**

11. What is your main occupation?
12. How long have you been doing this main occupation?
13. What major challenges do you face in carrying out tasks related to your main occupation?
    - PROBE: Are these challenges related to person (labor shortage, health, skills, time), environmental (weather, water, proximity to markets), social, etc.?
    - How could these challenges be overcome?
14. Do you have any other occupations? If yes, how long have you been doing this occupation?
    - PROBE: Why did you choose this occupation?
15. What major challenges do you face in carrying out tasks related to your secondary occupation?
    - PROBE: Are they related to person (labor shortage, health, skills, time), environmental (weather, water, proximity to markets), social, etc.
    - How could these challenges be overcome?
16. Would you like to have any other occupations in addition to or in place of your current occupation? If yes, what kind and why? What is preventing you from pursuing this occupation?
17. Can you describe your normal day activities from the time you wake up to when you go to sleep?
18. What major challenges do you face in carrying out your daily activities (example: non-occupational related activity)?
    - PROBE: Personal (health, time), environmental (weather, distance/proximity to things), social, etc.
19. If you had extra time in a day, what would you do with the extra time?
    - PROBE: Can you provide examples of an activity you would do if you had 1 extra hour in your day versus an extra 3-4 hours in your day? And why?
20. Are there **livelihood related activities** that you want to do in order to improve your **livelihood**? What is preventing you from doing them?
    - PROBE: For example, spend more time on farm to increase production; gain more skills to fix machinery/equipment.
21. Are there **non-livelihood related activities** that you want to do in order to improve your **quality of life**? What is preventing you from doing them?
    - PROBE: For example, sleeping, spending time with children, helping children study.

**FOR CURRENT INTERVENTION STOVE USERS:**

22. Since you started using the intervention stoves, has there been a change in the way you carry out your daily domestic activities? If so, can you explain how they have changed?

- PROBE: Domestic activities include any activities conducted in and around home such as food preparation; dish washing; cleaning and other upkeep; laundry, ironing, handicrafts; gardening; construction; repairs; shopping and services; child care; adult care; and others.

23. Since you started using the intervention stoves, has there been a change in the fuel wood load, type of wood or the frequency, duration, and pattern of fuel wood collection? If so, can you explain how they have changed?
    - PROBE: Please explain these changes that are specific to you and then for your family members who are involved in fuel wood collection. How have these changes impacted your quality of life and that of your family members?
24. Has the use of intervention stoves affected any other aspect of your life outside of domestic setting, such as in your occupation, social interaction with others, health, etc.? If so, can you explain how it has been affected?
25. Since you started using the intervention stoves, has there been a change in the number or size of dishes prepared for a meal or number of meals cooked in a day compared to when you did not have intervention stoves? If yes, in what way and why?
26. Do you believe that use of intervention stoves has resulted in time savings or time loss relating to cooking? Can you tell me the activities where you experience time savings or time loss?
    - PROBE: Specify activities, including type of item cooked.
    - PROBE: **If time is saved**, what activities do you do more of as a result of the saved time? How does this new activity affect your quality of life and that of your family members?
    - **If time is lost**, what activities that you do less of as a result of the lost time? How has this affected your quality of life and that of your family members?

27. Do you believe that use of intervention stoves has resulted in time savings or time loss relating to fuel wood use and collection? Can you tell me the activities where you experience time savings or time loss?
    - PROBE: Activities include fuel wood cutting at home and in the field, harvesting, carrying load back home, etc.

**IV. Wrapping Up**

28. Is there anything we haven't covered that you'd like to mention relating to cooking and fuel wood collection activities, and livelihood practices?

We want to thank you for your time and help with this study.

**Appendix C.1.2: Key informant interview questions**

KEY INFORMANT INTERVIEW (KII) GUIDE

I. CDM PROGRAM IMPLEMENTATION - GENERAL

1. How long have you been working with the NGO's CDM stove program?
2. What is your position in the CDM program?
3. What are your responsibilities in the CDM program?
4. Can you describe your activities on most days related to the CDM program?
5. What are the major goals of the stove intervention program?
6. Which goals would you say the program has been <u>MOST</u> effective in achieving?

II. CDM PROGRAM IMPLEMENTATION - SPECIFC TO VILLAGES

**Now we would like to ask you specifically about stove intervention program in Chickonkuni or Deodurga.**

7. When did the CDM stove intervention program begin in Chickonkuni (for Balappa) or in Deodurga?
8. Can you describe the sequence of activities that took place [in Chickonkuni (for Balappa)] or in a village <u>BEFORE</u> the CDM program implementation?
   PROBE: Education/awareness activities, surveys (including frequency administered and purpose), etc.
   PROBE: How frequently were those activities?
9. What kinds of activities are done <u>AFTER</u> the intervention stoves are distributed in a community?
   PROBE: Activities related to monitoring, motivation (i.e. lottery), training, etc?
   PROBE: What is the frequency of those activities, i.e. monitoring once a week in each home, etc?
10. What kind of challenges do you face in getting households to <u>initially adopt</u> the intervention stoves?
    PROBE: Do the challenges vary by different types of households, such as men vs. women as head of household; younger vs. old head of household, rich vs. poor, etc.?
11. How did you overcome those challenges to get households to adopt the intervention stoves?
12. Once households have taken the intervention stoves into their homes, what kind of challenges do you face in getting households to <u>continue their usage</u>?
    PROBE: Are there cultural or behavioral challenges?
    PROBE: Do the challenges vary by different types of households, such as men vs. women as head of household; younger vs. old head of household, rich vs. poor, etc.?
13. How did you overcome the challenges to get households to continue usage of intervention stoves?

II. LIVELIHOODS

14. From your experience working in the rural communities here, what are the major challenges that households face in carrying out their livelihood activities?
    PROBE: Are these challenges related to credit, person (labor shortage, health, skills, time), environmental (weather, water, proximity to markets), social, etc.?
15. Do these challenges differ by gender (i.e. for men and women)? Can you explain how they defer for women and men separately?
16. Do these challenges differ by caste or socio-economic groups? Can you explain how they defer for poor and lower caste groups versus richer and higher cast groups?
17. Based on your experience working in the rural communities in Deodurga, what are the major strategies you have seen used by households to improve their livelihoods?
    PROBE: Do household members migrate to cities, borrow money to buy more animals, building irrigation, take a secondary or third occupation, etc.?
18. Do these strategies differ by gender? Can you explain how they differ for women and men separately?

Key Informant Interview Guide, 7/8/2014 Page 1 of 2

19. Do these strategies differ by caste or wealth? If yes, how do they differ?

## III. TIME-USE

20. Have you noticed any changes in households' practices related to **domestic activities** since the adoption of intervention stoves? In what ways have the intervention stoves improved domestic activities?
    PROBE: Domestic activities include any activities conducted in and around home such as food preparation; dish washing; cleaning and other upkeep; laundry, ironing, handicrafts; gardening; construction; repairs; shopping and services; child care; adult care; and others.
    PROBE: Anything related to cooking and fuel wood collection activities?
21. Have you noticed any changes in households' **livelihood practices** since adoption of intervention stoves? In what ways have the intervention stoves improved livelihood activities in villages (or Chickonkuni for Balappa)?

## IV. WRAPPING UP

22. Is there anything we haven't covered that you'd like to mention relating to CDM program, potential impacts on time-use and livelihoods?

We want to thank you for your time and help with this study.

**Table C-1: Job title and responsibilities of key informants interviewed**

| Job title | Responsibility |
|---|---|
| Project Trainer | Train staff members working in the CDM project, including the coordinator, animators, etc., covering 17,000 families. Prior to intervention in a village, a “Roll out Team” is formed which undergoes 5 day of training involving about 32 members of coordinators and animators.<br><br>One project trainer was working on the CDM project in Deodurga at the time of the interview. |
| Hobli Coordinator | Supervise intervention stove usage in 34 villages of Deodurga through 7 animators. Attending VCCC meeting, organize incentive program related to intervention stove usage, visiting families and encouraging them to use the intervention stoves regularly. Also visits the traditional stove homes to convince them to use the intervention stoves.<br><br>A total of 4 Hobli Coordinators were working on the Deodurga CDM project at the time of the interview. |
| Animators | Animators are usually from one of the villages where cookstove intervention is occurring. They are responsible for 3-5 villages depending on size of the villages. Responsibilities include visiting houses and providing information about the intervention stoves to convince their uptake. They also visit homes of current intervention stove users to answer questions and address issues, and do any repairs needed, including replacement of broken stoves. A village receiving the intervention is visited at least once a week by an animator.<br><br>A total of 27 animators were working on the Deodurga CDM project at the time of the interview. |

**Appendix C.2: Results**

**Figure C-1: Observed vs. self-reported morning cooking time**

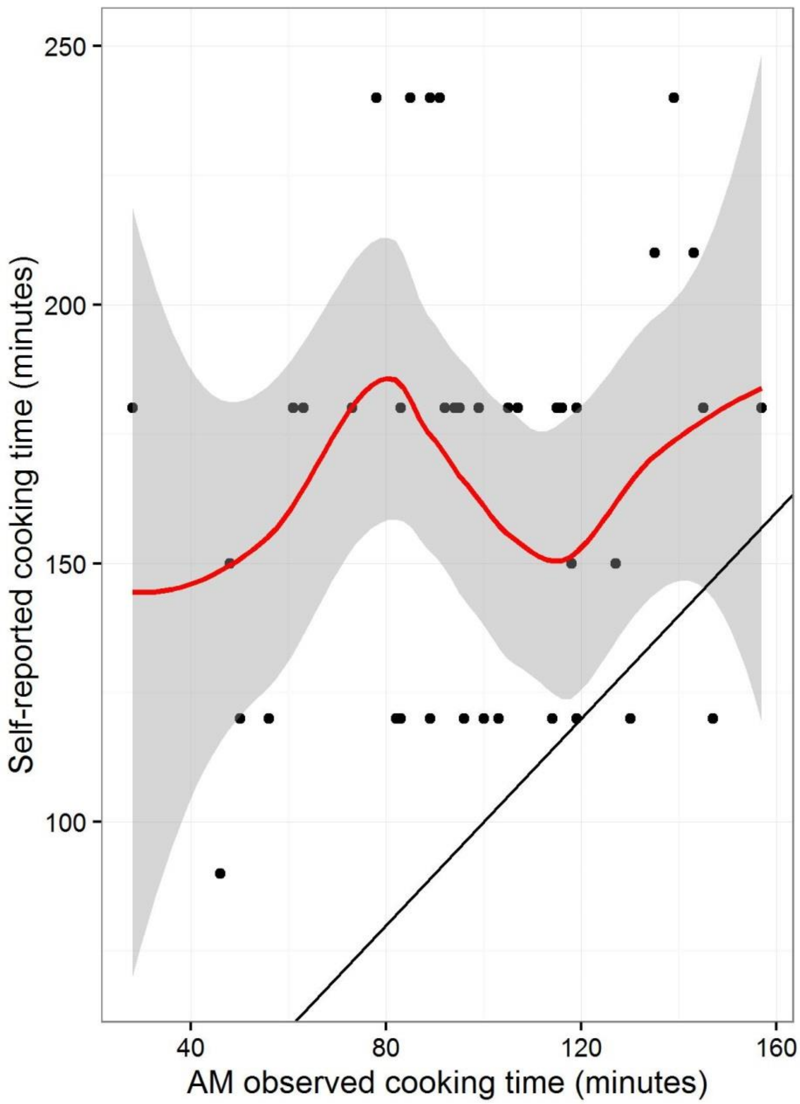


**Figure C-2: Observed vs. self-reported evening cooking time**

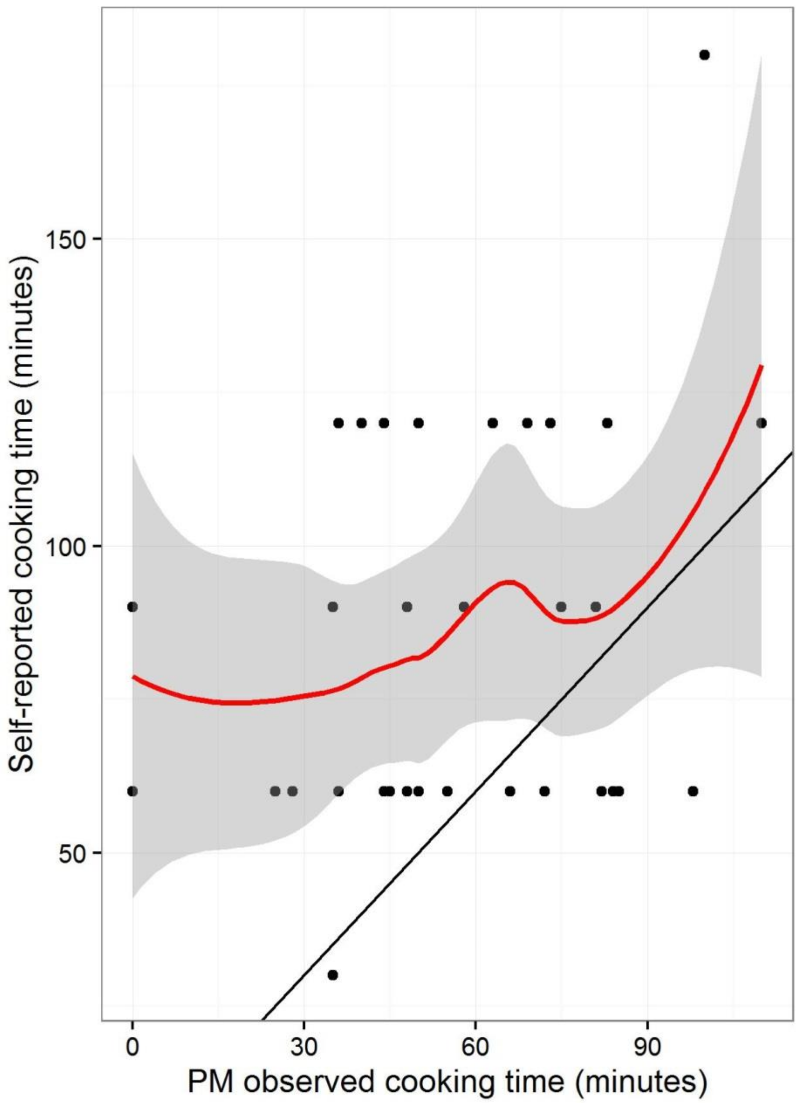
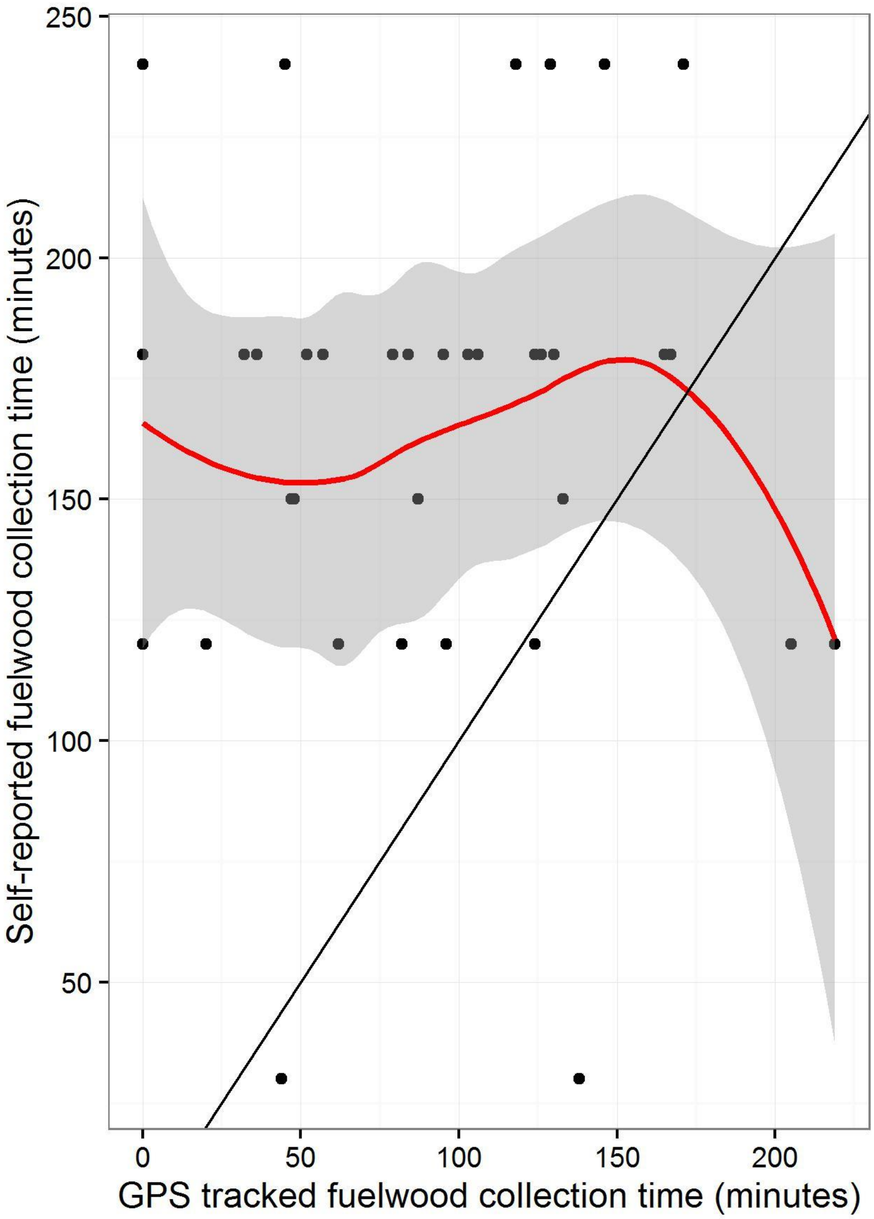


**Figure C-3: GSP tracked vs. self-reported time spent collecting fuelwood per day**




In Figures C-1 to C-2, red lines represent loess smooth line which showed little to no correlation between observed or GPS tracked time with self-reported time on cooking and fuelwood collection activities. The majority of self-reported responses sit above the black lines (slope=1) meaning large overestimating in self-reported time spent on cooking and fuelwood collection activities.

## Table C-2: Cooking times and patterns between exclusive and mixed stove groups

| | Exclusive intervention stove | Mixed stoves | |
|---|---|---|---|
| **Morning** | **Median (25th-75th quartile)** | **Median (25th-75th quartile)** | **p-value[1]** |
| Cooking time from start-finish (minutes) | 85 (56-100) | 114 (89-125) | 0.10 |
| Time of all dishes cooked combined (minutes) | **115 (85-124)** | **151 (120-196)** | **0.02** |
| Number of dishes cooked (mean) | **3.4** | **4.4** | **0.05** |
| Number of non-cooking activities done | 2.5 | 2.8 | 0.27 |
| **Evening** | | | |
| Cooking time from start-finish (minutes) | 50 (40-69) | 52 (46-72) | 0.39 |
| Time of all dishes combined (minutes) | 55 (43-70) | 82 (52-112) | 0.07 |
| Number of dishes cooked (mean) | 2.5 | 2.9 | 0.15 |
| Number of non-cooking activities done | 2.0 | 2.0 | 0.90 |

[1] *Significance test using Wilcoxon test between exclusive and mixed stove groups*

**Table C-3: Regression results**

**Regression 1: Distance travelled per week**

$$\text{Distance per week} \sim \beta_0 + \beta_1 \text{StoveUse} + \beta_2 \text{Assets}$$

```
Residuals:
   Min      1Q  Median      3Q     Max
-10.073  -4.001  -1.217   2.714  13.230

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)   14.8268     4.4904   3.302   0.0045 **
StoveUse1     -3.8477     4.1176  -0.934   0.3640
StoveUse6      2.3531     3.4466   0.683   0.5045
Sum_HH_items  -2.0871     0.9163  -2.278   0.0368 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.354 on 16 degrees of freedom
Multiple R-squared:  0.3227,    Adjusted R-squared:  0.1957
F-statistic: 2.541 on 3 and 16 DF,  p-value: 0.093
```

**Regression 2: Distance travelled per trip**

$$\text{Distance per trip} \sim \beta_0 + \beta_1 \text{StoveUse} + \beta_2 \text{Assets}$$

```
Residuals:
   Min      1Q  Median      3Q     Max
-3.6206 -1.2033  0.2721  0.9735  3.6132

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)    3.3912     1.3422   2.527   0.0224 *
StoveUse1      2.6156     1.2308   2.125   0.0495 *
StoveUse6      0.6185     1.0302   0.600   0.5567
Sum_HH_items  -0.3098     0.2739  -1.131   0.2747
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.899 on 16 degrees of freedom
Multiple R-squared:  0.3592,    Adjusted R-squared:  0.239
F-statistic: 2.989 on 3 and 16 DF,  p-value: 0.06212
```