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An Evaluation of Market Based Policy Instruments for Clean Energy in the Global South

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An Evaluation of Market Based Policy Instruments
for Clean Energy in the Global South

By

Jimmy Hung Tran

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University of California, Berkeley

Committee In Charge:

Professor Dara J. O’Rourke, Chair
Professor Katherine M. O'Neill
Professor Thomas B. Gold

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ABSTRACT

An Evaluation of Market Based Policy Instruments
for Clean in Energy in the Global South

By

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Doctor of Philosophy in Environmental Science, Policy, and Management
University of California, Berkeley

Professor Dara O'Rourke, Chair

The growth of carbon markets over the past decade has emerged as a powerful form of pro-poor financing that has quickly increased the number of rural household energy efficiency programs implemented in the global south. This dissertation explores the role that market-based policy instruments can have in advancing the dual goals of rural energy access and sustainable development in the global south. Historic low carbon prices combined with contentious international climate negotiations and an uncertain future for emission trading systems serve as the context for this study, which offers insights for policymakers in structuring future market mechanisms for increasing energy access for the global poor. My findings highlight the important role of nonstate actors in creating predominantly private and voluntary systems of market-based policy initiatives that are only now emerging in the face of faltering international action for climate change in a post-Kyoto Protocol era. Through grounded case studies I examine key assumptions that underlie carbon accounting rules and metrics to understand the consequences for practical monitoring, reporting, and verification (MRV) under market-based policies. I also present empirical data from household air pollution and fuel consumption measurements from village homes in China to highlight the importance of developing robust monitoring protocols for new technologies prior to inclusion into market-based programs.

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CHAPTER 1 INTRODUCTION

Market-based solutions for climate policy underpin the main political frameworks that have emerged from the Kyoto Protocol and continue to influence current climate policy discussions today. One of the largest market-based policy frameworks to result from the Kyoto Protocol's first commitment period — what is now collectively known as carbon markets and their related emission trading systems — is the focus of this dissertation. Through empirical evidence from fieldwork in China and case study of existing carbon financed programs, I investigate the fundamental operations of carbon markets to identify the opportunities and barriers offered by market-based policy approaches to promoting energy access and sustainable development in the global south. I also examine the growth of new ancillary markets that have capitalized on the carbon market framework to create new markets for climate and development "co-benefits" and I explore possible future pathways for global governance over energy access.

With the global recession and downturn in carbon markets by the end of Kyoto Protocol's first commitment period ending in 2012, the success and sustainability of carbon markets to serve as an effective tool for rural energy development in the global south has been called into question. Private actors have emerged as strong sources of innovation and have capitalized on the carbon market framework and its monitoring, reporting, and verification (MRV) architecture to create new models of finance. The emergence of this nonstate led "private authority" continues a pattern found by Green (2013) that shows an increasing number of private environmental standards and rules to come out of the private sector, which is in contrast to more typical governmental rule making and regulation over environmental issues (Green, 2013). The increasing importance of nonstate actors to support action on the dual goals of climate mitigation and sustainable development reflects a broader landscape of public and private authority over environmental governance, or what Ostrom (2010) refers to as "polycentric" authority (Ostrom, 2010). The promotion of markets, nonstate actors, and private finance as primary vehicles for responding to climate change and sustainable development represents a deepening of traditional market-based approaches into global climate politics (Newell & Paterson, 2010).

The growth of carbon markets over the past decade led to a proliferation of carbon financed rural energy programs that have sought to address the climate externalities caused from the combustion of solid fuels in rural homes. With the crash in carbon markets in 2012, nonstate actors have once again turned to markets for possible solutions to addressing development needs. Energy access programs in the global south have been at the vanguard of creating new market mechanisms in support of climate and sustainable development. Recent initiatives have sought to more closely link human health outcomes to private markets. The relationship between global climate change and human health has only grown stronger in recent years (K. R. Smith, A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn 2014). Globally, the World Health Organization (WHO) estimates that the lack of access to clean energy results in nearly four million premature deaths per year due to illnesses attributable to household air pollution from the use of traditional cooking and heating fuels[1]. In China alone, WHO estimates that 420,000 premature deaths per year occur due to exposure to indoor air pollution from the use of solid fuels (WHO, 2006a). Understanding the policy tools and mechanisms available for tackling such large health burdens is crucial. China in particular will play an outsized role in "moving the needle" on improving health outcomes due to its disproportionate share of worldwide household users that still rely on solid fuels for cooking and heating. Policies, standards, finance, technology, and human behavior are all important factors necessary for understanding possible future pathways for clean energy transitions that address both the health and climate needs of the global south and emerging economies such as China.

Chapter two provides a case study from field research conducted in China during early 2009. Over the course of 3 months, I monitored indoor air pollution in village households to understand the effects of fuel switching on climate and health outcomes. My results show that reductions in area concentrations of health damaging pollutants were not directly correlated to reductions in GHG emissions, and in the case of the technology examined for this study, the concentration of health damaging pollutants may in fact be higher in homes with "improved" stoves as compared to the traditional baseline technology. In contrast to the many claims of health and climate "co-benefits" resulting from stove intervention programs, this work demonstrates the importance of on-the-ground monitoring, reporting, and verification (MRV) of not only carbon reductions but also of sustainable development co-benefits. Energy programs operating cookstove programs must develop comprehensive laboratory testing protocols that more closely reflect actual in-home operation. More broadly, my results highlight the health risks to local communities and climate risks for national energy policy when holistic programmatic outcomes are not measured, but rather assumed, prior to large scale dissemination and inclusion into environmental markets.

Chapter three examines the role of nonstate actors in advancing decarbonization and clean energy development in rural communities of the global south. I argue that the establishment of a global carbon market has provided the critical architecture and framework for new market innovations to emerge. I begin by tracing the institutional and normative processes that have shaped the current financial markets for carbon credits for rural household energy. I briefly explain the historical arc of market-based approaches (i.e. emissions trading and carbon markets) as a regulatory tool for environmental governance, and introduce the mechanics of carbon markets as a way to ground my discussion of emerging markets for results-based financing. By understanding the organizational and functional forms of carbon markets, we can begin to explore the ways in which new emerging market-based policy instruments have been able to leverage the existing carbon market architecture to create new opportunities for pro-poor finance outside of the regulated Kyoto-centered emissions trading system. Through case studies of three emerging results based financing (RBF) methodologies for clean energy in the global south, I identify a hybrid form of public-private governance that is collaborating to create private markets that parallel much of the monitoring, reporting, and verification (MRV) architecture established by the Kyoto-centered carbon market. I further find that these new markets are gaining political authority through the systematic use of pre-existing knowledge, relationships, and finance from the "carbon regime." I conclude by situating their

[1] http://www.who.int/mediacentre/factsheets/fs292/en/ [last accessed 4.23.2015]

activities in a broader "polycentric" landscape of environmental governance and discuss the implications for international climate and development policy.

Chapter four explores the role of quantification and objectivity discourse in formulating the greenhouse gas (GHG) accounting metrics that underlie carbon markets. Specifically, I show how classification and framing of scientific climate metrics at the Intergovernmental Panel on Climate Change (IPCC) have directly configured current carbon offset markets and how this, in turn, has defined how and which actors are allowed to participate in the global carbon trading economy. I go on to explore the consequences, both intended and unintended, of "climate metrification" for programs that participate in carbon markets. My research questions the environmental integrity of existing carbon quantification methodologies by diving into the underlying GHG accounting principles used for constructing carbon offsets. I discuss the trend towards simplified MRV rules to highlight the risks that carbon methodologies pose for environmental integrity. I conduct an analysis of a United Nation's methodology for cookstove carbon quantification to demonstrate the high variability and fluidity inherent in climate accounting rules and standards. These findings challenge the widely held perception that carbon financial markets are technically precise and objective. I conclude by positing on the nature and function of climate metrics for global environmental governance and its relevance to international negotiations towards a potential climate accord in 2015.

Chapter five concludes with a discussion of the role of common and comprehensive metrics and standard setting for emerging market and non-market based programs in achieving climate policy objectives. In the absence of guiding principles and appropriate rules and regulations for on-the-ground monitoring, reporting, and verification (MRV), the growth of new environmental markets can lead to a further erosion of trust and legitimacy of pro-poor market-based programs and impede the long-term sustainability of these new endeavors. I provide policy recommendations to improve the social and environmental integrity of carbon markets and related results-based financing programs. This research is critical at a time when policymakers are questioning the appropriateness of including small-scale decentralized energy-efficiency projects under the umbrella framework of compliance-based carbon markets, and provides key considerations for future market-based programs.

CHAPTER 2 FIELD MEASUREMENTS OF HOUSEHOLD AIR POLLUTION IN CHINESE VILLAGE HOMES

ABSTRACT

Exposure to household air pollution (Sasser et al.) from cooking and heating with solid fuels contributes to global health burdens and greenhouse gas (GHG) emissions. A class of stove technology described as "semi-gasifier" has been shown to greatly reduce HAPs and GHG emissions in laboratory settings, yet few studies have conducted field measurements to validate HAP concentrations from gasifier stoves in actual homes. We conducted in-field HAP measurements in 56 intervention homes that received semi-gasifier stoves. The study utilizes a paired before and after study design. Particulate matter with aerodynamic diameter <2.5 µm ($PM_{2.5}$) and carbon monoxide (CO) were measured continuously for 24 hours first in homes with traditional coal stoves (pre-intervention) and then followed by improved biomass semi-gasifier stoves (post-intervention). The sample was divided into 35 households with separate kitchens and 21 with attached kitchens. The average 24-h area concentration of $PM_{2.5}$ showed no statistical change between pre-intervention and post-intervention homes with attached kitchens [106 µg/m^3 (95% CI: 67, 147) vs. 132 µg/m^3 (95% CI: 68, 196); P = 0.34; N=19], and no statistical difference between homes with separate kitchens [158 µg/m^3 (95% CI: 85, 230) vs. 97 µg/m^3 (95% CI: 57, 136); P = 0.15; N=30]. Average 24-hr area concentration of CO showed no statistical difference between pre-intervention and post-intervention in homes with attached kitchens [10.6 ppm (95% CI: 2.6, 18.6) vs. 6.6 ppm (95% CI: 5.6, 22.8); P = 0.30, N=19], but a statistical reduction in CO was found in separate kitchens when comparing pre-intervention and post-intervention stoves homes [14.2 ppm (95% CI: 2.6, 18.6) vs. 5.3 ppm (95% CI: 2.8, 7.8); P = 0.03, N=23]. World Health Organization guidelines recommend limiting exposure to peak 15-minute CO concentration to below 87 ppm. The maximum 15-min average was exceeded by at least 50% in both attached and separate kitchens by the post-intervention stove [highest arithmetic mean 15-min average, 145 ppm (95% CI: 65, 22; N=19) vs 137 ppm (95% CI: 53, 220; N=22)]. Collectively, these results show that reductions in area concentrations of health damaging pollutants are not directly correlated to reductions in emissions based on laboratory testing, and that in fact, the concentration of health damaging pollutants may be higher in homes with "improved" stoves as compared to the traditional baseline technology. These findings are important for future stove intervention programs and can inform the development of emerging results-based financing schemes that seek win-win solutions for improving climate and health outcomes. Most importantly, these findings highlight the importance of developing improved lab testing protocols that more accurately reflect in-home conditions and actual usage patterns.

INTRODUCTION

Background

Co-Benefits

The World Health Organization (WHO) considers reliance on solid fuel to be both a cause and a result of poverty (WHO, 2006a). Poor families do not possess the resources necessary to secure access to cleaner fuels and improved technologies. Further the health and climate complications that result from dependence on traditional appliances and fuels are severe enough to hinder economic development and further entrench households in poverty.

The growth of carbon markets over the past decade has emerged as a powerful form of pro-poor financing that has quickly increased the number of stove intervention programs in the Global South. Mitigating greenhouse gas emissions in the household energy sector has been viewed as a cost-effective approach to simultaneously achieving ancillary benefits such as human health improvements, poverty reduction, and climate mitigation (Aunan, Fang, Hu, Seip, & Vennemo, 2006; Haines et al., 2009; Kirk R. Smith & Haigler, 2008). Collectively, these ancillary benefits have been termed "co-benefits." Co-benefits from cookstove programs are achieved primarily by reducing human exposure to household air pollution through fuel savings during cooking, heating, and water purification.

Actual health co-benefits from stove programs, however, are generally assumed rather than measured. This is due to the high cost and technical capacity required to conduct epidemiologically based exposure assessments and air pollution monitoring. In contrast, estimation of greenhouse gas (GHG) reductions can be more easily calculated using technology performance specifications, or through relatively low-cost monitoring techniques. For carbon offset programs, methodological rules and GHG accounting guidelines require intervention programs to estimate Kyoto-GHG reductions through a combination of measurements and calculations that use default equations and emission factors provided by the Intergovernmental Panel on Climate Change (IPCC). In contrast, there are no methodological requirements for carbon offset programs to measure or estimate health burdens from co-emitted emissions during fuel burning, despite the many claims of "co-benefits" that result from intervention programs.

This paper provides important insights for future stove intervention programs that seek to maximize the co-benefits achieved by their programs. This research highlights the importance of developing comprehensive testing protocols that fully evaluate stove performance prior to large scale stove dissemination. These findings can also inform the broader development of emerging results-based financing schemes that seek win-win solutions for improving climate and health outcomes.

China

The scale of CO2 emissions and human health burdens from cooking and heating with solid fuels is most pronounced in emerging economies such as India and China that are home to large populations of solid fuel users. In China alone, half of all households, and over 80% of all rural households, still rely on solid fuels such as coal and biomass for a significant portion of their household energy (WorldBank, 2013). Despite three decades of coordinated stove intervention programs by the Chinese central government, $PM_{2.5}$ concentrations in rural Chinese homes remain consistently above Chinese Indoor Air Quality (IAQ) standards (35-75 $\mu g/m^3$-24hr) and World Health Organization (WHO) Air Quality Guidelines (25-75 $\mu g/m^3$-24hr) (R. Edwards, 2004; R. D. Edwards et al., 2007). The most recent comparative risk assessment for the Global Burden of Disease estimates that HAP from solid fuels was responsible for nearly 3.5 million deaths worldwide in 2010, with nearly 1 million deaths attributable to China alone (Lim et al., 2013). Parts of China are also home to endemic "dirty coal" which is bound with health damaging pollutants such as arsenic, fluorine, and selenium and that are particularly toxic to human health (Liu et al., 2002; Zheng et al., 1999). Increased risk of developing lung cancer, chronic obstructive pulmonary disease (COPD) in adults, and acute lower respiratory infection (ALRI) in children, are amongst the growing epidemiological evidence emerging that has linked exposure to HAP to premature death and ill-health (Gordon et al., 2014).

$PM_{2.5}$ Measurements

Particles smaller than 2.5 microns ($PM_{2.5}$) pose the greatest risk to human health because of their ability to enter deep into airways and reduce lung function and affect respiratory health. As a result $PM_{2.5}$ is the best single indicator of household air pollution. Pollutant $PM_{2.5}$ concentrations in rural Chinese homes have been shown to vary dramatically depending on stove and fuel combination used (K. R. Smith et al., 2000; J. Zhang et al., 2000; Z. Zhang & Smith, 2007). Lab-based ex-ante estimates of emissions compared to ex-post in-field household measurements often differ due to external factors faced in the real world (R. Bailis et al., 2007; Johnson, Edwards, Alatorre, & Frenk, 2007; Christoph A Roden, Bond, Conway, & Pinel, 2006). Behavioral patterns and stove operation techniques such as fuel lighting, choice of wood fuel (type, size, moisture), cooking style, and refueling rate, are just a few of the known behavioral and external factors shown to greatly affect overall particulate matter emissions (Berrueta, Edwards, & Masera, 2008; Ezzati, Mbinda, & Kammen, 2000; Jetter et al., 2012; Christoph A. Roden et al., 2009).

Technology

This study was conducted in 2009 following a multi-year collaboration between the Shell Foundation and the Chinese Ministry of Agriculture which sought to identify the cleanest and most efficient types of biomass stoves currently available in the Chinese cookstove market. A national stove competition was hosted to identify promising clean stove technologies and subsequently, to help the local technology manufacturers commercialize and scale the distribution of clean stoves to communities using inefficient and dirty traditional stoves.

The competition focused on a new stove technology classified as “semi-gasifier” that had been shown in lab tests to greatly reduce emissions of both climate and health damaging pollutants (HAPs). This class of stove design utilizes unique airflow to allow pollutants from fuel combustion to be burned both at the bottom (primary) and the top (secondary) of the stove, thus allowing for more complete combustion of fuel emissions through a process of primary and secondary “gasification.” Many semi-gasifiers also use a fan to improve combustion efficiency by increasing airflow to the firing chamber. The combination of gasification and the use of a fan was shown in lab tests to greatly reduce fuel consumption and health damaging “products of incomplete combustion” (PICs). In some cases, these stoves perform as cleanly as LPG cooking devices (Mukunda et al., 2010).

Few studies, however, have actually measured direct emissions concentrations from semi-gasifier stoves in real homes (BerkeleyAir, 2012). Lab-based emission measurements from Chinese manufactured semi-gasifier stoves have shown a wide range of lab performance, and in some cases, have been found to have emissions exceeding those from a 3-stone fire, a stove that is considered by many to be among the most rudimentary of traditional stoves (Carter, Shan, Yang, Li, & Baumgartner, 2014; Jetter et al., 2012). Poor phase burning, fuel quality, and cooking technique likely contribute to the variability seen in recent lab testing. For Chinese semi-gasifier stoves, the lighting phase alone has been shown to contribute nearly half of total $PM_{2.5}$ emissions during lab tests, and medium power firing phase (such as water simmering) can double $PM_{2.5}$ when compared to high power firing (Carter et al., 2014).

China National Improved Stove Program (NISP)

The first wave of improved stove dissemination in China occurred in the early 1980’s through a National Improved Stove Program (NISP) which disseminated over 100 million improved stoves (Kirk R. Smith, Shuhua, Kun, & Daxiong, 1993). NISP initially focused on improving fuel efficiencies of biomass stoves, and later coal stoves, and incorporating chimneys into new designs in order to address concerns of high HAP exposures. Due to their robust design (cement or brick) and permanent construction into the walls of homes, many of these decades old “improved” stoves remain in use today, despite being eclipsed by cleaner and more efficient stove technologies. The NISP stoves are used in this study as part of the baseline pre-intervention study group.

Amidst explosive economic growth and widening income disparity between urban and rural households, there is now renewed focus to improve access to clean fuels and technologies for China’s remaining rural population. The Chinese government has collaborated with various international agencies to begin scoping work for a 21st century clean energy transition plan that would launch a possible “2nd National Improved Stove Program” (hereafter “NISP2”). Along with many other stove models, semi-gasifier stoves have been identified as a possible technology for the scaling of clean stoves in China (WorldBank, 2013) during NISP2.

This chapter contributes to the sparse literature on HAP from semi-gasifier stoves and provides valuable insights for policy makers that are mapping new large scale stove dissemination initiatives.

METHODS

A combination of ex-ante household surveys and household air pollution measurements were conducted in village homes to evaluate programmatic effectiveness of a cook stove intervention program in rural regions of Yangquan City, Shanxi.

Study Location

Residents in Shanxi Province rely heavily on raw and briquette coal for heating and cooking, and rely on agricultural residues such as corn cobs and corn stalks for winter heating. Heating in the winter is often supplemented by “kang” heating systems, which are beds with combustion chambers in the cavities beneath the sleeping platform (Cao et al., 2011; Zhuang, Li, Chen, & Guo, 2009). The baseline pre-intervention stove technologies examined for this study are primarily traditional metal stoves or large built-in “NISP” stoves that use raw coal as fuel. Coal dominates the fuel mix for residents in Shanxi, which reflects the vast reserves of coal available to residents in a province that possesses China’s largest known coal deposits. In 2009, nearly 80% of households in Shanxi and 93% of households in Yangquan City used coal for cooking and heating (Yangquan City Government Statistics 2010, China Energy Statistical Yearbook 2011).

Household Air Pollution Measurements

This study was conducted in March 2009 in Xiaohu village of Yangquan city, Shanxi province, China. We evaluated the effectiveness of a stove intervention program to reduce area concentrations of HAPs. We monitored $PM_{2.5}$ and CO continuously for 24 hours in homes that previously used traditional coal stoves (pre-intervention) and then switched to new biomass-based semi-gasifier stoves (post-intervention).

Village Selection

Due to our before- and after- study design and the constraint of pre-scheduled stove sales to communities, a single village was selected by local government officials to represent the best case scenario for the intervention program. Although our household selection criteria confirmed that socio-economic and demographic characteristics of Xiaohu village were congruent with the broader study region, we do not conclude that our data are representative or generalizable beyond that of the study population. Instead, the study results are intended to provide an illustrative case study of the potential impacts of semi-gasifier technology on household air pollution levels.

Household Selection

Participants were randomly selected from a pool of households that had chosen to pre-purchase the stove. Only homes that agreed to informed consent were allowed into the final sample pool. Sampling schedules were coordinated with the manufacturer to allow for a 2 week “adoption” period prior to beginning post-intervention measurements. Participation was voluntary, and those taking part were compensated with bed coverings, which was equivalent to 40 Chinese Yuan ($6.88USD). Household selection criteria included:

1) Village's primary economic output is maize-based agriculture.
2) Household previously used coal stoves, but has since switched completely to an improved corncob-based semi-gasifier stove.
3) Household has adopted for greater than 2-weeks an improved biomass semi-gasifier stove (Jinqilin Brand);
4) Household is still using the improved semi-gasifier stove.
5) Household still has an operational traditional coal stove that they are currently not using, but that they are willing to use for a 24 hour period for the study.
6) Household size is between 3 to 6 persons.
7) Head of household is between 25 yrs to 60 yrs old.
8) Head of household is not retired.
9) Household income is between 5,000 to 50,000RMB/yr (China's annual per capita income is $7,600USD, or slightly greater than 50,000RMB. Previous surveys in Shanxi reveal average HH incomes between 10,000RMB and 40,000RMB).
10) Household has either (1) Kitchen attached to main house but is a separate room, or (2) Kitchen is a separate building from main house.
11) Improved stove must be used in same room as Traditional Coal Stove.
12) Kitchens are either attached to the main home, or separate (Appendix A)

Sampling Design

A total of 56 households participated in this study – 21 households with attached kitchens and 35 households with separate kitchens. Monitoring of a single household with pre- and post-intervention stoves occurred over 3 days. Households were asked to first use the post-intervention biomass semi-gasifier stove from breakfast on day #1 to breakfast on day #2 (including day #2 breakfast), followed by the pre-intervention traditional coal stove from lunch on day #2 to lunch on day #3 (including lunch on day#3). Each home was visited 48 hours prior to HAP monitoring to ensure stove setup and preparation was complete.

Actual monitoring was conducted by a field team of 2 persons who arrived on day #1 between 9am-11am to setup and launch the monitoring devices for the post-intervention stoves and returned on day #2 during the same time period to remove the devices. Data downloading and device re-launching occurred between 12-1pm in a village council meeting room using a portable laptop. Launching and calibration of devices for pre-intervention stoves occurred on day #2 between 2-5pm, and device pickup occurred on day #3 during the same time period. All times were noted and final data was adjusted accordingly.

Standard procedures for device placement were used to harmonize field measures across homes, and placement was chosen to roughly match typical cooking distance and corresponding exposure. The following procedures were used:

1. Measure a horizontal distance of 100 cm from the center of the main stove
2. Measure a vertical distance of 150 cm from the floor.
3. Ensure the located point is at least 150 cm from any operable doors and windows.

Particulate Matter

Indoor household $PM_{2.5}$ concentrations were monitored continuously for 24 hours in all households using UCB Particle Monitors (Berkeley Air Monitoring Group; Berkeley, CA, USA). UCB Particle Monitors use light scattering technology from widely available residential smoke detectors to estimate particle mass concentrations. Housed within the UCB-PATS is a light-emitting diode (Aguilar) that continuously transmits at wavelength 880nm. As particles from the ambient environment enter the chamber, light is scattered and a photodiode measures the intensity of scattered light at an angle of 45° from the forward direction. The photoelectric signal is measured every 1 second and is recorded every minute as the average of the previous sixty 1 second readings (Chowdhury et al., 2007). The monitors were calibrated with wood smoke in a chamber in the Berkeley Air lab prior to use in households. To account for differences in coal smoke found in this study, adjustment factors were derived from linear regression between co-located gravimetric filters and UCB devices (see Appendix 2). Separate adjustment factors were applied to final pollutant concentrations based on which fuel was used in the home, i.e. either coal or biomass fuel. Data from each fuel type was pooled for separate and attached kitchens.

In a subset of 10 homes, gravimetric filter measurements were co-located next to the UCB Particle Monitor for both pre- and post- intervention measurements. Gravimetric filters used SKC universal PCXR series pumps (SKC Inc, Eighty Four, PA Wales, WI, USA), BGI Triplex cyclones (BGI Inc., Waltham, MA, USA), and 37 mm Teflon filters (Pall Corp., East Hills, NY, USA). SKC pumps were checked pre- and post-field deployment using a 0.4-5.0 L/min rotameter (SKC Inc, Wales, WI, USA) and were calibrated with a Bios Defender Model 510M Primary Calibrator (SKC Inc, Wales, WI, USA). Pumps were set to 1.5 L/min to correspond to particles ≤ 2.5 µm.

Standard protocols were followed for filter handling, including 24-h equilibration prior to microbalance weighing in a humidity and temperature controlled clean room. Filter measurements were conducted at Nankai University in Tianjin, China.

Carbon Monoxide

Onset HOBO electrochemical CO loggers (model #H11-001, Onset Computer Company; Bourne, MA, USA) were used to estimate mean 24-h CO levels. All devices were calibrated against a balanced 50 ppm CO span gas both before and after field deployment in a laboratory at Beijing University of Chemical Technology in Beijing, China. CO diffusion tubes (model #810-1DL, Gastec Corporation, Japan) were also collocated in a subset of homes to provide reference data for the continuous monitors. The diffusion tubes provided a cumulative concentration of CO during the measurement period, from which an average concentration could be derived and compared to results from Onset HOBO CO loggers.

Qualitative Survey

A qualitative survey was conducted with each household during the monitoring session. The survey captured household and cooking characteristics known to impact area concentrations of HAPs, including physical parameters of the living room and kitchen, other combustion devices used, and cooking habits of the household.

ANALYSIS

The study results are stratified by kitchen type and categorized as either having kitchens that are attached or separate from the main home. Separate structures that are detached from the home are common throughout China and are described here as "separate." To assess the role of home heating, 24-h measurements were further stratified temporally into daytime, early evening, and late evening time periods.

The arithmetic mean of $PM_{2.5}$ and CO mass concentrations were used to characterize area concentration in kitchens over a typical 24-h period. Arithmetic mean area concentrations are considered as proxies for human exposure and can be compared to national and international guidelines for HAP levels. All arithmetic mean comparisons utilized 2-sided paired t-tests, and all gravimetric mean comparison tests utilized nonparametric Wilcoxon matched-pairs signed rank tests. Statistical analyses were performed using STATA 12.0 (StataCorp, 2011).

Adjustments to $PM_{2.5}$ results were derived from linear regression of gravimetric filter verses UCB device results, which account for differences in fuel type used during initial manufacturer calibration and household measurements. Traditional coal stoves are denoted "pre-intervention," and biomass gasifier stoves are denoted "post-intervention."

RESULTS

HAP Concentrations

Distribution of Data

A Shapiro-Wilk test for normality suggests the sample population does not follow a standard normal distribution (p-value < 0.05), and distributional plots show the HAP data to be positively skewed with heavy right tails (Table 2). Log transformation resulted in lognormal distributions but with light right tails (Table 1).

Table 1 Log transformed $PM_{2.5}$ for attached and separate kitchens using parametric pairwise 2-sample t-test.

Log Transformed $PM_{2.5}$ ($\mu g/m^3$)					
24hr Mean	N	Pre-intervention Stove	Post-intervention Stove	Diff	Paired T-Test (p-value)
Attached Kitchen	19	4.4 (0.7)	4.4 (1.0)	0%	1.00
Separate Kitchen	30	4.5 (1.1)	4.1 (0.9)	-9%	0.07

Table 2 Shapiro-Wilk test for normality. H_0=Sample population is normally distributed. P-value < 0.05, thus reject null hypothesis and conclude sample population is not normally distributed.

Shapiro Wilk Test									
		Pre-intervention Stove				Post-intervention Stove			
	N	W	V	Z	Prob>z	W	V	Z	Prob>z
Separate Kitchen	30	0.683	10.073	4.776	0.00	0.711	9.197	4.588	0.00
Attached Kitchen	19	0.817	4.187	2.877	0.00	0.76802	5.296	3.348	0.00

Gravimetric means and nonparametric significance tests are reported to account for skewed and outlier data. Five homes with separate kitchens were removed because it was discovered that they did not meet household selection or monitoring criteria; these homes did not use the improved stove, or erroneously used fuels that were not measured by enumerators.

World Health Organization Guidelines

The World Health Organization (WHO) sets guidelines for pollutant levels to protect human health. Household air pollution $PM_{2.5}$ and CO levels in developing countries can exceed World Health Organization (WHO) standards by 2-3 orders of magnitude, with average 24-hour concentrations of $PM_{2.5}$ reaching 300-3,000 $\mu g/m^3$ (WHO, 2006b). Field measures of average 24-hour PM concentrations in Chinese village homes using traditional stoves have reported a range of values depending on fuel type (Baumgartner et al., 2011; R. D. Edwards et al., 2007; He et al., 2005). Table 3 shows typical PM and CO concentration levels in village homes across three provinces in China (R. D. Edwards et al., 2007). By comparison, $PM_{2.5}$ mass concentrations in metropolitan Beijing during the period 25 September to 15 November 2013 averaged 114 $\mu g/m^3$, with single day peaks reaching nearly 400 $\mu g/m^3$ (Guo et al., 2014).

Table 3 Summary of 24-h PM and CO concentrations in kitchens aggregating by fuel types from field measurements conducted across three provinces: Hubei, Shaanxi, Zhejiang

	n	Mean	s.d
Coal			
PM μg/m^3	39	141.9	83
CO ppm	4	13.1	26.4
Crop Residues			
PM μg/m^3	48	282.9	286
CO ppm	12	28.3	30.9
Wood and crop residues			
PM μg/m^3	33	192.5	107.1
CO ppm	3	2.9	2.4

**Table adapted from (R. D. Edwards et al., 2007)*

Table 4 compares our study results to the WHO maximum 15-minute and 8-hour guidelines for carbon monoxide, and average 24-h guideline for $PM_{2.5}$. Pairwise 2-sided t-Tests were used for significance tests (95% confidence).

Table 4 World Health Organization guidelines for $PM_{2.5}$ and CO

			WHO				GB 3095 - 2012**	
Pollutant	Period*	Unit	(IT-3)	(IT-2)	(IT-1)	AQG	Grade 1	Grade 2
$PM_{2.5}$	Annual	μg/m^3	35	25	15	10	15	35
	24-h	μg/m^3	75	50	37.5	25	35	75
CO	8-h	ppm	-	-	-	9	-	-
	1-h	ppm	-	-	-	25	8.7	8.7
	15-min	ppm	-	-	-	87	-	-

Sources: Adapted from (MEP, 2012; WHO, 2004, 2006b)
**Time weighted average exposure*
***Note conversion factors: [1ppm = 1.145 mg/m^3] and [1 mg/m^3 = 0.873 ppm]*

Particulate Matter 2.5 μg/m^3 ($PM_{2.5}$)

All 24-h $PM_{2.5}$ measures exceeded WHO AQG in both pre-intervention and post-intervention homes. The average 24-h area concentration of $PM_{2.5}$ showed no statistical change between pre-intervention and post-intervention homes with attached kitchens [106 μg/m^3 (95% CI: 67, 147) vs. 132 μg/m^3 (95% CI: 68, 196); P = 0.34; N=19], and no statistical change between homes with separate kitchens [158 μg/m^3 (95% CI: 85, 230) vs. 97 μg/m^3 (95% CI: 57, 136);

P = 0.69; N=30]. Geometric means using log transformation also resulted in no statistical difference between pre-intervention and post-intervention $PM_{2.5}$ levels in attached kitchens [83 µg/m^3 (95% CI: 58,119) vs. 83 µg/m^3 (95% CI: 52,133); P = 0.15; N=19], or separate kitchens [96 µg/m^3 (95% CI: 65,144) vs. 65 µg/m^3 (95% CI: 46,91); P = 0.36; N=30]. The impact of the intervention program on area $PM_{2.5}$ concentrations is largely inconclusive, but our results indicate that no improvements in household air pollution can be detected as a result of the improved stove.

Table 5 Mean 24-hour concentrations of $PM_{2.5}$ (µg/m^3) and CO (ppm). 95% CI are shown in parentheses, and N is the total number of households.

			PM 2.5 (µg/m^3) in Attached Kitchen			
24hr	N	WHO AQG	Pre-Intervention	Post-Intervention	Diff	T-Test (p-value)
Arithmetic Mean	19	25	107 (67,147)	132 (68,196)	23%	0.34
Geometric Mean	19	-	83 (58,119)	83 (52,133)	6%	0.69
			PM 2.5 (µg/m^3) in Separate Kitchen			
24hr	N	WHO AQG	Pre-Intervention	Post-Intervention	Diff	T-Test (p-value)
Arithmetic Mean	30	25	158 (85,230)	97 (57,136)	-39%	0.15
Geometric Mean	30	-	96 (65,144)	65 (46,91)	-30%	0.36

Carbon Monoxide

The WHO provides duration-based guidelines for exposure to CO due to its cumulative toxic effect in the blood stream. Exposure to high concentrations of CO during short durations can have an equal, if not worse, effect on human health when compared to exposure to lower level concentrations over longer periods (WHO, 2004).

We find a statistically significant decrease in CO concentration between pre- and post-intervention during 24-h averages for separate kitchens [pre-intervention = 14 ppm (20) vs. post-intervention = 6 ppm (6); P=0.05], and a statistical increase during 15-min peak averages for attached kitchens [pre-intervention = 55 ppm (50) vs. post-intervention = 145 ppm (166); P=0.03]. We also find that the maximum 15-min average in post-intervention homes are roughly the same between kitchen types [attached kitchen = 145 (SD: 166) vs. separate kitchen = 133 (SD: 184); P = 0.85], which represents a near 2-fold increase above the WHO maximum 15-min guideline of 87 ppm.

We did not find statistically significant differences in maximum 15-min CO concentrations between pre- and post- intervention homes within separate kitchens [pre-intervention = 140 ppm (173) vs. post-intervention = 133 ppm (184); P=0.90]. The absence of a statistical change is due to outliers in the pre-intervention homes that positively skew 15-min CO concentrations. For the purposes of this study these high concentration outliers are not removed due to the chance that these homes are indeed representative of high concentrations found in the broader population.

We also find the number of homes to exceed the 15-min maximum WHO guideline to occur at a higher proportion in the post-intervention sample homes as compared to the pre-intervention sample of homes [post-intervention vs. pre-intervention, respectively: [37% vs 21% in attached kitchens] and [65% vs. 43% in separate kitchens]. In contrast, the proportion of homes to exceed 8-h averages are roughly the same between pre- and post- intervention homes [post-intervention vs. pre-intervention, respectively: [58% vs 58% in attached kitchens] and [70% vs. 74% in separate kitchens].

Table 6 Comparison of kitchen CO concentrations to WHO air quality guidelines.

				CO (ppm) Attached Kitchen			
		N	WHO AQG	Pre-Intervention	Post-Intervention	Diff.	P-value
15 MIN	15-min	19	87	55 (50)	145 (166)	164%	0.03
24 HR	24-hr	19		11 (17)	7 (5)	-36%	0.31
CO (ppm) Separate Kitchen							
		N	WHO AQG	Pre-Intervention	Post-Intervention	Diff.	P-value
15 MIN	15-min	23	87	140 (173)	133 (184)	-5%	0.90
24 HR	24-hr	23		14 (20)	6 (6)	-57%	0.05

Table 7 CO kitchen concentrations exceeding WHO air quality guidelines.

	CO Attached Kitchen			
		Coal Stove	Biomass Stove	Diff.
15 MIN	HH with 15-min Avg. > WHO	21% (n=4)	37% (n=7)	16%
8 HR	HH with 8-hr Avg > WHO	58% (n=11)	58% (n=11)	0%
CO Separate Kitchen				
		Coal Stove	Biomass Stove	Diff.
15 MIN	HH with 15-min Avg. > WHO	43% (n=10)	65% (n=15)	22%
8 HR	HH with 8-hr Avg > WHO	74% (n=17)	70% (n=16)	-4%

Daytime Versus Nighttime

We investigated daytime and nighttime HAP levels to understand the influence of non-cooking events (i.e. home heating) on overall average 24-h CO and $PM_{2.5}$ levels. Based on user feedback, we structured the daytime phase to occur from from 6am-10pm, and the nighttime phases were broken into Phase #1 (10pm-2am) and Phase #2 (2am-10pm) segments. We hypothesized that an earlier nighttime phase would capture household heating initiated just prior to sleeping, while the latter nighttime phase would capture any additional re-lighting and heating initiated during the night. All arithmetic mean comparisons utilize 2-sided paired t-tests, and all gravimetric mean comparison tests utilize nonparametric Wilcoxon matched-pairs signed rank tests, both at 95% confidence.

Table 8 Daytime and nighttime mean 24-hour concentrations of $PM_{2.5}$ (µg/m^3). Standard deviations are shown in parentheses, and n is the total number of households.

		$PM_{2.5}$ (µg/m^3) in Attached Kitchen			
		Coal Stove (n=19)	Biomass Stove (n=19)	Diff.	T-Test (p-value)
Arithmetic Mean	Day 6am-10pm	145 (128)	190 (197)	31%	0.24
	Night 10pm-2am	30 (51)	21 (35)	-30%	0.49
	Night 2am-6am	14 (4)	15 (15)	7%	0.68
Geometric Mean	Day 6am-10pm	101 (2)	122 (3)	21%	0.42
	Night 10pm-2am	19 (2)	14 (2)	-26%	0.07
	Night 2am-6am	13 (1)	13 (2)	0%	0.13
		$PM_{2.5}$ (µg/m^3) in Separate Kitchen			
		Coal Stove (n=30)	Biomass Stove (n=30)	Diff.	T-Test (p-value)
Arithmetic Mean	Day 6am-10pm	223 (269)	139 (157)	-38%	0.17
	Night 10pm-2am	38 (73)	12 (3)	-68%	0.06
	Night 2am-6am	18 (14)	15 (19)	-17%	0.44
Geometric Mean	Day 6am-10pm	126 (3)	89 (2)	-29%	0.43
	Night 10pm-2am	20 (2)	11 (1)	-45%	0.00
	Night 2am-6am	16 (2)	11 (2)	-31%	0.04

Table 9 Daytime and nighttime mean 24-hour concentrations CO (ppm). Standard deviations are shown in parentheses, and n is the total number of households.

		CO (ppm) in Attached Kitchen			
		Coal Stove (n=18)	Biomass Stove (n=18)	Diff.	T-Test (p-value)
Arithmetic Mean	Day 6am-10pm	11.1 (8.2)	12.9 (9.5)	16%	0.52
	Night 10pm-2am	11.2 (6.6)	1.5 (2.2)	-87%	0.16
	Night 2am-6am	12.5 (31.8)	0.4 (0.6)	-97%	0.13
Geometric Mean	Day 6am-10pm	7.6 (2.4)	9.9 (2.0)	30%	0.59
	Night 10pm-2am	2.4 (5.6)	0.5 (3.6)	-79%	0.00
	Night 2am-6am	1.2 (7.4)	0.3 (2.0)	-75%	0.00
		CO (ppm) in Separate Kitchen			
		Coal Stove (n=23)	Biomass Stove (n=23)	Diff.	T-Test (p-value)
Arithmetic Mean	Day 6am-10pm	18.1 (19)	10.3 (11.1)	-43%	0.12
	Night 10pm-2am	29.2 (59.8)	4.6 (13.2)	-84%	0.07
	Night 2am-6am	24.6 (72.5)	2.4 (0.2)	-90%	0.16
Geometric Mean	Day 6am-10pm	10.7 (2.9)	6.1 (2.8)	-43%	0.56
	Night 10pm-2am	3.9 (9)	0.5 (5.1)	-87%	0.03
	Night 2am-6am	2.1 (9.3)	0.3 (3.4)	-86%	0.02

Log transformation resulted in statistically significant reductions ($P < 0.10$) between pre-intervention and post-intervention for all $PM_{2.5}$ and CO night time averages, except for $PM_{2.5}$ in attached kitchens ($P = 0.13$). No statistical difference was found, however, between pre-intervention and post-intervention homes during the daytime hours.

There were also no statistically significant differences ($P<0.05$) in daily outdoor low temperatures during the testing periods, which could have affected the intensity of household heating used during the monitoring period. The average low temperature during measurements in pre-intervention households was 0.2 Celsius (95% CI: -1.1,1.5), and in post-intervention homes -0.9 Celsius (95% CI: -1.5,-0.2), as recorded by the local Yangquan Meteorological Bureau.

Meals Cooked

We also examined the possible influence of meals cooked on $PM_{2.5}$ levels, since more cooking events uses more fuel and creates more emissions. The number of "meals cooked" was determined by examining UCB data files for "peaks" of $PM_{2.5}$ levels. A cooking event was defined as being greater than 10 min in duration, and starting and ending times were recorded when the photoelectric signal was within 0.25 mg/m^3 (250 $\mu g/m^3$) of baseline levels. "Meals cooked" may or may not represent an actual cooking event since we aren't able to discern smoke from different combustion source. Rather, it denotes when $PM_{2.5}$ levels surpassed threshold levels during the 24-hour monitoring session, and thus refers to when a combustion device was used in the kitchen that may or may not correspond to pre- or post-intervention stoves. Although we cannot fully distinguish between the stove being left on and an actual cooking event, all times used for "meals" in this analysis, however, roughly corresponded with normal eating times. Comparison tests were conducted with two-sided two-sample mean t-tests (95% confidence).

Table 10 Mean 24-hour concentrations of $PM_{2.5}$ (µg/m^3) and CO (ppm) stratified by number of cooking events conducted in homes with separate kitchens. Standard deviation is denoted as "sd," and total number of households as "n."

		$PM_{2.5}$ (µg/m^3) in Attached Kitchen		
# Meals Cooked	Coal Stove	Biomass Stove	Difference	T-Test (p-value)
1	80 (sd=87, n=3)	22 (sd=5, n=2)	-73%	0.43
2	103 (sd=83, n=12)	55 (sd=29, n=5))	-47%	0.24
3	128 (sd=116, n=3)	157 (sd=105, n=8)	23%	0.7
		$PM_{2.5}$ (µg/m^3) in Separate Kitchen		
# Meals Cooked	Coal Stove	Biomass Stove	Difference	T-Test (p-value)
1	36 (sd=10, n=5)	22 (sd=6, n=2)	-39%	0.14
2	86 (sd=135, n=10)	86 (sd=133, n=12))	0%	1
3	145 (sd=80, n=6)	98 (sd=85, n=10)	-32%	0.28
4 or greater	184 (sd=86, n=3)	116 (sd=62, n=5)	-37%	0.23

Stratifying by number of meals cooked did not reveal statistically significant differences in CO or $PM_{2.5}$ as a result of switching from pre-intervention to post-intervention in either separate or attached kitchens (Table 7). Interestingly, pooled results for total number of cooking events in separate kitchens increased from 55 in pre-intervention to 76 in post-intervention, while in attached kitchens the pooled total was constant at 36 cooking events for both pre-intervention and post-intervention. This suggests that post-intervention stoves were used more frequently in homes with separate kitchens as compared to attached kitchens, and overall, homes with separate kitchens cooked more often than homes with attached kitchens.

DISCUSSION

Phase burning

Particulate Matter

Our study finds no statistical change in 24-h average $PM_{2.5}$ concentrations between pre- and post- intervention, and that all 24-h average $PM_{2.5}$ concentrations from “traditional” and “improved” stoves exceed WHO AQG for 24-h average $PM_{2.5}$. It is clear that the intervention stove was not performing as expected from lab testing. In particular, we observed high levels of smoke during the initial lighting phase, and during relighting phases when the fire was accidentally extinguished in the middle of cooking sessions. High emissions during certain phase of burning is supported by Carter et al. (2014) who found that Chinese gasifier stoves had a 2-fold increase in PIC emissions during medium power testing as compared to high power burning, and that the stove lighting phase accounted for nearly 50% of overall PIC emissions during testing. Ezzati et al (2000) also shows that the greatest reductions in $PM_{2.5}$ (77%) can be found during the smoldering phase of fires when comparing the use of improved stoves to a traditional stove, which is congruent with Hildeman (1991) who found a 10-fold difference in mass concentration of particles when comparing a steady burn phase and dying fire phase. Improvements in stove design that improve combustion efficiency during all phases of burning have the potential to improve overall stove performance. In particular, this study indicates that efficiency improvements in the initial stove lighting and subsequent re-lighting phases could yield the greatest reductions in pollutant concentrations.

Carbon Monoxide

We find that all post-intervention homes exceeded WHO 15-min CO guidelines by nearly 50% (Table 2). The highest peak CO concentrations were found during short 15-min intervals, with post-intervention levels for attached kitchens at 145 ppm (SD: 50) and for separate kitchen at 133 ppm (SD: 184). High peak concentrations of 15-min CO concentrations suggest that certain phases of fuel burning are experiencing extremely poor combustion efficiency that leads to forceful ejection of short-duration and high-concentration pollutants that are very harmful to human health.

We also find that the number of homes to exceed the 15-min maximum WHO CO guideline occur at a higher proportion in the post-intervention sample homes as compared to the pre-intervention sample homes [pre-intervention vs. post-intervention, respectively: [21% vs. 37% in attached kitchens] and [43% vs. 65% in separate kitchens]. In contrast, the percentage of homes exceeding the 8-h WHO CO guideline occurs in roughly the same proportion in pre- and post- intervention homes [post-intervention vs. pre-intervention, respectively: [58% vs. 58% in attached kitchens] and [70% vs. 74% in separate kitchens]. This suggests that short duration spikes of high concentrations of CO are occurring at a disproportionately higher rate in post-intervention homes, and that relatively low 24-h average CO concentrations can mask dangerously high 15-min exposures. The former requires changes in training on proper and efficient use of the post-intervention stove, or more likely, a redesign of the stove itself. The latter emphasizes the importance of data collection and the application of appropriate metrics for evaluating stove performance.

Heating

Our study finds that the majority of HAP are generated during the daytime cooking hours, although no statistical difference was found in a comparison of daytime pre-intervention and post-intervention homes for either $PM_{2.5}$ or CO. When examining night time periods alone, we find statistically higher levels of HAPs in pre-intervention homes as compared to post-intervention homes, which suggests that heating plays a role in overall HAP concentrations.

Supplemental surveys also showed that in homes having adopted the gasifier stove for over one year, winter heating by coal stoves is more convenient than biomass because of the long burn cycle of coal, especially when raw coal is pulverized and mixed with clay to create a semi-combustible material. A household can stoke a traditional coal stove with more coal after dinner has been made and still have reliable heat into the night. In contrast, biomass stoves burn quickly and cannot sustain long-term thermal output. Thus, coal stoves are preferred during heating months but are disliked during hot summer months due to the excess thermal output after cooking is done, and because of the high cost of purchasing coal. This study was conducted in March 2009, which represents a transitional period from winter to spring. Future studies would benefit from field measurements conducted exclusively during winter or summer months in order to fully differentiate the effects of heating and cooking on area pollutant concentrations.

These behavioral patterns support our findings of higher HAP in pre-intervention homes during the night time periods, which is likely due to fuel smoldering from traditional stoves after cooking dinner, and from lighting and fuel stoking in heating devices such as kang heating beds and metal stoves. It is also possible that much of the night time averages are due to ambient levels of indoor and outdoor pollution originating from outside the home, which may or may not be attributable to combustion devices from within the home. Future intervention programs should account for nighttime heating requirements of homes and design improved stoves that can provide appropriate heating functions.

Stove Stacking

Stove stacking and the cooking patterns associated with different types of stoves directly impacts area concentration of HAP. Stacking refers to the use of multiple stoves and fuels at the same time due to a new stove technology not meeting the complete needs of the user. While it is well established that the introduction of improved stoves can lead to reductions in HAP and improved health outcomes, the relationship between stove stacking and HAP concentrations is not well characterized (Ruiz-Mercado, Canuz, & Smith, 2012; Ruiz-Mercado, Masera, Zamora, & Smith, 2011).

Stove stacking may have occurred in sample homes during HAP measurements which would affect area concentrations and confound our ability to interpret the results. It is well known that stacking continues throughout much of rural China and Stacking as a result of numerous stove intervention programs beginning with the Chinese NISP program in the 1980's. It is not uncommon to find upwards of 5 or more different stove types in a typical rural Chinese home ranging from LPG, Traditional Coal, Improved Metal Coal, Biomass Stove, Electric Hot Plates, Rice Cookers – on top of several stove types used for cooking and heating. This study emphasized to participants the importance of using only the traditional or improved stove during field measurements, but it is possible that participants did not fully report stove stacking activity to enumerators. Future policy prescriptions must account for the historical and cultural views of stove intervention programs in China and understand behavioral patterns such as stacking and cooking practices amongst various stove types. Methods for fully tracking multiple stove use in a home while enumerators are not present would allow for more robust understanding contributing factors to pollutant concentration levels in a home.

Conclusions

Phase Burning

The Chinese government is planning large scale stove dissemination that could incorporate gasifier type stoves. While lab-based results have shown clean performance during optimal high power cooking phases, we are not aware of any studies that have examined emissions of Chinese gasifiers used in actual homes.

It is clear that peak HAP concentrations are emitted during specific phases of burning, and in particular the lighting, relighting, and smoldering phases. Our study results showing dangerously high 15-min peak CO in post-intervention stoves suggests that phase burning is affecting overall 24-h average CO, and that reducing 15-min peak emissions could also reduce overall 24-h average $PM_{2.5}$ and CO concentrations. Unintentional smoldering during nighttime heating are additional sources of HAP emissions and exposure, which was more commonly found in pre-intervention homes which repurposed their cooking stoves as nighttime heating stoves.

The United Nation Foundation's Global Alliance for Clean Cookstoves (GACC) has acknowledged the challenge of establishing universal performance testing protocols that can encompass the range of cooking and heating found throughout the world. GACC experts have determined that current testing standards used to determine stove efficiency (i.e. water boiling test (WBT)) are inadequate for characterizing low power cooking phases due to the high variability in steam produced during water simmering (otherwise referred to as latent heat) and the low detectability of heat transfer due to the protocol's requirement to maintain constant water temperature during the simmer phase (Jetter et al., 2012). Our results suggest that a comprehensive test that encompasses a locally-appropriate range of stove power sis critical to understanding a stove's overall performance. The absence of comprehensive lab metrics can have unfortunate consequences in real-world homes and communities.

Context-Specific Exposure Assessments

Further compounding efforts for comprehensive exposure assessments in China are the vast differences in geography that necessitate varying levels of home heating type and intensity, a pantheon of legacy "improved" stoves that serve mixed uses given spatial and temporal needs, economic and resource disparity that makes intra- and inter-regional comparisons between households a difficult endeavor, and variable fuel quality including poisonous coal in regions of the southern China that confound efforts to generalize fuel impacts. Complex landscapes such as China, and other regions with high proportions of solid fuel use, require expanded research that enables a systematic characterization of exposures across site-specific needs of local communities. In-field emissions and area concentration measurements can begin to help characterize the level and intensity of local intervention programs.

Policy implications and recommendations

This study highlights the importance of developing more rigorous laboratory testing protocols that target specific phases of burning that have been shown to disproportionately affect overall emission levels. The United Nations foundation Global Alliance for Clean Cookstoves has initiated efforts to standardize international stove testing protocols. In 2012 an interim draft standard for evaluating cookstove performance was released through the International Organization for Standardization (ISO) guideline IWA 11:2012 "Guidelines for evaluating cookstove performance."[2] The development of ISO standards is an effort to standardize laboratory testing protocols that will be used for evaluation of stove performance prior to large scale dissemination into communities. In 2014, the World Health Organization (WHO) mobilized research efforts to more comprehensively understand emissions rates from cookstoves and specifically stated a needed for differentiating "*emission rate targets [that] apply to each individual device used for cooking, heating or lighting*."[3] This study emphasizes the importance of incorporating into WHO and ISO standards new testing protocols that reflect the various patterns of usage, phase burning, and stove stacking that is found within and amongst different geographies. This study further supports the importance of replicating laboratory results in actual homes to ensure appropriate and clean technologies chosen prior to mass dissemination efforts.

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[2] ISO guidelines for evaluating cookstove performance: http://www.iso.org/iso/catalogue_detail?csnumber=61975 [last accessed 4.4.2015]

[3] World Health Organization develops emission rate targets for cookstoves: http://www.who.int/indoorair/guidelines/hhfc/recommendation_1/en/ [last accessed 4.4.2015]

CHAPTER 3 THE CARBON REGIME: AN ARCHITECTURE FOR NEW PRO-POOR MARKETS

ABSTRACT

This paper examines the role of nonstate actors in advancing decarbonization and clean energy development in rural communities of the global south. I argue that the establishment of a global carbon market regime has provided the critical architecture and framework for new market innovations to emerge. Through case studies of three emerging results based financing (RBF) methodologies for clean energy in the global south, I identify a hybrid form of public-private governance that is collaborating to create private markets that parallel much of the monitoring, reporting, and verification (MRV) architecture established by the Kyoto-centered carbon market. I further find that these new markets are gaining political authority through the systematic use of pre-existing knowledge, relationships, and finance from the "carbon regime." I conclude by situating their activities in a broader "polycentric" landscape of environmental governance.

INTRODUCTION

The Rise and Fall of Carbon Markets

International carbon markets grew rapidly during the Kyoto Protocol's 2008-2012 first commitment period (Kossoy & Guigon, 2012). Assigning a price to carbon through an emissions trading system (ETS) proved to be the catalyst needed to attract traditional forms of private capital and finance to projects implemented in the global south. Most of the investment in the global south was channeled through compliance carbon markets such as the Clean Development Mechanism (CDM), and voluntary markets such as the Gold Standard Foundation (GS) and the Voluntary Carbon Standard (VCS). The growth of carbon markets during Kyoto's first commitment period reached a peak of €23 euros in 2008 for a certified emission reduction (CER) sold on the spot market. By 2012, total carbon market transactions had ballooned to an estimated $176 billion (Kirkman, Seres, Haites, & Spalding-Fecher, 2012; Kossoy & Guigon, 2012; Peters-Stanley & Yin, 2013).

As the success of business models leveraging carbon finance achieved proof of concept that real return on investment could be achieved through energy efficiency programs implemented in developing countries, project financing for pro-poor rural energy projects began to attract "establishment" finance that ushered in an era of rapid growth for development finance. Dedicated carbon desks were established at the world's largest financial and energy institutions — JP Morgan Chase, Barclays, the Swedish Energy Agency, among others — to oversee new investment under the CDM, GS, and VCS that included investments in cookstoves, solar lighting, and rural heating programs. Multilateral institutions provided further support to rural energy access programs through the Green Climate Fund, Asian Development Bank, and the German government's development bank KfW, amongst others.

The explosive growth in carbon markets would not last, however, as it was followed by a precipitous fall in carbon prices in 2013 (Figure 1). The sharp decline in carbon prices — to as low as €1 euro/CER — can be attributed to a combination of events: 1) global economic recessionary pressures that lowered industrial output and consequently lowered industrial emissions, which resulted in lower demand of compliance CERs to meet abatement requirements; 2) increasing stringency of regulatory requirements for renewable energy; 3) failure of nations to develop a post-Kyoto agreement that binds nations to mitigation goals, which determines the "cap" on cap-and-trade systems and provides the regulatory requirement to engage in emissions trading; 4) an excess supply of Kyoto credits from a growing number of newly registered CDM projects (Koch, Fuss, Grosjean, & Edenhofer, 2014; Kossoy et al., 2014).

Figure 1. Graph of spot-market price (euros) for certified emission reductions (CER). CER prices have declined from a high of €23 Euros in 2008, to less than €1 Euro in 2013. Source: http://carbonfinanceforcookstoves.org/carbon-finance/prices-for-improved-cookstove-projects/

The initial rapid flow of capital into the developing world through carbon investment vehicles dwindled just as quickly alongside the fallout of carbon prices. Lower profits from carbon investments led much of the capitalist network to abandon further pro-poor investments in the developing world and exit the carbon economy entirely. By the end of 2013, news agencies covering global environmental and energy markets had reported a succession of closures to carbon investment portfolios at leading banks such as Barclays, Deutsche Bank, JP Morgan and UBS.[4] The decline in carbon trading and finance also led several leading auditing firms that were integral to the process of auditing and certifying carbon credits, otherwise referred to as "designated operating entities" (DOE), to quickly close their climate change advisory practice. A February, 2014 press release by the DOE firm Det Norske Veritas, which had been the leading provider of DOE services in the CDM market by volume, announced the closure of their carbon auditing services due to the rapid decline in carbon trading activity. The following press release succinctly summarizes the state of carbon markets by early 2014:

> *Recently, the price of carbon credits on the international carbon market has dropped to a level that no longer provides incentives to invest in climate change mitigation projects. The number of projects has decreased to less than one-tenth of the volume seen 1 year ago. As a consequence of this downturn in the carbon market, DNV GL has had to significantly reduce its activities and thus resources. The current volume of work is no longer sufficient to support the number of qualified staff needed to meet*

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[4] News reporting on the closure of carbon trading desks at leading financial banks was widespread in 2013. An example includes this Financial Times article: http://www.ft.com/intl/cms/s/0/cbb749ba-506b-11e3-9f0d-00144feabdc0.html [last accessed 2.27.15].

accreditation requirements…. As DNV GL sees no visible signs of a recovery in the foreseeable future, DNV GL has thus made the strategic decision to cease providing validation and verification services for CDM projects and other international climate change mitigation projects. [5] *–DNV GL Group Press Release 02.13.2014*

The emergence of "beyond carbon" markets

Governance over clean energy transitions in the developing world is increasingly being shaped by international coalitions of nonstate actors that rely on market-based mechanisms that were created under the Kyoto Protocol's framework for emissions trading (Meckling, 2011). In the face of downward pressure from recessionary financial markets – namely the crash in prices of international carbon offsets – nonstate actors are building new models of private governance that parallel much of the monitoring, reporting, and verification (MRV) architecture established by the Kyoto-centered carbon market, and that nonstate actors are gaining political authority for these new markets through the systematic use of pre-existing knowledge, relationships, and finance from the "carbon regime." I utilize Raustialia's (2001) definition of "nonstate actors" as "any organization that does not have a formal or legal status as a state or agent of a state" (Raustiala, 2001), which includes NGOs (environmental and business), scientific communities, and financial institutions. The crash in carbon market prices has presented nonstate actors with both peril and opportunity – on one hand nonstate actors are forced to identify new business models in order to survive, and on the other hand, it has provided an opportunity for private sector firms to develop a potentially larger and more wide-ranging market for co-benefits.

One of the most significant forms of market-based governance models to emerge outside of regulated carbon markets is popularly described as results-based financing (RBF), pay-for-performance (P4P), or conditional cash transfer (CCT). The term RBF is used in this paper but is considered interchangeable with P4P and CCT. RBF is a funding model that provides payment only after verified proof is provided that an intervention has achieved a specified outcome. This is in contrast to traditional funding models that provide finance for programmatic inputs for setup and execution, which leaves funders with less control over the quality of final outcomes. A carbon credit is a type of RBF that requires evidence that the equivalent of one ton of carbon dioxide has been mitigated in exchange for payment of a credit.

In relation to emerging markets for clean energy in the global south, this paper finds that nonstate actors originally participating in carbon markets are now independently convening and organizing– including scientists, certification bodies, funding organizations, and firms – to create new voluntary pro-poor RBF markets. Collectively, these loosely connected collaborations are co-producing knowledge and social systems to self-govern in the face of faltering international action for climate change in a post-Kyoto Protocol era. For nonstate actors operating rural energy access programs in the global south, the response to carbon market failures has been to create new RBF markets that capitalize on previously un-

[5] DNV GL Press Release: http://www.dnvgl.com/news-events/news/dnvgl-ceasing-to-provide-validation-verification-services-for-CDM.aspx [last accessed 2.2.2015]

commoditized externalities that result from rural energy programs in an effort to replace the shrinking market for carbon finance.

This paper identifies an emerging hybrid form of public-private governance that is appropriating existing carbon market frameworks in order to gain political authority for alternative forms of RBF funding models. The Gold Standard Foundation, which is the leading certification body issuing carbon credits from rural energy programs such as clean cookstoves, has been at the vanguard of creating RBF markets and is host to three emerging methodologies for use by rural household energy programs: 1) Black Carbon Credits (BC); 2) Water Benefit Certificates (WBC); and 3) Avoided Disability Adjusted Life Year credits (ADALY). These methodologies quantify each credit/commodity by assessing the amount of fuel reduced through improved cooking and lighting technologies, or avoided through decreased water boiling practices. I examine these three RBF methodologies to demonstrate that the "carbon regime" developed under Kyoto's ETS has provided the necessary preconditions for nonstate actors to quickly innovate and put into practice novel pro-poor market-based approaches. By understanding the processes and strategies employed by these nonstate actors we can develop a stronger understanding of emerging patterns of global governance for clean energy systems in the global south.

CONCEPTUAL BACKGROUND

Through methods of process-tracing of historical events and document review of certification methodologies, I derive an explanatory narrative for understanding the drivers of new and rapidly unfolding modes of pro-poor results-based financing (RBF) and governance. I draw on international relations (IR) literature to understand the role of markets, institutions, and firms in developing new "beyond-carbon" models of governance, and I situate these actors within the study of "private authority" to characterize the forms of collaboration that are emerging amongst public and private nonstate actors. Within these networks and collaborations I find social entrepreneurs experimenting with traditional forms of market based mechanisms to create new self-governing models of pro-poor climate finance.

Using theories of global environmental governance, I assess the extent to which RBF markets constitute private authority in the absence of a globally binding climate change accord. This work builds upon recent literature that suggests private authority is increasingly appropriating functional elements of previously established regulatory regimes, as opposed to developing completely new "de novo" systems of governance, to establish models of private governance over unregulated arenas of environmental protection(Green, 2013). This paper supports the theory that private authority resides in a broader landscape of multi-loci spheres of authority, and that increasingly, this "polycentric" view of parallel state and nonstate authority may become more the norm in global environmental governance over climate change (Ostrom, 2010).

Global Environmental Governance and Private Authority

The study of global environmental governance provides fertile ground to explore the ways in which science is mediated and translated to the regulatory and policy environment. I utilize international relations literature on private authority to develop a framework for understanding the drivers of new and rapidly unfolding modes of pro-poor climate financing and governance, and to theoretically ground the modes in which new self-governing collaborations and regulations are gaining legitimacy and credibility.

In broad terms, the literature on private authority contends that the internationalization of production, trade, and integration of global economies has led to a weakening of state authority. Hall and Bierstker (Hall & Biersteker, 2002) have characterized private authority as "claiming to be, performing as, and being recognized as legitimate by some larger public as authors of policies, practices, rules, and [of] norms." Susan Strange (Strange, 1996) has argued that, in fact, the authority of all governments has weakened to some extent as a result of global economic integration and of technical innovations, and that states are increasingly losing their authority to markets, multi-national corporations, industry coalitions, and non-governmental organizations (NGOs). Claire Cutler has further illuminated the importance and relative power of epistemic communities such as NGOs in influencing and granting authority to transnational policy decisions (Cutler, Haufler et al. 1999), and more recently, demonstrated the role that experts and specialized knowledge can have in legitimizing private transnational governance ((A. Claire Cutler, 2010; A Claire Cutler, Haufler, & Porter, 1999). Others have examined the emergence of governance through markets and the creation of voluntary certification schemes in the forestry and fisheries markets, suggesting a role for nonstate actors in creating authority through self-regulation (Cashore, Auld, & Newsom, 2004). These claims are contrary to the prevailing Weberian and Westphalian notions of nation-states, whose camps would argue that the state remains as powerful as ever, and that globalization and private governance are enabling, rather than disabling, conduits for states to exert their sovereignty.

I utilize a definition of private authority defined by Green (Green, 2013) as "situations in which nonstate actors make rules or set standards that other relevant actors in world politics adopt." Green further distinguishes between two types of authority: one in which states delegate authority to private actors, and another in which entrepreneurial actors are independently creating their own rules and regulatory frameworks. Green's comprehensive analysis of more than 100 voluntary environmental standards that have emerged since 1950 provides robust evidence that the majority of environmentally related private authority has only recently arisen in the past two decades. Green ascribes the emergence of private authority to a realignment of existing institutional landscapes that have allowed nonstate actors to gain agency and traction over environmental governance. The noted political economist Elinor Ostrom provides support for the growing numbers of self-organized systems and actors that are emerging to combat climate change(Ostrom, 2010). Instead of presenting a binary notion of state vs. nonstate authority, Ostrom paints a world in which authority comes from many sources and that private authority is only one of many spheres of authority that emerge as a result of various socio-political conditions. This paper builds upon this theory to show the strategic shifts in climate and development finance used by clean energy programs in the global south. I analyze three emerging RBF programs to show how a strategy of rearticulation and appropriation of elements from the existing carbon regime is helping to spur new market-based policy instruments for clean energy development programs.

MARKET-BASED POLICY INSTRUMENTS

The Origins of Emissions Trading

Market-based approaches to climate change mitigation have become a dominant political narrative for 21st century climate negotiations at the international and sub-national level (Aldy & Stavins, 2012; Jaffe & Stavins, 2008; MacKenzie, 2009; Pellizzoni, 2011). In practical terms, emissions trading as a regulatory tool began to form in the 1970s within the US Environmental Protection Agency (US EPA) under the mandate of the Clean Air Act. The US EPA used its new authority to begin conceptualizing market-based policy instruments for controlling atmospheric pollutants such as sulfur dioxide (SO_2), nitrogen oxide (NO_x), and carbon monoxide (CO). One of the earliest trials with market-based policies was through permit trading in the US EPAs Lead Trading Program, which allowed US refineries to earn credits when they produced gasoline containing less lead than required by newly enacted regulations. Government regulators found early success with this program when inter-refinery trading of lead permits helped the US achieve a 10% reduction in levels of lead in gasoline in just 5 years (1982-1987) (Schennach, 2000; Stavins, 1998). But it was under Title IV of the 1990 Clean Air Act when market-based emissions trading became most well-known and publicized. Title IV legislation formalized emissions trading under the Clean Air Act and provided the legal basis for utilizing cap-and-trade systems as a tool for environmental oversight of industry. The US EPA used these new rules to establish the US Acid Rain Program which sought to use emissions trading as a regulatory tool to control SO2 and NO, which are the primary precursors to ozone, in northeastern United States. These early experiments with ETS and permit trading gradually expanded to other environmental markets and provided the seeds for broader climate governance within the international community.

Compliance and Voluntary Carbon Markets

The early success of market-based emissions trading in the United States became a blueprint for the Kyoto Protocol's inclusion of market-based mechanisms as a viable policy instrument for controlling global greenhouse gas emissions. Flexible mechanisms were included in the Kyoto Protocol that allowed countries to find least cost abatement options, which include Joint Implementation (JI) and the Clean Development Mechanism (CDM). JI allows firms in industrialized nations to reduce emissions through cooperation with other industrialized nations; CDM allows firms in industrialized nations to reduce emissions through cooperation with developing countries.

Here we focus on the CDM, which allows developed Annex I countries to offset their GHG emissions by investing in emission reduction projects in non-Annex I developing countries, otherwise described as a "baseline-and-credit" model. Under a baseline-and-credit model, firms can choose to use permits created through project-based programs that reduce carbon emissions and that are certified through an accreditation program. The number of permits generated is based on the amount of emissions reduced below a negotiated baseline. By virtue of having lower cost structures in under-developed economies, most baseline-and-credit programs are implemented in the global south due to the lower cost of implementing low carbon programs in these countries. Thus the "flexibility" provided by Kyoto rules allows firms the option to meet abatement requirements through the trade of inter-firm allowances (cap-and-trade), or to purchase offsets through CDM's baseline-and-credit program (otherwise termed certified emission reductions (CERs)).

At the same time that Kyoto's first commitment period launched in 2008, nascent voluntary carbon markets began to emerge as an alternative mechanism for monitoring, reporting, and verifying (MRV) carbon reductions generated under project-based baseline-and-credit programs. Voluntary markets provided an opportunity for stakeholders not governed by Kyoto's compliance requirements such as businesses, individuals, and NGOs, to offset their emissions through the purchase of carbon credits. Voluntary carbon market standards have historically been viewed as more approachable and innovative than the highly bureaucratic UN led CDM scheme (Michaelowa, 2005). At the outset, voluntary carbon market standards were especially attentive to the methodological needs of small scale projects that were focused on the poor and that sought eligibility and access to carbon finance and private investment. Rural energy standards and methodologies were developed for various household technologies including cookstoves, solar lighting, and safe water delivery programs. Researchers have also pointed to the willingness of the voluntary carbon market to embrace more quickly new methods of quantifying emission reductions from "pro-poor" projects as an avenue to explore the CDM's original mandate of "GHG reductions and promotion of sustainable development" (Smith and Haigler 2008). Indeed, many project developers and carbon market actors espouse the "co-benefit" social and environmental returns for voluntary market investments in pro-poor household energy programs that strive for benefits beyond carbon reductions (Gregory L Simon, Bailis, Baumgartner, Hyman, & Laurent, 2014; Kirk R. Smith & Haigler, 2008). The agility of voluntary standards to respond to stakeholder needs, innovate and adjust rules and standards, and adopt a heuristic approach with the public to create new methodologies, has positioned voluntary markets at the vanguard of new markets for RBF credits.

In the face of collapsed compliance and voluntary carbon markets and exacerbated by the exit of traditional private finance, coalitions of industry, scientists, and non-profits have begun to rapidly experiment with new results-based financing mechanisms in an effort to ameliorate the financing gap for pro-poor energy programs. The baseline-and-credit model used in carbon markets has been the primary blueprint for extension into new types of initiatives, including black carbon reductions, avoided health outcomes, and safe water credits. Voluntary standards such as Gold Standard Foundation (GS) and Verified Carbon Standard (VCS) — known for their history of agility and innovation in meeting the needs of their stakeholders — are now at the vanguard of new market formation as they seek to buttress and reimagine the immense carbon regime created under Kyoto. Market-based policies remain the dominant framework for regional and international climate policy discussion; yet, at the same time, parallel voluntary initiatives are emerging to govern energy access initiatives in response to the fall of carbon prices in ETS markets worldwide.

THE CARBON REGIME PLATFORM

A large political economy has grown out of the rise of global carbon markets that includes industry coalitions, trade groups, consultants and project developers, investors and banks, public institutions, and firms, which were all in service of a functioning global market for carbon. The literature on global environmental governance allows us to situate these actors and networks within a broader political, scientific, economic, and social system of governance. In the case of energy systems for rural communities in the global south, such as clean cookstoves or solar lighting initiatives, a program's level of scale, rate of dissemination, and overall financial sustainability are reflexive to the broader systems that govern finance, regulatory science, and cultural norms that span transnational-national-local boundaries (S. Jasanoff, 1991; Newell & Paterson, 2010). Under Kyoto's emissions trading system, the UNFCCC was principal in providing "top down" authority over global carbon markets.

I utilize theories of private authority for global environmental governance as a starting point from which to begin exploring the collaborations to have emerged from the complex interplay between international climate policy, public and private sector activity, technological innovation, scientific knowledge, and social and cultural norms. By organizing energy systems and climate policy within a governance framework, we can begin to understand and characterize the integrated forces that are shaping new models of development finance that are emerging in the aftermath of a carbon market decline, and to define emerging modes of governance over clean energy transitions in the global south.

Standards Bodies: Conferring legitimacy to the certification process

Standards: Appropriation of existing standards for legitimacy

There have been no stronger advocates for private markets than the certification bodies that operate them. The UN's CDM Executive Board (CDM EB) acted as the central regulatory body for Kyoto's compliance carbon market by overseeing the process of certification and issuance of carbon credits. This included mediating stakeholder input on new methodology development, standards, and guidelines used to operate the carbon market. The CDM EB was also responsible for creating and overseeing the procedural process for reviewing and approving carbon credits, which involved adherence to a lengthy and complex set of rules.

Carbon markets are fundamentally a rule-based mechanism, and as such, standards bodies are instrumental in legitimizing the process of quantifying a "carbon" or "RBF" credit, assigning ownership of those credits, and ultimately certifying a commodity that can be traded in global economies. Increasingly, we have seen voluntary certification bodies mediate the development of new methodologies and standards that benefit pro-poor clean energy programs. The participation of voluntary standards bodies in the development of new RBF markets lends legitimacy and confidence to the certification process of these new RBF credits. From the perspective of the voluntary standards body, their participation in developing new markets is motivated in part by declining revenues accrued from fewer carbon programs validating and verifying carbon credits in the face of low carbon prices. A second reason for the adoption of new methodologies by standards bodies is due to the increasing recognition that a singular focus on "carbon" benefits obscures the social and political dimensions of the locales from which the offset was derived.

Table 11 organizes one carbon and three RBF methodologies relevant to rural energy access programs, and that were developed or are under development within the voluntary certification body Gold Standard Foundation. The network of actors involved in the development of these methods highlights the pivotal role of nonstate actor collaborations for providing input or support in their development and operation. In each case a network of actors representing scientific knowledge, procedural processes of standards and certification, finance, and implementing firms, have played key roles in providing support for the development of new methods.

Table 11 Carbon and RBF methodologies for rural energy access programs

Commodity	Science	Standard	Finance	Methodology Author
Carbon Offset (Voluntary) *(Final draft released 2008)*	-Intergovernmental Panel on Climate Change (IPCC)	-Gold Standard Foundation	-Corporations and individuals	-Climate Care [NGO]; -Impact Carbon [NGO]; -Berkeley Air [NGOs]
Black Carbon Credit[6] *(Jan. 2015 draft methodology released for public comment)*	-Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC)	-Gold Standard Foundation	-UN Global Alliance for Clean Cookstoves (GACC) -UNDP Black Carbon Finance Working Group	-Surya [NGO] -TERI [Scientific Epistemic Community]
Water Benefits Credit[7] *(Final draft released Sept. 2014)*	-Int'l Union for Conservation of Nature	-Gold Standard Foundation	-Swiss Agency for Development and Cooperation SDC	-Whave Solutions [NGO] -First Climate [Social Enterprise]
ADALYs Credit[8] *(Draft methodology in development & pilot phase)*	-University of California at Berkeley -Berkeley Air Monitoring Group	-Gold Standard Foundation	-UN Global Alliance for Clean Cookstoves (GACC) -Bix Fund	-CQuest Capital [Social Enterprise]

[6] Black Carbon Credit - Full methodology titled "Quantification of climate related emission reductions of Black Carbon and Co-emitted Species due to the replacement of less efficient cookstoves with improved efficiency cookstoves." Draft methodology posted for public comment here: http://www.goldstandard.org/seeking-input-into-our-new-black-carbon-methodology [last accessed 2.15.2015]

[7] Water Benefit Credit – Full methodology titled "Gold Standard Methodology for Accreditation of Water Benefit Certificates: Water Access and Water, Sanitation and Hygiene (Burnett et al.) Projects". Final methodological requirements posted here: http://www.goldstandard.org/water/rules-requirements [last accessed 2.15.2015]

[8] ADALY Credit – Draft methodology titled "Averted Disability Adjusted Life Years (ADALY)." Draft scoping methodology: https://www.astae.net/sites/astae/files/documents/Lao%20CSI%20BBL%20Sept16_2014.pdf [last accessed 2.15.2015]

The appropriation of carbon certification processes created under the carbon regime by emerging RBF markets is not surprising. The standards bodies that oversee the operations and functioning of carbon markets have strong incentive to align new RBF methodologies with the existing "validation" and "verification" procedures already in place under carbon markets. Previous studies have shown a growing convergence of certification procedures for voluntary standards. A study by Green (Green, 2013) analyzed a dataset of "119 private codes, regulations, or standards that included some environmental criteria… [and that] spanned transnationally in scope" that emerged since 1950. Her analysis finds that the majority of civil regulations for environmental governance were created in the past two decades (1990-2009), and that within this period a majority of the private standards were based partially on existing rules and standards, as opposed to being wholly new "de novo" standards (Table 1). Put more simply, although the number of private standards for environmental oversight have grown substantially over the past two decades, the actual substance of the private standards are increasingly utilizing and appropriating aspects of existing standards.

Table 12 Ratio of DeNovo Civil Regulations over Time.

Founding Dates	Total N	# of De Novo Standards	% of De Novo per Decade
1950-59	1	1	100%
1960-69	1	1	100%
1970-79	3	3	100%
1980-89	7	5	71%
1990-99	38	28	74%
2000-9	69	25	36%
Total	119	63	53%*

**53% is the total proportion of de novo standards across all six decades.*

The appropriation of elements from the carbon regime for use by new RBF programs provides is logical since it provides an easy to use MRV framework for new RBF programs to follow. Existing procedural steps used for certifying carbon credits are already being designated for use and/or proposed for use for RBF methodologies, including templates for creating Project Design Document (PDD) and calculation tools, Guidelines for Local Stakeholder Consultation, and Sampling Standards for statistical sampling and monitoring.[9] The standards bodies are also actively working to harmonize the overall auditing framework used across various methodologies for carbon and RBF to further ensure that differences in procedures remain as little as possible.[10]

With deeper examination of the constellation of actors involved in developing new RBF methodologies, we begin to see that a seemingly loose collaboration amongst nonstate actors is in fact one of strategic partnership that ultimately results in the strengthening of nonstate

[9] Existing rules and standards used for carbon accreditation have been repurposed or modified for use by new RBF methodologies. Water Benefit Credits requirements are reported here: http://www.goldstandard.org/water/rules-requirements, and proposed Black Carbon procedures proposed here: http://www.goldstandard.org/seeking-input-into-our-new-black-carbon-methodology [last accessed 2.1.2015]

[10] The Gold Standard Foundation is actively harmonizing auditing frameworks across carbon and non-carbon methodologies: http://www.goldstandard.org/audit-framework [last accessed 2.1.2015]

authority. We further see that these partnerships are not new, and that indeed many of the nonstate actors involved in RBF development have also been long involved as key actors within the carbon regime. Indeed, much of the innovation in new RBF markets stems from reorienting collaborations amongst existing carbon actor networks and appropriating MRV processes and standards developed under the carbon regime.

The role of experts in providing credibility

Scientific quantification of metrics for markets

Epistemic communities of science have been a cornerstone for policy makers in the credibility battle over climate change. The community of scientists that form the Intergovernmental Panel on Climate Change (IPCC) continue to provide the public with the latest in scientific consensus on climate change, and were principal in developing the scientific parameters within which carbon markets and emissions trading systems function and operate today. Most relevant to carbon markets is the IPCC's definition of six greenhouse gases that are used to develop emission inventories, create models for climate warming patterns, and assess the policy & technology implications of emission reduction programs. The scientific metrics used for quantifying carbon emission reductions – emission factors, global warming potentials, and time scales – underlies the very definition of a carbon credit commodity. Despite the long standing public debate over whether climate warming is human induced and whether it represents a long term trend, very few people debate the veracity of the chemical nature and potency of GHG's that are currently used in carbon markets. Much of this credibility is conferred by the knowledge that originates from scientific communities that provide us with our understanding of GHGs.

Scientists continue to develop new methods for quantifying the positive and negative externalities that result from climate change. Many of these metrics have long been studied in traditional disciplinary fields but are only now becoming part of mainstream climate-policy discussions. In the case of the Black Carbon Methodology, methods for quantifying black carbon have a strong research history in the field of atmospheric science, but only now has the policy environment become conducive for marketing black carbon as a commodity used for environmental regulation. A United Nations convened coalition called Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) has commissioned a working group titled "Black Carbon Finance" to determine how black carbon crediting could be incorporated into existing market-based policies such as emissions trading. The United States EPA has contributed knowledge through a 2011 Report to Congress on Black Carbon that summarized the current state of knowledge on black carbon, with a specific chapter on the contribution of emissions from residential cooking and heating in the developing world(Sasser et al., 2012). The scientific studies and reviews by CCAC, U.S. EPA, and other scientists form the basis for how we understand and conceptualize the possibility of emerging markets for black carbon today, and this knowledge is foundational to providing the necessary creditability for new markets to adopt new standards.

Similarly, our understanding of the health implications of clean energy for the poor has been guided by scientific studies in traditional academic disciplines of public health and epidemiology. In 2014, the World Health Organization released updated Guidelines on Indoor Air Pollution that prescribe safe levels of pollutant concentration for residential homes in developing countries.[11] These guidelines are derived from scientific studies that have long quantified the health burden caused by exposure to air pollutants caused by the burning of solid fuels for cooking and heating in rural homes (Gordon et al., 2014), for example, provides an excellent overview of research to date on health burdens from indoor air pollution). Once again, the study of these health outcomes (i.e. respiratory diseases such as asthma and chronic obstructive pulmonary disease) have become the basis for how new RBF methodologies seek to quantify and commoditize social and environmental externalities from clean energy interventions. Most recently, the private firm "CQuest Capital" has partnered with researchers at the University of California at Berkeley to begin pilot testing a new methodology for quantifying tradable credits from averted health outcomes from a clean cookstove intervention in rural Laos. The researchers at Berkeley were also seminal in developing the academic field of health exposure measurements from rural energy. The scholarly credibility conferred by the Berkeley scientists that participate in the development of techniques for quantifying ADALY credits represents a blurring of who defines authority within an unregulated market. The use of ADALY credits as a commodity that can be sold and traded in markets marks a new era for the science of health impacts from indoor air pollution, and indeed represents a more progressive role for scientists as they begin to participate more actively in the development of new markets.

Monitoring, Reporting and Verification (MRV) in the Digital Age

Innovations in information technology are allowing new RBF programs to strengthen their after-sales monitoring of technology adoption and usage, both of which are critical to the "monitoring, reporting, and verification" (MRV) framework utilized by the certification bodies for auditing of tradable credits. The growth of telecommunications in the developing world has made the global south one of the largest growth markets worldwide for mobile and digital services (Lee, Chandler, Lazarus, & Johnson, 2013). The mobile phone in particular has ushered in a tsunami of digital information for data scientists, researchers, and companies to analyze and leverage as they try to understand a rising consumer class in the global south and adhere to MRV requirements (Asongu, 2013; Carmody, 2013). Engineering scientists studying new digital services are providing newfound access for private firms to reach highly distributed and historically underserved communities that have long been viewed as unviable markets due to the difficulty of servicing and monitoring "bottom of the pyramid" clients.

Alstone et al. (Alstone, 2015 In Press) identifies the Global System for Mobile telecommunications (GSM) as perhaps the strongest platform for MRV innovation in support of consumers in the developing world. In many parts of Africa, mobile phones are increasingly becoming the preferred and trusted method for communication, banking, and overall information sharing. In 2007, Vodofone and Safaricom, which are the largest providers of mobile networking in East Africa, launched a mobile-money transfer and

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[11] WHO indoor air quality guidelines for household fuel combustion: http://www.who.int/indoorair/guidelines/hhfc/en/ [last accessed 3.6.2015]

payment system called M-Pesa (M = Mobile, Pesa = Money in Swahili). M-Pesa currently operates in Kenya, Tanzania, South Africa, and is expanding into new markets in India, Afghanistan, and Eastern Europe. M-Pesa uses mobile phone technology to facilitate micro-financing, loans, and payments for consumers that historically have not had access to brick and mortar banking institutions (Jack & Suri, 2011).

New companies are rapidly capitalizing on M-Pesa's digital technologies for consumer finance in order to strengthen understanding of their consumers. M-Kopa (M = Mobile, Kopa = To Borrow in Swahili) was founded in 2012 and is one example of social entrepreneurs partnering with engineering researchers to better understand the consumers they serve. M-Kopa is a clean energy company that provides home solar lighting systems to off grid consumers and to consumers with unreliable access to electricity. The solar home systems are embedded with GSM sensors that allow the company to remotely operate, monitor, and control the device from any location in the world. Consumers benefit from their innovative payment model that leverages M-Pesa's mobile banking system that allows for "pay-as-you-go" (PAYG) payment plans. If consumers fail to make scheduled payments, then M-Kopa simply deactivates the solar home system until further payments are made. The typical PAYG payment plan lasts one year, after which, if all payments have been paid in full, the solar system becomes fully owned by the consumer (Moreno & Bareisaite, 2015; Rolffs, Byrne, & Ockwell, 2014).

Business models such as M-Kopa and M-Pesa are not only revolutionizing the ways in which we think about consumer finance and technology adoption of clean energy products in the global south, but they are also resulting in what can simply be described as "Big Data" (Alstone 2015). The vast amounts of consumer information resulting from digital payments and product usage, among a dizzying array of other information that is becoming available, is allowing researchers and scientists a never before opportunity to begin to quantitatively segment and understand the consumer market at the "bottom of the pyramid." RBF markets are now seeking partnerships with researchers to reimagine ways of unlocking consumer preferences through analyzing the patterns of loan repayment, rates of technology usage, and even daily habits of consumers. Perhaps most important to RBF programs is the ability to remotely monitor the habits of a rising consumer class and their preferences for technology, which ultimately can be used in MRV frameworks for certifying "credits" derived from quantified social and environmental externalities.

The role of firms in spurring market innovation

The growth of carbon markets over the past decade has led to a proliferation of carbon financed rural energy programs that have been championed as models for technology innovation, generation of co-benefits, and as sources of sustainable financing . Proponents of market-based mechanisms argue that privatizing rural energy development in low income countries shifts responsibility for domestic development away from inefficient governments towards more effective private sectors that consist of non-governmental organizations, investors, and other market-based actors (Gregory L. Simon, Bumpus, & Mann, 2012; Somanathan, 2008).

Transnational business coalitions partnering with NGOs and public entities were indeed significant in providing the required influence, power, and leadership that governments needed to move forward with enacting market-based regulatory reform that was utilized under the UNFCCC's compliance carbon markets (Meckling, 2011). From a neoliberal institutionalist view, the rise of Kyoto's ETS can be viewed as a result of state interests in defining responsibility for historical emissions(I.H. Rowlands, 2001). A cognitive approaches view recognizes the role of non-state transnational actors, including business and non-profits, in mobilizing and influencing political decision making over environmental regulation. The theory of cognitive approaches suggests that the emergence of norms and ideas can stem from epistemic communities and nonstate actors that are instrumental in the ideation of liberal environmentalism and the normalizing of market-based policy approaches such as carbon trading (Adler & Haas, 1992; I. H. Rowlands, 2001).

In the case of pro-poor clean energy programs, NGO's and social enterprises have been particularly instrumental in driving methodological innovation for clean energy programs under ETS markets. The first methodology for cookstoves were principally authored by the non-profit organizations Climate Care and Impact Carbon. Nearly a decade later, NGO's and socially-oriented enterprises have again been at the vanguard of developing RBF methodologies that expand the types of financing available to pro-poor household clean energy programs. The principal authors for the most recent RBF methodologies include: Black Carbon Credit was authored by the NGO Project Surya; Water Benefits Certificates was authored by the social enterprise First Climate; ADALYs is being authored by the social enterprise CQuest Capital.

Private sector firms that have historically traded strictly in carbon offsets have also begun to expand their portfolio of services and projects to include RBF innovations. Carbon retailers such as Carbon Neutral Company, and project developers such as First Climate (principal authors of the WBC methodology), are openly marketing the development and sales of new Water Benefit Certificates alongside their traditional portfolio of carbon credits.[12] Industry coalitions such as the Global Alliance for Clean Cookstoves (GACC) have also been central in devising strategic direction for the cookstove community and making linkages to new markets for cookstove funding. The success of GACC's ability to drive a vision for innovative finance for the cookstove sector is due in part to its ability to mobilize substantial funding from both philanthropic and multilateral sources.[13] A significant portion of this funding has been channeled towards fast-tracking development of innovative RBF programs related to cookstoves, which include supporting research on quantifying ADALY credits through a pilot program in Laos, and supporting research on Black Carbon Credits through participation in the UNDP Black Carbon Finance Working Group.[14]

[12] Carbon Neutral Company develops and sells water benefit certificates: http://www.carbonneutral.com/our-services/water-benefit-certificates [last accessed 3.28.15]
[13] GACC raises financial commitments from both private and public sectors institutions. http://www.cookstovesfuturesummit.org/commitments/ [last accessed 1.12.15]
[14] GACC provides funding and financing for innovative business models that increase access to clean cookstoves: http://cleancookstoves.org/market-development/supply-strengthening/our-portfolio.html [last accessed 1.12.15]

Interestingly, the emergence of trade associations focused on supporting the continued development and strengthening of global carbon markets have been acute locales for resistance to efforts that enable greater access to climate finance. The International Carbon Reduction and Offset Alliance (ICROA), which is a specialist working group within the broader industry group International Emissions Trading Association (International Emissions Trading Association (IETA)), have been particularly vocal opponents to initiatives that lower barriers to entry for new carbon programs through the simplification and standardization of rules. ICROA is an industry coalition that seeks to protect the interests of its members, and thus is driven by a desire to limit competition for the dwindling sources of carbon buyers in the marketplace, and a reaction to the market realities of depressed carbon prices and an oversupply of credits in the marketplace. Their opposition has manifest in public commentary to new proposals for simplifying carbon methodological rules for cookstove programs that would ease requirements for developing new programs and thus increase the number of carbon credits available in an already saturated marketplace for cookstove credits.[15] The approach of increasing barriers to entry in order to limit credit generating activities has direct relation to RBF methodologies such as the Black Carbon Methodology, which allows project developers to increase the carbon credits generated by claiming emission reductions from a GHG (i.e. black carbon) that previously was not allowed.

Transnational entrepreneurship continues to be a powerful agent for technology transfer and innovation under market-based climate policies carried out in the global south (Jordan, van Asselt, Berkhout, Huitema, & Rayner, 2012). Entrepreneurial actors, whether through private firms or non-profit organizations, have been integral to the ability of market-based policy instruments to carry out the implementation and monitoring requirements of their regulatory framework. Industry groups such as GACC have viewed entrepreneurial agents as efficient conduits through which the market for "innovative ideas" can pilot a vast array of novel approaches for providing clean energy to the poor. These innovation hubs are mitigating the risks associated with establishing proof of concept for new RBF innovations by pursuing a wide spectrum of ideas. On the other hand, industry groups such as ICROA-IETA have vested interests in protecting the competitive landscape for its constituency, and thus has been less amenable to market innovations that increase the supply credits that threaten competition for credit buyers. This competitive environment, however, has spurred carbon firms to adapt and evolve to changing business models that utilize new forms of finance for their program. It is clear that donor and state funding will continue to play a critical role in expanding markets for technologies such as stoves and lighting that provide minimal financial returns, yet provide large public goods such as improved health and climate from reduced air pollution. But it is the firms that are providing the access and innovation needed to link ideas between the whims of global markets and the needs of local communities.

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[15] ICROA-IETA comment to simplified rules for small-scale cookstove programs developing carbon credits: http://www.ieta.org/assets/LU-WG/icroa_comments_to_gold_standard_simplified_micro-scale_efficient_cookstoves_methodology.pdf [last accessed 2.24.15]

The role of finance in support of energy access

Multilateral and National Funds

Multilateral funds for climate finance are perhaps the strongest reflection of neoliberal capitalism at work today. The growth and scale of climate funds are a driving force behind the continued reliance on structured mechanisms for mitigation and adaptation finance. Market-based mechanisms are presented as "transparent" and "established" processes for efficiently allocating funds to programs implementing projects in the developing world. The vast wealth that is being mobilized through multilateral and national climate funds, combined with the dominance of neoliberal regulatory tools as preferred approaches for environmental governance, has ushered in an era in which wide-ranging sectors and issue areas have linked themselves to climate change… with the hopes of also gaining access to the financing associated with climate mitigation and adaptation efforts. Hagerman et al. (2012) describe "climate-motivated responses" as a strategy employed by environmentalist, and in particular conservation biologist, that have linked traditional environmental issues such as biodiversity with the broader climate debate in order to generate new opportunities for funding and initiatives (Hagerman et al., 2012). The IPCC has itself encouraged the approach of establishing "inter-linkages" between broad cross-sections of adaptation and mitigation initiatives, which has resulted in varied relationships with climate change that include gender equality, food access, environmental justice, and a wide ranging set of livelihood linkages (Briner, Kato, Konrad, & Hood, 2014).

Several multi-lateral and national funds have emerged as a form of "stop-gap" financing to help carbon programs that are at risk of discontinuation due to the collapse in carbon credit prices. These funds have also broadened their scope to allow "inter-linked" energy access programs such as cookstoves, solar lighting, and safe water to be included in their investment portfolios. New RBF programs have sought linkages with these climate funds in order to scale their renewable energy programs while also pilot testing new approaches to creating non-carbon commodities. The Norwegian government's Carbon Procurement Facility (NorCaP) is an initiative established in October 2013 and has become an example of stop-gap financing seeking to buttress the market for carbon credits until Post-Kyoto policies for climate change mitigation are agreed upon. NorCaP states:

> "*The purpose of the Facility is to purchase carbon credits in the second commitment period of the Kyoto Protocol (2013-2020). Through this agreement Norway will purchase carbon credits from stranded UN-approved projects facing a risk of discontinuation due to the low prices on Certified Emission Reductions (CER).*"
>
> *"The principal objective of NorCaP is to prevent reversal of emission reduction activities by procuring credits from registered and commissioned projects whose continued emissions reduction activity depend on a higher carbon price than achievable under current market conditions. NorCaP will only purchase CERs from registered and commissioned CDM projects and PoAs which are facing the risk of termination due to the prevailing low CER prices (vulnerable projects) and which have no Emissions Reduction Purchase Agreement (ERPA) in force as of 7 October*

2014."[16]

Other multilateral funds aim to target early stage market innovations that will eventually strengthen a broader market for carbon and clean energy technologies. These funds act to de-risk financial investments for pro-poor markets until further private-sector funding is able to commercialize ideas at a later stage. The "Scaling-Up Renewable Energy Program for Low Income Countries" (SREP) program operates under the World Bank administered Climate Investment Fund (CIF) that seeks to spur innovation in clean technology and renewable energy in middle- and low- income countries. The state goals of SREP are:

> *"The SREP is designed to demonstrate the economic, social and environmental viability of low carbon development pathways in the energy sector in low-income countries. It aims to achieve five main objectives:*
>
> *1. Assist low income countries foster transformational change to low carbon pathways by exploiting renewable energy potential;*
>
> *2. Highlight economic, social and environmental co-benefits of renewable energy programs;*
>
> *3. Help scale up private sector investments to achieve SREP objectives;*
>
> *4. Enable blended financing from multiple sources to enable scaling up of renewable energy programs; and*
>
> *5. Facilitate knowledge sharing and exchange of international experience and lessons."*[17]

Funds such as SREP have a clear focus on co-benefits that reach beyond climate and carbon benefits. This highlights a diversified approach and a general trend of increased broadening of issue areas that are inter-linked to climate change. The sector for household energy access is no different, and in the case of pro-poor carbon offsets buyers, the industry term "charismatic carbon" has come to signify the need to provide offset buyers with credits that represent multiple co-benefits beyond just carbon reductions. RBF programs have sought to fill the need for "charismatic carbon" by systematically quantifying beyond-carbon co-benefits with hopes of being able to market and trade these credits to a new group of credit buyers. More and more, financiers, multi-lateral funds, and impact investors are mandating that multiple co-benefits are created from projects that have historically been marketed only as carbon reduction programs. Proponents of RBF programs are rearticulating their programmatic goals in part to reach these new financial sources of funding.

[16] NorCap: http://www.nefco.org/financing/carbon_finance_and_funds and http://norcap.org/docs/Letter%20of%20Invitation%20Final%207%2010%202014_revs%2031%2010%202014.pdf [last accessed 3.25.15]

[17] SREP: http://www.climatefundsupdate.org/listing/scaling-up-renewable-energy-program [last accessed 2.20.15]

Corporations and Individuals

Industry and corporations are increasingly being held accountable for the social and environmental impacts of their corporate footprint and supply chains. Tailored RBF and "charismatic carbon" credits have increased in popularity amongst corporations that seek to meet their CSR objectives. As the Gold Standard aptly describes, "*different types of carbon credits suit different buyers depending on their needs and obligations… buyers building a comprehensive CSR strategy may prefer more 'charismatic' projects that meet both their environmental and the social-economical commitments*[18]." The emergence of corporate accounting of greenhouse gas footprints has paved the way for other forms of accounting that include the tracking of industry specific non-carbon footprints. Corporate buyers are increasingly requesting charismatic projects that *"… are chosen not just for the offset aspect but also the secondary benefits that they have for the local environment and communities involved."* –The Co-operative Group [corporation][19]

A recent example of non-carbon accounting is within water conservation initiatives by companies that consume large quantities of water in their operations. PepsiCo began footprinting their water consumption in 2007 and subsequently began to aggressively reduce waste through water efficiency programs. In 2013, PepsiCo announced that they were partnering with international organizations to provide access to safe water for at least three million people.[20] Similar to carbon footprinting, water footprinting has provided the basis for corporations such as PepsiCo to begin offsetting their corporate water consumption through "water credits" in voluntary markets. The Water Benefit Certificate is likely to emerge as a trusted commodity for corporations such as PepsiCo. that seek to offset their water consumption through "certified" water credits. The certification process and third party auditing provides further certainty of credit quality and a platform for companies to more easily and publicly report on their sustainability activities.

Creating markets for co-benefits has also opened new lines of credit financing through micro lending programs such as Kiva, which allow individuals to provide loans to clean energy programs in the developing world.[21] These loans are collateralized against the carbon credits that are created and then sold to corporations, multilateral funds, or philanthropist and impact investors. Although not yet in existence, one can imagine Kiva loans for new RBF markets such as Water Benefits Certificates that could be collateralized against purchase agreements for water credits. Innovative finance organizations such as Kiva are drawn to market based approaches to development because of the perceived certainty and confidence provided by certification procedures for monitoring and reporting. New RBF markets are particularly attractive because of their ability to provide tailored "charismatic" credits that appeal to a cross-section of stakeholders.

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[18] Gold Standard FAQ: http://www.goldstandard.org/frequently-asked-questions/carbon-market [last accessed 3.28.15]

[19] Co-op: http://www.co-operative.coop/our-ethics/our-plan/protecting-the-environment/carbon-offsetting/carbon-offsetting-case-studies/ [last accessed 3.28.15]

[20] http://www.pepsico.com/Purpose/Environmental-Sustainability/Water [last accessed 2.28.15]

[21] http://blog.kiva.org/kivablog/2013/09/09/a-new-way-of-thinking-carbon-as-currency [last accessed 2.28.15]

The methodologies that underpin market mechanisms will continue to evolve and innovate as the buyers of carbon and RBF credits increasingly demand broader ranging social and environmental impacts from their credits. As reported in the industry news reporting service Ecosystem Marketplace, the carbon market expert William Theisen states "*Demand [for carbon credits] will continue turning to charismatic carbon credits, with premium prices extending beyond cookstove projects to other community projects, such as water filtration or household biogas interventions. Project developers and buyers will … focus on the measurement of a project's development impacts.*"[22] Market-based approaches to financing climate and development programs will continue to seek new linkages to both traditional and novel forms of finance as the expectations of credit buyers and investors change.

DISCUSSION

The largest policy framework to emerge from Kyoto Protocol's first commitment period is what now can be described as carbon markets and their related emission trading systems (ETS). The rise of a large and complex carbon regime has been foundational in providing the necessary pre-conditions for the emergence of the rapidly growing space of results based financing. Nonstate actors in particular have been pivotal in mediating between science and new market-based policies for clean energy finance. The number of voluntary market methodologies (including both carbon credit methodologies, as well as RBF methodologies) available for use by pro-poor energy programs has steadily increased since the inception of the Kyoto's first compliance period. The RBF methodologies discussed in this paper represent very nascent steps towards creating new markets outside of the regulated and voluntary carbon markets, and indeed have only emerged in the past two years and are still evolving at the writing of this paper.

Polycentric Authority: Supply and Demand

Significant barriers remain for the growth and full adoption of RBF markets. Drawing on Green's (2013) definition of private authority, which implies consent between those who define and govern the rules with those who utilize and consent to following the rules, "private authority" for RBF markets will only have been achieved after "consent" and demand is created for the purchase of these new types of credits (Green, 2013). Voluntary by nature, RBF credits will rely on the willingness of corporations, impact investors, philanthropist, and altruistic individuals to adopt and purchase these new credits. Alternatively, government development aid could eventually choose to be more closely tied to RBF markets as a means of tracking and measuring progress. Regardless of where the "demand" for credits come from, the examples of Black Carbon Credits, Water Benefit Certificates, and ADALY credits, highlight the role of nonstate actors as explicit agents for "supplying" and defining the methodological rules for creating new tradable commodities, which is the first and perhaps the most important step in creating new market mechanisms.

[22] Ecosystem Marketplace: http://www.ecosystemmarketplace.com/pages/dynamic/newsletter.page.php?page_id=9539&section=newsletters&eod=1 [last accessed 3.12.15]

In light of the continued role of governments in providing both finance through multilateral funds, and their potential role as agents of "demand" for RBF credits, this paper adopts the idea that new RBF methodologies do not usurp top-down governmental power and authority, but rather co-exists within a "polycentric… constellation of governing institutions" for climate governance (Figure 2) (Ostrom, 2010).

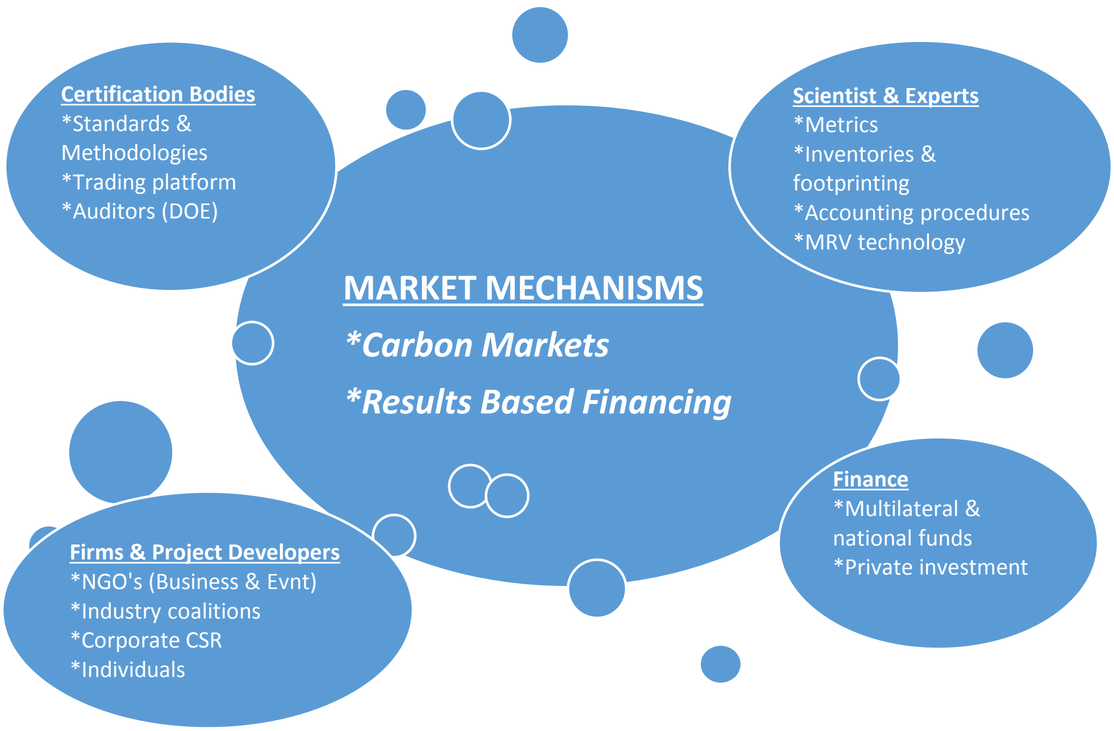

Figure 2 Polycentric authority for market mechanisms

Table 13 outlines the public and private actors that have collaborated in the creation of new results based financing methodologies. The methodologies represent voluntary markets that have been conceived and developed primarily by private nonstate actors, yet with the assistance of public financing.

Table 13 Emerging results based financing methodologies created under a polycentric framework of authority.

Meth	Actor	Public	Private
Water Benefits Credit	Methodology Author		*Whave Solutions [NGO] *First Climate [Social Enterprise]
	Certification Body		*Gold Standard Foundation [NGO] *Voluntary buyer (corporate, individual, impact investors, etc.) of Water Benefit Certificate (WBC)
	Financial Support	*Swiss Agency for Development and Cooperation SDC	
	Scientific Adviser		*Int'l Union for Conservation of Nature [NGO] *International research community at large
Black Carbon Credit	Methodology Author		*Surya [NGO] *TERI [Scientific Body]
	Certification Body		*Gold Standard Foundation [NGO] *Voluntary buyer (corporate, individual, foundations, etc.) of Black Carbon Credit
	Financial Support	*UN Foundation Global Alliance for Clean Cookstoves (GACC) *UNDP Black Carbon Finance Working Group	
	Scientific Adviser	*UNDP Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC)	*International research community at large
ADALY Credit	Methodology Author		*CQuest Capital [Social Enterprise]
	Certification Body		*Gold Standard Foundation [NGO] *Voluntary buyer (corporate, individual, impact investors, etc.) of ADALY credit
	Financial Support	*UN Global Alliance for Clean Cookstoves (GACC)	*Bix Fund
	Scientific Adviser		*University of California at Berkeley [Academic] *International research community at large

Table 13 shows a form of hybrid authority emerging for governance over new RBF markets. It is the shifting loci of innovation between and amongst the existing network of experts, NGO's, and scientists that blurs the line of between state led governance and nonstate private authority. Nonstate actors have acted in loose concert to define new methods and standards for clean energy finance and governance. The participation of key nonstate actors, whether used explicitly at the outset in the creation of a new methodology or implicitly ex-post in defense of a methodology, contributes to establishing credibility, authority, power, and market access for the methodology. Multi-loci spheres of governance is perhaps a more apt way to understand emerging markets and standards for results-based finance.

This framework does not preclude the important and explicit role of government in granting authority to these new methodologies, but it also does not diminish the real and tangible efforts by nonstate actors in defining wholly voluntary and independent standards and methodologies for pro-poor clean energy finance. These nascent RBF methodologies reveal nonstate actors taking on the role of methodology developer in order to create voluntary RBF markets, much in the same way that the UN CDM Executive Board acted as mediator for the creation of Kyoto's carbon market rules and standards.

CONCLUSION

The emergence of new voluntary "results-based" or "performance-based" markets signals a continued pattern towards devolving power to non-state actors in the face of faltering international action over climate mitigation and sustainable development. In the case of climate governance through voluntary RBF markets, we see a precarious balance between a predominantly private non-state led form of governance with financial support from nation states. The state remains staunchly in control by virtue of legislating over national commitments to climate change, and perhaps more importantly, are often the benefactors for multilateral and national funds that constitute the bulk of mitigation and adaptation financing available for clean energy programs in the global south. Yet, we still find that communities of science, voluntary certification bodies, and private sector firms have been successful at exerting, at least in the early stages of RBF market formation, strong influence over the structure and content of market based policies to achieving the goal of clean energy access for the poor.

Future considerations for RBF markets

It is important to note, however, that significant differences exist between carbon credits and RBF credits. Energy consumption is pervasive throughout every aspect of the global economy and touches upon economic actors at all levels from individuals to nations. Emission trading systems are considered to be effective policy instruments for reducing greenhouse gas emissions precisely because of their ability to signal a price for carbon to all actors within this energy economy. RBF markets for ADALYs and Water Benefit Certificates, however, differ from GHG mitigation because of their localized effects and limited scope in the global economy. Market based strategies for combatting programs such as water, sanitation, and hygiene (Burnett et al.) must consider the difference that natural market forces can play in driving lasting investment and change in sectors that are not as deeply engrained in the global economy. Market mechanisms that trade RBF credits such as WASH benefits may in fact never reach the scale of growth experienced in carbon markets, but rather, could simply be used as a "charismatic add-on" for potential carbon buyers.

In the wake of the global recession and downturn in carbon markets, it is also apt to reflect and evaluate the efficacy and sustainability of market-based mechanisms to serve as an effective tool for rural energy development in the global south. RBF programs must acknowledge that a reliance on markets for distributing clean energy products to the poor can also result in the adverse effect of preventing the best technologies currently available from being implemented. Providing price signals for environmental externalities are meant to incentivize businesses to continually innovate and improve upon their technologies in order to provide increasingly higher quality services and products. The stringency of certification rules and processes, however, makes it difficult for project developers of RBF programs to adapt to changing innovations and provides barriers to adopting new, cleaner, and perhaps more appropriate technologies. The local implementing program generating carbon emission reductions or RBF credits lacks incentive to further improve upon their own technologies that have already yielded them successful offsets and the associated revenue stream that comes from implementing a certain type of technology. The RBF- and Carbon-credit revenue stream can further impede innovation by channeling funding and subsidies towards a single technology and thereby sidelining equivalent performing technologies, or worse, impeding the entry of more efficient or effective types of technology that are either not aligned or too costly to implement under an existing RBF-Carbon program.

Progress toward universal energy access

It is clear that market-based mechanisms used to finance clean energy programs in the developing world have firm footing in policy debates and indeed are evolving to adapt to current economic and political realities. This paper shows that the establishment of a global carbon market regime has provided the critical architecture and framework for new market innovations to emerge. The confluence of global economic forces, advances in information technology, innovations in delivery systems for clean energy products, and a greater understanding and appreciation for a consumer class residing in the global south, have come together and allowed nonstate actors to leverage the traditional "carbon regime" to create new forms of pro-poor market mechanisms.

Understanding the patterns and drivers of emerging structures of governance for climate mitigation and sustainable development are timely in the face of a possible 2015 climate accord in Paris. Under a post-Kyoto agreement, industrialized nations are mandating participation from global south nations through reciprocal guarantees of nationally appropriate mitigation plans. At the same time, global south nations are mandating that financing and resources to enact national commitments are provided by industrialized nations. The experimentation with new RBF schemes may be the precursors for an eventual international system of tradable permits that allows project-based "RBF" offset programs to be conduits for technology and financial transfers from Annex I to non-Annex I nations, utilizing a “pledge and review” process that conditions climate funding on MRV and third party certification of outcomes. In the very least RBF programs may act as “bridging strategies” until post-Kyoto policies for climate mitigation are formally adopted and implemented. The dominance of market based approaches to climate mitigation and sustainable development are likely to continue for the foreseeable future. The study of emerging RBF markets will strengthen our ability to effectively respond to a changing global climate, and to more quickly adapt to the needs of those most disproportionately affected by growing GHG emissions.

CHAPTER 4 PEALING BACK THE LAYERS OF CLIMATE METRICS: AN EXAMINATION OF CARBON MARKET METHODOLOGIES

ABSTRACT

This chapter explores the role of quantification and objectivity discourse in formulating greenhouse gas (GHG) accounting metrics. Specifically, I show how classification and framing of scientific climate metrics at the Intergovernmental Panel on Climate Change (IPCC) have directly configured current carbon offset markets and how this, in turn, has defined how and which actors are allowed to participate in the global carbon trading economy. I go on to explore the consequences, both intended and unintended, of "climate metrification" for programs that participate in carbon markets. Through analysis of a United Nation's methodology for cookstove carbon quantification, I demonstrate the high variability and fluidity inherent in climate accounting rules and standards. These findings challenge the widely held perception that carbon financial markets are technically precise and objective. I conclude by positing on the nature and function of climate metrics for global environmental governance and its relevance to international negotiations towards a potential climate accord in 2015.

INTRODUCTION: CLASSIFICATION AND FRAMING

“Carbon credits” represent both a financial and scientific mechanism for reducing greenhouse gas (GHG) emissions. In financial terms, a carbon credit is a commodity that allows emitters in one locale to offset their emissions through purchasing an equal volume of reduced emissions in another locale. In scientific terms, a carbon credit is an emissions metric used to communicate the relative climate impact of various pollutant emissions in the form of equivalent ton of carbon dioxide (tCO2e) reduced or avoided. The commercialization of carbon trading in recent years has increased scrutiny of the accounting systems that govern the process of quantifying and certifying carbon reductions (Bachram, 2004; Bumpus, 2011; MacKenzie, 2009). This paper explores the critical assumptions and values involved in the construction of a carbon credit.

The carbon market is structured around a set of six GHG pollutants that the Intergovernmental Panel on Climate Change (IPCC) has characterized as the primary contributors to human-induced climate warming. Theses six GHG are converted to equivalent tons of carbon dioxide through the application of global warming potentials (GWP) that estimate the absolute and relative contribution of each GHG over a specified time horizon using the equivalent unit of tCO2e. Carbon certification programs publish methodologies that provide the framework of rules and requirements for monitoring, reporting, and verifying (MRV) the inputs and calculations used for determining a carbon credit. In the case of distributed energy technologies such as cookstoves, MRV protocols also require an estimation of the fraction of renewability of forests (f_{NRB}) from which woodfuels are harvested, and the combustion efficiency of the cookstove used for burning the fuel. Ultimately, a carbon credit is calculated from the combined estimates of GWP, f_{NRB}, technology efficiency, usage intensity, and other inputs resulting from MRV.

Carbon markets are rule-based mechanisms guarded by strict layers of guidelines and methodologies, and are situated within a complex and evolving regulatory framework of governance. These strict layers of rules are in constant tension with the need for simplicity, standardization, and defined categories in order for lay practitioners to easily and effectively participate in carbon markets. The friction between complexity and standardization, and elitism and lay population, has only grown since the inception of the Clean Development Mechanism (CDM) and various voluntary carbon markets such as the Gold Standard (GS). Indeed, the CDM and GS pride themselves as “learning mechanisms” which adapt to the needs of actors, markets, and local conditions – and it is precisely this heuristic approach to rule-making that contradicts the carbon markets’ public persona of being extensions of immutable science, and constituted by robust metrics that are governed by strict compliance and standards.

As an emission metric that is used for both financial accounting as well as scientific climate accounting, each step of the carbon certification process must adhere to careful and detailed documentation followed by rigorous third party auditing. What results is a “carbon credit” that is viewed as a transparent and fungible commodity robust enough for use in financial markets and climate policy decision making. In contrast, this paper “peals back” the procedural layers used for GHG accounting to reveal the inherent value-based decisions and negotiation that underlie the process of quantifying and certifying carbon credits, and explores the consequences for both financial and climate accounting.

As Miller (2000) argues, scientific framing and classification techniques are often based on assumptions and values that reflect the agents that champion them, and are constantly changing as a result of social, cultural, and political environments, which ultimately can result in the inclusion and exclusion of groups, values, and ideas (Miller, 2000). Using Miller's understanding of classification, I show how techniques of framing, metric formation, and categorization have shaped the current carbon economy, and I analyze the implications of increased standardization of carbon accounting rules on local communities and the global climate. I conduct sensitivity analysis on key carbon metrics to further reveal a carbon market that is far from objective, and that, indeed, cultural and political institutions have played significant roles in defining the operational form and function of carbon trading. Generating a carbon credit hinges upon

METRICS IN CLIMATE MITIGATION POLICY: CATEGORIZING THE CARBON LANDSCAPE

The categorization and metrification of our world are efforts to either spatially, temporally, or spatio-temporally segment and compartmentalize the world into common communicative currency. The process of developing metrics and categories requires judgment to be placed on what is worthy of acknowledgment and what is not, or what Bowker and Star describe as "residual categories" (Bowker & Star, 1999). Metrics often isolate the world into variables to which primacy is given in future research, work, or use, and result in directing attention and resources towards describing a world that consists singularly of these variables. Understanding why and how decisions are made to not classify certain variables is particularly useful in understanding the norms on which the metrics we use were built, and informs our understanding of cultural assumptions and ultimately the consequences of classification decisions.

Most commonly we understand metrics as having an ability to act as boundary objects that allow for the fluid functioning of society and systems (Leigh-Star, 2010) . Their ubiquity can be seen in how deeply they are embedded in society, both physically and cognitively becoming part of the built environment, and at times integrating so seamlessly that they become invisible. Lost in this ubiquity, however, are the political processes and normative pressures that surround their original conception and construction. We can begin to unpack the process of metric formation by examining the nature of their ubiquity, the practical politics surrounding them, perceptions of materiality and use of metrics, and the fluid and continual process of redefining metrics over time.

A retrospective examination of climate policymaking allows us to reveal the political narratives that script many of the metrics that we perceive as universal today when, in fact, these narratives involve debate, conflict, and negotiations that are carried out in organizations and are bounded by the rules and norms of institutions and society. The ramification of these ideals can result in the co-construction and rewriting of human histories (Miller, 2005). The politics of environmental policy and in the case of this paper, carbon methodology rule-making, are governed by distinct institutional processess that are structured around a formal architecture for risk analysis and decision making (Arrow et al., 2001). But it is often the unseen politicization of metric development that leads scholars of the epistemology of metrics to be much less concerned with the physical and stated appearances of categorization, and rather, more focused on the processes and outcomes of metrics. An example would be to not use the scientific and politically safe narrative that carbon credits are simply quantified reductions in pollutants that benefit all, but rather that a powerful political economy has been built around carbon markets and is reliant upon the continuation of a capitalist "carbon economy." Understanding the true nature of the latter can provide both a more practical and richer understanding of our increasingly categorized and metric-centric world, as well as a more holistic view of the social context and consequences of metrification.

Binary Classification

Imbued in the process of metrification is the assumption that societal perceptions of categories is constant and universal. Contrary to this view, there are a multiplicity of variables competing within spheres of knowledge and practice, which initiate a complex cognitive processing of categories that rarely result in clean binary outcomes. For example, the rules governing safe exposure to particulate matter less than 2.5 microns per meter cubed (PM2.5) allows us to see how classification schemes can force us into viewing the world through binary lenses, which in this case defines a threshold for toxic exposure that is deemed either "safe" or "harmful." Although scientific and epidemiological studies have established strong links between exposure to PM2.5 and poor health outcomes, the policies that govern public exposure to PM2.5 vary widely across political geographies (Burnett et al., 2014; Pope et al., 2009; K.R. Smith & Mehta, 2003). The World Health Organization air quality guidelines (AQG) set 24-hr exposure limits at 25 $\mu g/m^3$, whereas China prescribes less stringent 24-hr exposure limits at 35 $\mu g/m^3$ for urban areas and 75 $\mu g/m^3$ for rural areas (MEP, 2012; WHO, 2006b). The allowance for more universal interpretation and understanding of toxics exposure, such as incorporating the analysis of social and biological stressors that may compound or ameliorate the effect of exposure to toxics, allows us to utilize a broader lens that bridges the binary world of metrics with the realities of a complex universal world.

The dominant paradigm of binary classification has allowed policymakers to smooth over ambiguity while skirting some of the more ethically challenging aspects of categorizing. Understanding the process of how acceptable levels of ambiguity and uncertainty are determined and consequently interpreted as public policy, is central to the unpacking of metrification. The interplay between individual and institutional expectations provided by metrics, and the negotiations that occur amongst actors that use and develop metrics, can exert undue "torque" on society (Bowker & Star, 1999). Torque is the abrasion and subversion of metrics by individuals to reach personal ends; the misalignment of metrics with individual needs and expectations can provide perverse incentives to reengineer how metrics are used. Not surprisingly, the use of carbon credits as a financial tool for technology investment and regulatory compliance provides a scenario in which torque may be applied to the accounting procedures used for measuring and certifying GHG reductions. We will explore this issue further by examining the evolving methodological rules governing carbon offset generation for clean energy programs in the Global South. As the methodological rules have been revised and changed over time, so has the nature and statistical certainty of the resulting carbon offset.

ORIGINS OF INTERNTATIONAL CARBON METRICS: EXPLORING THE DEVELOPMENT OF THE "CARBON CREDIT"

Perceived Objectivity of Metrics

Metrics sit atop a mantle of perceived objectivity and neutrality in our society, utilizing both quantitative techniques and numerical representations to buttress their stature as a supreme form of fairness and transparency (Porter, 1995). Historical examinations of quantification processes can help to reveal some of the reasons and rationale for why metrics have achieved this lofty position of authority. Porter (1995) suggests that (a) Cultural, and (b) Political structures are primary agents (beyond the properties of natural objects) in influencing the process of quantification. I refine this hypothesis by suggesting that the dialectical tension between (1) complexity and elitism, and (2) standardization and lay, are also significant factors allowing for the continued reign of quantitative power in carbon accounting rules and methodologies. The structure of communities in which science and policy are debated weigh immensely on metric formation; from organizational pressure to communicative capacity, the embedded forms from which the public persona of metrics emerges are hard to disentangle.

Complexity and elitism may be best exemplified in the culture of climate science. A positivist viewpoint of measurement activities sheds light on how scientific endeavors rely on assumptions of quantitative objectivity and rigid processes to validate research and theoretical claims (Longino, 1990). Under this positivist lens a description of our world can be summarized exclusively by numbers and supported by statistical certainty, and argues that this work can be achieved through a standard ordered model of investigation of our natural world (Madill, Jordan, & Shirley, 2000). These ordered models of investigation and complex knowledge are further legitimized within elite epistemic communities of science. The process of knowledge production rarely reflects only the physical, however, as social measures and political factors co-exist in the science-to-policy debate as actors negotiate notions of validity and credibility.

In the broader climate policy arena, a constructivist view of quantification proffers notions of impersonality and rigid prescriptive rules as being the causes and consequence of quantification (Madill et al., 2000). Porter (1995) argues that quantitative-based decision making arose not from a desire by powerful elites to make better decisions, but rather, emerged as a strategy by policymakers to distance themselves from the subjective and personal nature of decision-making (Porter, 1995). This "impersonality" shields decision-makers from the potential for personal scrutiny, and allows them to rely on numbers to provide the appearance of fairness and impartiality, or providing the option to "make decisions without seeming to decide" (Porter, 1995). This prescriptive form of quantitative decision-making sets up the tension between the markets' rigid rules and guidelines against the practical needs of firms to implement projects in the "real world." The perceived objectivity of policymaking obscures the ongoing social negotiations and human rationale that occur "behind the scenes" between regulators and firms as they navigate these new markets together.

Standardizing Climate Science

Although lacking exact scientific understanding of how the climate is impacted by human and natural perturbations, scientific consensus regarding the state of climate science knowledge has nonetheless been reached by the Intergovernmental Panel on Climate Change (IPCC). One of the most significant policy-relevant IPCC findings was the identification and subsequent adoption by the United Nations Framework Convention on Climate Change (UNFCCC)) of six greenhouse gases (GHGs)[23] that are understood to be the primary anthropogenic-induced drivers of climate change during the industrial era. The IPCC has also taken steps to translate these variables into policy prescriptions through the use of global warming potentials (GWP) that allow for different gases to be compared equally. Thus, the IPCC has succeeded in defining the internationally accepted "short-list" of official GHG, and has defined the operational terms by which GHGs are applied in the policy setting. This metrification of the environmental commons allows governments and international negotiators to more concretely plan national policy positions and to more effectively discuss and negotiate the details of international climate accords. Substantively, the focus on specific gases enabled the ratification of the Kyoto Protocol by a majority of LDCs and industrial nations and provided market based climate policy instruments the legal and normative basis needed to garner private and public participation.

The classification of GHGs and the development of a GWP metric have, however, also resulted in a marginalization of technologies, industries, and even segments of society. Specifically, the identification of only six official Kyoto GHGs has been to the detriment and exclusion of other climate warming pollutants such as carbon monoxide (CO) and black carbon (BC), which are widely known to exert significant radiative forcing, and which are found predominantly in less developed countries (LDC) as a result of incomplete combustion -- such as from forest fires, residential fuel use, and open field burning of agricultural residues (Ramanathan & Carmichael, 2008). A large body of scientific evidence has emerged in the last decade revealing the contribution of pollutant emissions to climate change that are co-emitted in addition to carbon dioxide, otherwise known as "products of incomplete combustion" (PICS). The latest IPCC assessment report 5 (AR5) states global black carbon emissions exert radiative forcing equal to that of methane, and aerosols and white carbon have a nearly equal or even greater cooling effect (Myhre et al., 2013). The exclusion of PICS from the Kyoto list of anthropogenic induced GHG has resulted in not only less scientific research and funding directed towards understanding the full effects of PICS, but has also resulted in climate negotiations placing substantially less attention on PICS as a mitigation option. The ultimate consequence is that PICS and the technologies responsible for their emissions, and the societies in LDCs that are most closely tied to PICS emissions, have been marginalized in climate policies originally designed to achieve efficient and equitable carbon reductions. It is clear that decisions to classify components of the climate and the construction of GHG

[23] Kyoto GHGs are: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and 3 forms of hydrocarbons (hydrofluorocarbon = HFC-23, hydrofluorocarbon = HFC-134a, sulfur hexafluoride = SF6).

metrics have direct impacts on climate governance. Below I explore the assumptions that are used to derive the climate GWP or "impact" of each of these gases, and how social and political processes have guided the way.

Global Warming Potentials

Central to unpacking and understanding the debate surrounding gaseous "impacts" on the climate is to first understand what a GWP is, how it is used, and what assumptions are used to determine it. As defined by the IPCC AR5, GWP is:

> *"Emission metrics such as Global Warming Potential (GWP)… can be used to quantify and communicate the relative and absolute contributions to climate change of emissions of different substances, and of emissions from regions/countries or sources/sectors. The metric that has been used in policies is the GWP, which integrates the [radiative forcing] of a substance over a chosen time horizon, relative to that of CO_2… There are significant uncertainties related to … GWP.... The values are very dependent on metric type and time horizon. The choice of metric and time horizon depends on the particular application and which aspects of climate change are considered relevant in a given context. Metrics do not define policies or goals but facilitate evaluation and implementation of multi-component policies to meet particular goals. All choices of metric contain implicit value-related judgements such as type of effect considered and weighting of effects over time."(Myhre et al., 2013)*

In other words, GWPs are the first step towards bridging science to policy. GWPs reduce GHGs to equivalent CO_2 emissions, providing a measure that presumably has the same climate impact over a specified period of time for any gas. For example, AR5 has given CH_4 a 100-year GWP of 35, which means that a reduction of 1 tCH_4 is equivalent to a reduction of 35 tCO_2 emissions. Scientific understanding of the climate impacts of Methane has expanded quickly, however, as reflected in changes in previous versions IPCC assessment reports: IPCC AR3 was published in 2001 and reported CH_4 100-year GWP at 21; AR4 was published in 2007 and reported CH_4 100-year GWP at 25; in 2013, AR5 reported CH_4 100-year GWP at 35 (Forster et al., 2007; Myhre et al., 2013; Ramaswamy, Boucher, Haigh, Hauglustaine, Haywood, Myhre, Nakajima, Shi, Solomon, et al., 2001). The change in CH_4 GWP from AR3 to AR5 represents a 48% increase in the climate warming potency of methane. The policy implications of an upward revision to GWP for CH_4 should not be underestimated. Our evolving understanding of methane's impact on the climate highlights the challenge of translating our shifting scientific understanding of a complex climate, to static policy instruments that are by nature exacting and prescriptive.

Implicit in the calculation of GWP are assumptions related to the accuracy and precision of the scientific models on which the GWP was determined. Most relevant to our discussion here are the assumptions regarding time-scale, namely: (1) The 100-yr GWP of gas "X" accurately reflects its impact on the climate system; and (2) The 100-year time horizon accurately reflects societies time preferences for social returns. Assumption 1 refers to the decreased predictive power of climate models as longer time scales are used, i.e., the predictive power of current climate models is more accurate for 10 years from now than for 100 years.

Assumption 2 refers to the discount rate derived from atmospheric lifetimes for varying gases, i.e. CH4 has an average atmospheric lifetime of 12 years (+/-3yrs), while HFCs have an average atmospheric lifetime of ~1300 years, thus the present value of a gas is altered by choosing different time scales (shorter time scales "weight" more heavily gases with shorter lifetimes, and vice-versa for longer time scales) (Ramaswamy, Boucher, Haigh, Hauglustaine, Haywood, Myhre, Nakajima, Shi, & Solomon, 2001).

IPCC assessment reports provide GWP values for 20-, 100-, and 500-year time scales for each Kyoto GHG, but it is the 100-year time scale that has been chosen by the IPCC to be used as the official conversion factor for reporting Kyoto-mandated annual national emission reports. By choosing a 100-year time scale, as opposed to a 20-year or 500-year , the IPCC has dictated which gases, and thus, which industries, are prioritized in policy instruments such as carbon offset markets. For example, if a 20-year time horizon was chosen by the IPCC to represent the lifetime of gases, it would mean that shorter lived gases such as CH_4 would be assigned lower discount rates relative to longer lived gases, resulting in a higher CH_4 GWP value relative to longer time scales. In the case of carbon markets, higher GWP values translate to greater numbers of carbon credits for a given gas, thus investors and project developers would likely shift investments towards methane producing projects. This is not a new phenomenon, as it has been well documented that an investment bias towards projects emitting HFCs has captured the lion share of approved clean development mechanism (CDM) projects, primarily because the GWP for HFCs is orders of magnitude larger than other GWPs for other GHGs (Sutter & Parreno, 2007; Wara, 2007).

The Climate's Natural Debt

The decision by the IPCC to use a 100-year time horizon has also directly influenced the budgeting of "natural debt," or the aggregate historical GHG emissions for a given country during the industrial era. The concept of natural debt has in turn directly influenced the development of normative arguments related to geographic and intergenerational equity, concepts that have served as cornerstones for climate negotiations. Since CO2, HFCs and SF6 have, prior to the latter half of the 20th century, almost exclusively been utilized and emitted by developed nations, the Kyoto Protocol has calculated a disproportionately larger natural debt for industrialized nations as compared to LDCs. Climate negotiations have leveraged these differences to champion the concept of "common but differentiated responsibilities," or the assigning of mitigation obligations in proportion to a country's stock of historic emissions. The natural debt of LDCs prior to the mid-20th century, on the other hand, are primarily sourced from natural activities that emit CO2 and CH4, such as from agriculture, clear-cutting, timber burning, landfills, and wetlands (K. R. Smith, 1996). A shorter IPCC time horizon for GHG's, for example 20-years, would increase the GWP value of methane and reduce the importance of CO2, meaning the overall LDC natural debt would be increased relative to its natural debt under a longer 100-year time horizon scenario, and the natural debt of industrialized nations would be decreased slightly due to a disproportionate fraction of its natural debt is from CO2 emissions. This increase in responsibility for LDCs would insert a new variable into climate discussions, a scenario for which LDCs would likely not be receptive to because of the greater responsibility assigned to them. It is also possible that industrialized nations such as those in Europe would also not be receptive to the use of a shorter time-horizon, as it runs antithetical to normative arguments of equity and justice used to sway nations to sign onto the Kyoto Protocol. Moreover, normative arguments of intergenerational equity would also be diminished under a shorter 20-year time horizon, as lower discount rates imply valuing present generations greater than future generations.

Translating Climate Science to Policy

The climate system is immensely complex and highly variable over time and space. Scientific knowledge over how our Earth's climate system functions and how it is affected by both human and natural perturbations is ever evolving. Models based on prevailing scientific climate knowledge are constantly being revised to more accurately forecast future atmospheric concentrations of gases and relevant sinks and sources, and the accuracy of these models directly affects the radiative forcing ability, or warming potential, of each GHG, which in turn directly influences GWP calculations. Although the IPCC has used the most "current scientific data" to create these models, the state of knowledge is still vigorously debated within the scientific community and scientific positions are ever changing. Amidst this flurry of activity, the IPCC expert body has taken on the task of distilling the large body information and reaching general consensus over the current state of knowledge. A changing pool of knowledge has meant that each subsequent IPCC assessment report endures social and subjective negotiation over key assumptions that are translated into policy recommendations.

The IPCC has projected an image of objectivity and scientific rigor, yet in reality, they are responsible for what Jasanoff calls "regulatory science," or science that is amenable to policy making and that is robust enough to endure the political whirlwind that shrouds international climate negotiations (Sheila Jasanoff, 1994). The IPCC has existed for over 3 decades, but it has not until recently found successes in garnering worldwide trust and respect from the public and international community (most notably, the United States, which still holds many skeptics). At first blush the IPCC's inability to convince the World of the validity of its findings is somewhat surprising as it is represented by roughly 200 scientists from top Universities and research institutions from around the world, and has developed a substantial evidence base in favor of its position, that is, that the Earth's climate is warming and that this warming is not part of the natural climate cycle, and instead is due primarily to human activity.

Boundary work has clearly been involved in this process of "making the case" for human-induced climate change. As seen with the development of GHGs, construction of GWP, and the generation of climate models, the IPCC and its advocates have relied heavily on the belief that the impression of "quantitative objectivity" would enable gains in the "credibility debate," and that a strategy of positioning scientific knowledge in a prominent position in the culturescape, while locating other forms of knowledge on the periphery, would secure legitimacy and power in the ongoing climate science-policy debate (Gieryn, 1995) [24]. It is clear that this has not worked. New priorities and more powerful groups have pushed back and redefined the boundaries of science.

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[24] Thomas Gieryn refers to the "credibility contest" in his work "Boundaries of Science," referring to the contested nature of scientific knowledge and the efforts by various actors to wrangle legitimacy and power from other competing claims to knowledge. A constant positioning of knowledge and actors occurs through "boundary work," wherein explicit contrasts are made between what constitutes legitimate knowledge and what is not. Boundary work and credibility contests are seen throughout climate negotiations.

As the IPCC and its advocates gain ground in the credibility contest, one must be cognizant of the stretch and reach that decisions by this expert body have on policy prescriptions. As I have laid out here, the metrification of the global environment by the IPCC has direct and significant consequences for global carbon offset markets. In short, GWPs have become the quantitative basis for which carbon offset markets function and trade. It is an effort to quantify emissions reductions in a uniform manner and to create a common currency with which markets, governments and businesses can interoperate. The introduction of GWPs as a policy tool has altered the governance landscape for carbon offset markets and has resulted in investors preferentially choosing (and exploiting) projects and industries that emit gases with high GWPs and high carbon dioxide equivalents, which yield a greater number of carbon credits and higher carbon credit revenues. The IPCC expert body has been given the responsibility of treading the thin line between science and policy, where social preferences and scientific rigor bleed into one, and where real world downstream outcomes are first seeded.

FRAMING TECHNIQUES: CARBON ACCREDITATION PROCESS

One of the first requirements in developing a CDM carbon offset project is creating a project design document (PDD) that describes the project, presents stakeholder views, calculates baseline emissions, establishes additionality, and proposes a monitoring plan. Project developers have vested interests in reporting favorable additionality and baseline calculations, publishing only supportive local and national stakeholder opinions, and trumpeting only the merits (and not the drawbacks) of the project's proposed technology intervention – all in an effort to receive CDM Executive Board (EB) project approval, and eventually, to receive issuance of certified emissions reductions (CERs) that can be sold on the regulated carbon market (Wara, 2007). The completed PDD is then submitted to the Designated National Authority (DNA), which is a nationally appointed group that reviews CDM applications prior to submission to the EB's Registration and Issuance Team (RIT) -- a Kyoto appointed review board that further assesses the project application and presents recommendations for approval or denial to the EB (Flues, Michaelowa, & Michaelowa, 2008).

The consequence of categorization and framing is reflected in every step of PDD development as developers seek to present projects in the best possible light for future auditors to review. A consequence of crafting carefully constructed PDDs is that the narrative scripted may not reflect fully the true nature of local and national circumstances, resulting in potentially misleading representations of the project. For example, it is in a project developer's interest to only publish stakeholder views and opinions that support the approval of the project. In the most perverse scenario, project developers may only invite allies to the stakeholder consultation meeting (which is required by the standards bodies) and selectively mine for favorable opinions. More common would be that the PDD simply does not provide technological alternatives because of the project owner's vested interest in promoting a single technology, despite alternative technologies that may be equally or more cost-effective and that may meet the same or higher standards for "sustainable development." There is no methodological requirement to provide alternative technologies, rather, the regulatory focus is to simply ensure that proposed technologies reduce emissions beyond baseline practices. Often times the communities that receive technologies are unaware of technology options beyond those that are presented to them, which reflects the limited competition that is pervasive throughout underserved communities. Carbon programs are often welcome entrants to rural markets, yet the carbon accreditation process that relies on self-documentation and reporting (as opposed to using an "independent" third party[25] whose financial interests are not as closely tied to the results of credit volumes received by a project) often results in a narrow representation of past and future histories of the project. This narrative is buttressed by a canonization of quantitative objectivity, a technique that is revealed in the next steps of the CDM accreditation process – Additionality determination.

According to CDM rules, a project is classified as "additional" if it generates emission reductions beyond a base scenario that would have existed without CDM financing. This classification ultimately entitles a project to reap financial returns in the form of Certified Emissions Reductions (CER) that are traded on the regulated carbon market (pending verification and validation of claimed reduction amounts by a third party Designated Operating Entity (DOE)) (Stripple & Lövbrand, 2008). The case for additionality is based on approved methodologies that outline how to quantitatively assess baseline levels, and subsequently, how to prove additionality. Throughout the process of documenting, applying for, and classifying variables for use in establishing additionality, project developers, investors and local-national project partners are engaged in a process of quantification and objectivity discourse (Shrestha & Timilsina, 2002). That is, there is a need to frame a project in such a way that convinces the DNA and the CDM RIT that additionality has been achieved.

The negotiation that occurs between carbon project developers and the CDM EB during the accreditation process is situated at the boundary of objectivity and subjectivity. As we will explore in the next section, the process by which methodologies are negotiated have substantial impact on quantitative outputs and statistical robustness. The tension and conflict between lay and expert collide as the market for carbon requires both activities of oversight and regulation, paired with practicality and programmatic implementation.

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[25] The true independence of a "3rd party" is never fully understood because contractually the "3rd party" auditor has been hired and is paid by the project developer.

CASE STUDY: TRUST IN NUMBERS AND STATISTICAL (UN)CERTAINTY

For the case of small scale energy efficiency programs -- which imply projects with potential for fewer emissions reductions[26] -- the methodologies for determining baseline, MRV, and the resulting overall reductions are simplified and less detailed than for larger projects. The ongoing simplification of methodologies are an effort to address critiques that high transaction and monitoring costs of the CDM excludes participation by pro-poor small scale projects that often lack the expertise, capacity, and financial resources to undergo the extensive carbon market certification process (Warnecke, 2014).

The simplification and standardization of methodologies has lowered transaction costs for small scale technologies seeking entry to the CDM, but it has also resulted in increased uncertainty surrounding the validity of projected emission reductions from these projects (Spash, 2010). For cookstove projects, the difficulty in measuring emissions stems in part to the difficulty in monitoring highly distributed units of households, in contrast to monitoring a single large-scale facility that operates a single source emission technology such as a co-generation power plant. The result of these differing monitoring requirements is that small-scale, capacity-constrained projects place a greater reliance on statistical analysis to maintain their claims to quantitative robustness and objectivity. Statistical techniques extrapolate measurements from small sample sizes to make population level estimations of emission reductions, which adds further uncertainty to the resulting "carbon credit."

In the case of small-scale bioenergy cookstoves, direct emissions testing of every stove would be cost-prohibitive and unpractical for a small-scale project seeking to certify carbon credits. Instead, proxies are used to calculate and predict overall emission reductions. One of the greatest difficulties is finding a representative population to sample. Households vary greatly in their size, fuel use, cooking patterns, style of cooking, ability to efficiently use fuel, stove type and efficiency, available alternative cooking technologies, and perhaps most importantly, length of time used to cook each meal. Although statistical techniques provide confidence intervals and levels of precision, it can never be certain that the variables and assumptions used by the project developer reflects fully the local conditions and actual emissions generated from highly variable and distributed household samples.

Critics have also shed doubt on the ability of project developers of small scale technologies such as cookstoves to reliably measure emissions reductions and have argued that these projects pose a risk for over-crediting and double counting of credits (Spalding-Fecher, 2013; Warnecke, 2014). As a case study, I analyze the development and evolution of the CDM cookstove methodology "AMS-II.G" (herein described "AMS-II.G") through review of the numerous technical revisions that have occurred since its inception.

[26] The UN's Clean Development Mechanism defines "small-scale" projects as generating less than 60,000 tCO_2e/year.

Table 14 shows that during the six year period 2008-2014 there were five substantive revisions to the original methodology.

Table 14 Key Revisions (Versions 1-6) to CDM methodology AMS-II.G

Version	***Date***	***Description of Revision***
1	1-Feb-08	EB 37, Annex 7 Initial adoption.
2	4-Dec-09	EB 51, Annex 18 To include: (a) Default efficiency factors for baseline cook stoves; (b) Procedures for sampling, (c) Revised procedures for determination of quantity of woody biomass that can be considered as non-renewable; and (d) Clarifications as to which leakage requirements are appropriate for projects versus PoAs.
3	15-Apr-11	EB 60, Annex 21 KPT for stove testing included, requirements for leakage estimation simplified, default net gross adjustment factor is included as an option to account for any leakages, emission factor for the projected fossil fuel revised, more options for sampling and survey included.
4	20-Jul-12	EB 68, Annex 23 Includes a reference to the available country specific default values for f_{NRB} and specifies requirements of using national or local f_{NRB} values for CPAs under a PoA.
5	23-Nov-12	EB 70, Annex 30 Includes clarification on monitoring requirements under different options; and provides a provision of wood to charcoal conversion factor.
6	21-Feb-14	EB 77, Annex 11 Revision to: Introduce simplified approaches to determine the thermal efficiency of project devices; Introduce default values for baseline fuel wood consumption.

The methodological revisions are a result of dialogue and debate between project practitioners who are operating carbon programs at the hyper-local level in communities and villages throughout the Global South, and the CDM standards body that acts at the boundary the international level to create universal rules and standards that are acceptable to the diverse set of stakeholders that use methodologies. The result of this debate has been that of an increasing trend toward standardization and simplification of the methodologies through the provision of default values. The standardization of metrics reduces monitoring requirements and thus decreases transaction costs for practitioners that seek carbon accreditation for their programs. Table 15 shows from 2008-2014, the number of default values listed in AMS-II.G has increased nearly five-fold from 2 default values in the original version (Version 1), to 9 in the latest version (Version 6).

Table 15 Default values provided in methodological revisions to AMS-II.G

Version	*#Default values added (cumulative)*	*Description of default value added to methodology*
1	2x	*default $NCV_{biomass}$ = 0.015 TJ/tonne; *default EF = 71.5 tCO2/TJ for kerosene or 63.0 tCO2/TJ for LPG
2	4x	*default n_{old} 3-stone or conventional stove default value = 0.1 or; * *default value n_{old} for semi-improved stove = 0.2
3	5x	*default net gross adjustment factor for leakage = 0.95
4	6x	*default f_{NRB} as endorsed by designated national authorities and approved by the CDM Executive Board
5	7x	*default wood to charcoal conversion factor = 6 kg of firewood (wet basis) per kg of charcoal (dry basis)
6	9x	*default baseline wood consumption = 0.5 tonnes woody biomass per capita per year; *default usage = 365 days if it can be demonstrated that the pre-project device has been decommissioned and is no longer used

As a thought experiment to test the effect of increased methodological standardization on the quantity of carbon offsets generated, I utilize the $ER_{y,i}$ equation[27] from AMS-II.G V6 to determine emission reductions from household cook stoves under various assumptions. The $ER_{y,i}$ equation is listed here and a full description of each variable is provided in Appendix 1 of this paper.

Equation 1

$$ER_{y,i} = \sum_{a=1}^{a=y} B_{y,savings,i,a} \times N_{y,i,a} \times \frac{\mu_{y,i}}{365} \times f_{NRB,y} \times NCV_{biomass} \times EF_{projected\_fossilfuel} - LE_y$$

I conduct a sensitivity analysis on two key parameters from this equation to demonstrate the effect of standardized default values on overall emission reductions – and thus the number of

[27] AMS-II.G V6 methodology: https://cdm.unfccc.int/methodologies/DB/UFM2QB70KFMWLVO7LJN8XD1O2RKHEK [last accessess 3.22.15]

carbon credits claimed by a project – as a result of key revisions to AMS-II.G and as outlined in

Table 14. The values used in this sensitivity analysis are drawn from cookstove carbon offset projects that have publicly listed their Project Design Documents on the CDM or Gold Standard project registries. The purpose of this analysis is to show the inherent variability in calculating emission reductions that often hinges on the interpretation of source data and the provision of "binary" default values. This analysis examines a range of values for the following parameters:

1) $B_{y,savings,i,a}$ = Quantity of woody biomass that is saved in tonnes per cook stove device of type i and age a in year y

   Default value added to methodology version #2:

   **default value stove efficiency n_{old} for 3-stone or conventional stove default value = 0.1 or;*
   **default value stove efficiency n_{old} for semi-improved stove = 0.2*

2) $f_{NRB,y}$ = Fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass

   Default value added to methodology version #4:

   **default fraction of non-renewable biomass f_{NRB} as endorsed by designated national authorities and approved by the CDM Executive Board*

Baseline Stove Efficiency (n_{old})

We first examine the variable: $B_{y,savings,i,a}$ = *Quantity of woody biomass that is saved in tonnes per cook stove device of type i and age a in year y*. The methodological revision affecting this variable was adopted on 4-Dec-09 in version #2 of AMS-II.G. The underlying change concerns the allowance for standardized "default efficiency factors for baseline cook stoves." Specifically, the rule change standardizes the values allowed for use by n_{old} baseline stove efficiency -- the rule change is represented below in italics:

"n_{old} = Efficiency of the baseline system/s being replaced, measured using representative sampling methods or based on referenced literature values (fraction), use weighted average values if more than one type of systems are encountered; *0.10 default value may be optionally used if the replaced system is the three stone fire or a conventional system lacking improved combustion air supply mechanism and flue gas ventilation system i.e., without a grate as well as a chimney; for the rest of the systems 0.2 default value may be optionally used." – AMS-II.G V2 P.2*[28]

Baseline stove efficiency (n_{old}) is used to determine $B_{y,savings,i,a}$ through the following equation:

Equation 2

$$B_{y,savings,i,a} = B_{old,i} \times (1 - \frac{\eta_{old}}{\eta_{new,i,a=1} \times \Delta\eta_{y,i,a}})$$

Where:

B_y	=	Quantity of biomass used in the absence of the project activity in tonnes
η_{old}	=	Efficiency of the system being replaced […]
η_{new}	=	Efficiency of the system being deployed as part of the project activity (fraction)

Fraction of Non-Renewable Biomass (f_{NRB})

The second variable examined is the fraction of non-renewable biomass (f_{NRB}). As a case study, I utilize a range of f_{NRB} values found in projects that have actually generated carbon offsets from cookstove projects operating in Kenya. I used a database from the Global Alliance for Clean Cookstoves (GACC)[29] to identify all carbon financed cookstove programs in Kenya. As of March 9th, 2015 there were 227 cookstove projects applying for carbon credit certification under either the CDM, GS Foundation, or VCS. Out of the 20 projects that are listed as operating in Kenya, there were 6 projects that had completed the entire carbon credit certification process and received carbon offsets from the certification bodies.

[28] AMS-II.G V2 methodology: https://cdm.unfccc.int/filestorage/A/U/B/AUBHMWJVKFSY9D1380NOI5ET26ZQLG/EB51_repan18_AMS-II.G_ver02.pdf?t=ekR8bmwwN3RwfDC47bOENf2Jv6LiMC7qLdFg [last viewed 3.10.15]

[29] Global Alliance for Clean Cookstoves project database: http://carbonfinanceforcookstoves.org/tools/projects/ [last accessed 3/10/15]

Table 16 lists the range of f_{NRB} values that were used by the six projects that achieved issuance of carbon credits. The value for f_{NRB} is highly variable due to AMS-II.G's wide latitude for determining f_{NRB}, which states: "…establish [f_{NRB}] using survey methods or government data or default country specific fraction of non-renewable woody biomass (f_{NRB}) values available on the CDM website." Thus, each project determines their own f_{NRB} value despite operating in the same geographic location.

Table 16 Publicly available f_{NRB} values from cookstove projects operating in Kenya

Project	Standard	Country	Project Owner	f_{NRB}
Shimba Hills Improved Cook Stoves[30]	Gold Standard	Kenya	co2balance	73.00%
Paradigm Healthy Cookstove and Water Treatment Project[31]	Gold Standard	Kenya	The Paradigm Project	82.14%
Stoves for Life: Energy Efficient Cook Stoves Project in Kakamega, Kenya[32]	Gold Standard	Kenya	Eco2librium LLC	89.63%
Energy Efficient Cook Stoves for Siaya Communities, Kenya[33]	Gold Standard	Kenya	myclimate Foundation	92.00%
Efficient Cook Stove Programme: Kenya CPA No. 2 Mathira East District[34]	Voluntary Carbon Standard	Kenya	Co2balance UK Ltd	96.00%
Kisumu Improved Cook Stoves[35]	Gold Standard	Kenya	co2balance	97.00%

[30] Shima Hills Improved Cookstoves source data: https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000002105 [last accessed 3.10.15]
[31] Paradigm Healthy Cookstove and Water Treatment Project: https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000001964 [last accessed 3.10.15]
[32] Stoves for Life: Energy Efficient Cook Stoves Project: https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000002159 [last accessed 3.10.15]
[33] Energy Efficient Cook Stoves for Siaya Communities: https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000002050 [last accessed 3.10.15]
[34] Efficient Cook Stove Programme: Kenya CPA No. 2 Mathira East District co2balance UK Ltd: https://vcsprojectdatabase2.apx.com/myModule/Interactive.asp?Tab=Projects&a=2&i=1082&lat=-0%2E379912511244233&lon=37%2E1204214051679&bp=1 [last accessed 3.10.15]
[35] Kisumu Improved Cook Stoves Program: https://mer.markit.com/br-reg/public/project.jsp?project_id=103000000002086 [last accessed 3.10.15]

In an effort to harmonize the f_{NRB} factors used by various projects that operated within the same geographic region, the CDM EB revised AMS-II.G on 20-Jul-2012 to introduce default values for f_{NRB}, which for Kenya is listed as f_{NRB} = 92%. Many of the programs listed above have since transitioned or are in the process of transitioning to the CDM default value – after having already generated carbon credits using the self-determined f_{NRB} values listed in

Table 16. However, on 19-Jan-2015 Bailis et al. published an exhaustive report detailing the most precise inventory to date of global f_{NRB} values (Robert Bailis, Drigo, Ghilardi, & Masera, 2015). The report utilizes spatial mapping to estimate woodfuel supply and demand and combines mapping with national and regional conservation plans to project rates of growth and decline in forest stocks. Bailis et al. (2015) estimates Kenya's range of f_{NRB} values at [54.2% - 63.90%], which is listed in Table 17 .

Table 17 Default f_{NRB} values as listed in Peer Reviewed Literature

Source	f_{NRB} **Value**
Bailis et al. (2015): Low Estimate - Kenya	54.20%
Bailis et a. (2015): High Estimate - Kenya	63.90%
CDM Default - Kenya[36]	92.00%

Now we can test the effects of f_{NRB} and n_{new} on emission reductions by keeping constant all other variables used to calculate emission reductions. Table 18 lists the assumptions used for this analysis:

Table 18 Fixed values for sensitivity analysis and emission reduction calculation

Variable	***Value***	***Units***
n_{new}	28%	Percent
By	3.00	tons wood-yr
$EF_{projected\ fossil\ fuel}$	81.6	t CO_2/TJ
$NCV_{biomass}$	0.015	TJ/tonne

[36] CDM default fNRB values: https://cdm.unfccc.int/DNA/fNRB/index.html [last accessed 3.22.15]

I now apply these assumptions to the ER Equation 1 and conduct sensitivity analysis on n_{old} ; and f_{NRB}.

Table 19 shows the result of utilizing default values for both n_{new} and f_{NRB} on overall emission reductions. The choice of default baseline stove efficiency (n_{old} = 10% or 20%) results in a doubling of emission reductions claimed by each project. Similarly, the choice of default f_{NRB} (f_{NRB} = 54% to 97%) can also result in a near doubling of resulting emission reductions claimed by a project. Combined, the overall emission reductions show a near 5-fold increase between the most conservative and most aggressive default values adopted (0.57 tCO2/yr vs. 2.29 tCO2/yr, respectively).

Table 19 Overall emission reductions (tCO2/yr per stove) using sensitivity analysis of n_{old} and f_{NRB}

Baseline stove efficiency [n_{old}]	Fraction of non-renewable biomass [f_{NRB}]							
SOURCE [f_{NRB}]	Masera Low	Masera Hi	Shimba Hills	Paradigm	Stoves for Life	Siaya	Mathira E. District	Kisumu
	54%	64%	73%	82%	90%	92%	96%	97%
10%	1.28	1.51	1.72	1.94	2.12	2.17	2.27	2.29
12%	1.14	1.34	1.53	1.72	1.88	1.93	2.01	2.04
14%	1.00	1.17	1.34	1.51	1.65	1.69	1.76	1.78
16%	0.85	1.01	1.15	1.29	1.41	1.45	1.51	1.53
18%	0.71	0.84	0.96	1.08	1.18	1.21	1.26	1.27
20%	0.57	0.67	0.77	0.86	0.94	0.97	1.01	1.02

The consequence of incremental changes in the estimate of emission reductions per stove is compounded when a carbon program scales its growth and distribution. Regulatory carbon rules limit small-scale projects to a cap of 60,000 tCO2/yr. If we conservatively assume the highest emission reduction per stove possible in our analysis (2.29 tCO2/stove-yr from), then a carbon program would be allowed to distribute 26,203 stoves (60,000 tCO2/yr ÷ 2.29 tCO2/stove-yr = 26,203 stoves). Compare this to the most conservative emission reduction possible which results in only 0.57 tCO2/stove-yr (

Table 19). For comparison, if we assume the "conservative program" distributes the same number of stoves as the "most aggressive program" (i.e. both programs distribute 26,203 stoves), and assume that the resulting credits are sold at a modest $5/tCO2 on the voluntary market, then the resulting difference in annual revenue between the two carbon programs would be over $225,000 per year. Furthermore, carbon programs are allowed to operate for 10 years, which would result in a $2.25 million difference in revenue between these programs over a 10-year period (not adjusted for inflation).

Perhaps more alarming is the consequence to the global climate, which would suffer a deficit of 1.72 tCO2/stove-yr (2.29 tCO2/stove-yr – 0.57 tCO2/stove-yr = 1.72 tCO2/stove-yr) as a result of accrediting a program using the "aggressive assumption" as compared to the "conservative assumption." Under the "aggressive" program, the climate could be cheated out of 45,100 tCO2/yr (26,203 stoves/yr * 1.72 tCO2/stove-yr = 45,100 tCO2/yr), and nearly 0.5 million tCO2 over a ten year crediting period.

It is clear that efforts to standardize methodological rules have direct consequences on climate and clean energy investment. On one hand the benefits of standardization lower transaction costs and have the potential to spur investment and innovation in underserved communities, and on the other hand, the simplification of MRV and methodological rules can increase the uncertainty of GHG accounting and indirectly bias investment strategies. Perhaps what is less clear are the implications to local communities that rely on the broader international donor community to spur a host of development activities that otherwise are not feasible. Directing limited resources, both financial and knowledge expertise, to carbon programs comes at the expense of other activities. The ways in which we create and utilize metrics have powerful effects on the communities for which they are meant to serve. What is quantified, and perhaps more importantly what is not, continues to shape our understanding of how sustainable development occurs, and is orienting the ways in which the global economy attempts to translate science and policy between scales of international, national, and the hyper local.

CONCLUSION: METRICS SHAPING FUTURE MARKETS & POLICY

This chapter has explored the ways in which policy formation in the climate change arena is reflexive to the broader power and politics of framing, metric formation, and categorization. Implicit in this complex landscape of public policy is the need to produce real and actionable outcomes through the development of accountable and transparent procedures for GHG accounting that are amenable to "on-the-ground" practitioners of clean energy programs. I began the chapter by analyzing the process by which international climate metrics for greenhouse gas accounting were developed at the IPCC, and subsequently, how carbon market methodologies have interpreted IPCC rules to meet the needs of practitioners who are tasked with operating within the regulatory environment. The analysis of the cookstove methodology AMS-II.G demonstrates how carbon metrics are experiencing a rapid succession of translations between scales of local, national, and international governance as carbon accounting rules and norms at each level are redefining the use and interpretation of established "climate science." In the case of carbon markets, the variables used in equations for GHG accounting are derived from local communities and fed into standardized equations and transformed into the international "carbon credit" vernacular. Carbon standards bodies have been at the powerful intersection of science and policy for determining what and how GHG emissions are measured and tracked. My analysis of CDM methodology AMS-II.G reveals how negotiated accounting rules can shape the fundamental strategies used by markets and society to implement current pro-poor decarbonization strategies.

The role and importance of standard setting and metric formation will only increase as policy makers seek to refine the "carbon vernacular" for communicating and coordinating national climate commitments between and amongst nations. With the possibility of a 2015 Paris climate accord, there is a sense that the multitude of political differences between developing and developed nations are beginning to narrow. Politically, this has involved balancing policy time frames that often outlast election cycles, acknowledging past and future contributions to climate change by individual nation-states, and leveling fluctuations in global economies and shifting geo-politics. Scientifically, this has resulted in standardizing and simplifying methods for calculating costs, benefits, and risks of carbon mitigation and adaptation initiatives. Future policy outcomes will inevitably strike a balance between these views, requiring policy makers to remain aware of the implications for what is both included as well as excluded in measurement.

CHAPTER 5 CONCLUSIONS AND FUTURE DIRECTIONS

Market-based policy instruments serve as a bridge between industrialized and developing nation goals for achieving resilience to a changing climate while at the same time promoting economic development and improving livelihoods for individuals and communities. Climate finance has emerged as a dominant policy tool for responding to the changing environment and the threats that humankind faces from climate change. This has set the stage for a world in which governments and private actors are reexamining how to govern North-South financial transfers and the governance and structure of traditional aid that seeks to balance the need for development, resilience, and low carbon development. Development politics lie at the core of climate policy debates. The scale of financing required to address these linked initiatives – sustainable development and climate mitigation – have provided renewed urgency for understanding the policy mechanisms available for overseeing financial and technological transfers between North-South nations.

This dissertation has examined the role that market-based policy instruments can play in promoting the dual goals of sustainable development and climate mitigation. I specifically examined the underlying methods and protocols that govern carbon markets, results based financing systems, and global greenhouse gas accounting rules and methodologies that have been critical conduits for development finance to the global south. In the process of tackling such seemingly large and intractable issues such as “energy access” for the global poor, it is critical for policy makers to understand both the “seen” and “unseen” effects that markets, methodologies, and metrics have on society and environmental outcomes.

A central theme of this dissertation has been to understand the implicit and explicit consequences of climate metrics and measurement methodologies. My measurements of household air pollution in Chinese village homes found that despite claims of improved health outcomes by the cookstove sector, not all stove programs are able to achieve claimed air pollution reductions when stoves are used in actual homes. These results underscore the need for the research community to develop new testing protocols for evaluating stove technology performance that more comprehensively evaluate stove operating parameters. The protocols should reflect the in-field operating conditions that the stoves will be used in and encompass the range of possible behavioral patterns experienced by typical cooks. Current testing protocols rely on laboratory testing that is often conducted in ideal conditions, and focus on average performance rather than performance during periods of phase burning, which in the case of gasifier stoves can lead to erroneous evaluation of stove performance. Testing protocols that misrepresent technology performance can at minimum result in the distribution of stoves that do not benefit human health and climate, and at worse, have the potential to contribute to and exacerbate negative health and environmental outcomes. Future research should focus on developing stronger and more targeted testing protocols that are conducted in context specific conditions. This work is critical at a time when influential organizations such as the Global Alliance for Clean Cookstoves (GACC) seeks to deploy over 100 million clean cookstoves by 2020, and the Chinese government seeks to initiate a new era of large scale stove dissemination to its vast rural population. Both initiatives require comprehensive and robust technology screening and evaluation tools prior to stove selection and dissemination… it is simply not an option to not update current stove performance testing protocols.

I also explored the trade-off between increasing standardized carbon accounting rules and environmental integrity, and the implications for investment in technologies that benefit global south communities. In the public arena, what gets measured and tracked is shaped by many forces beyond the pragmatic. World views, institutional bureaucracy, and practical on-the-ground realities are a few of the strategic pressures placed on decision makers who are responsible for creating the structure and rules governing carbon and RBF markets. What results is a complex web of social and scientific constraints that often change what is idealized by global policy, rearticulated by rigid institutions, and ultimately adapted by local communities. As policy makers continue to translate science and regulatory rules across multiple scales of governance – spanning from the international to the local – we cannot lose sight of the real and sometimes detrimental effects that these measurement protocols have on local communities. Under market-based systems, even small incremental changes in methodological assumptions or measurement techniques can vastly alter the financial outlook of development programs, which ultimately encourages or discourages further investment and expansion of energy access programs. Governing climate change and sustainable development policies through a highly structured regulatory process that relies on strict procedures for quantifying outcomes must also carefully consider the complex ways that these policies can drive downstream investment, technology innovation, and community outcomes.

Metrics for measuring technology performance and greenhouse gas reductions are foundational to the functioning of global carbon markets. The dominance of market-based approaches for governing climate and sustainable development is likely to remain a prominent tool for policy makers in a post-Kyoto Protocol era. My research sheds light on the potential form and function of pro-poor markets in future policy frameworks. In recent years the Kyoto-centered carbon market has provided an ideal architecture and platform on which new results based financing mechanisms have quickly emerged. Market innovation is emerging from both the public and private spheres. What is unclear is the sustainability of emerging results based financing systems that I have characterized as being predominantly private, voluntary, and non-state led. A possible future pathway for RBF programs may mirror the trajectory of private certification programs that were initiated in previous decades by organizations such as the Forest Stewardship Council (FSC) and the Marine Stewardship Council (MSC). FSC and MSC have evolved from being novel certification programs to what are now considered as benchmark standards for businesses operating within the forestry and fisheries sectors. It is very possible that RBF programs will simply become more integrated and commonplace in development and philanthropic programs. In other words, RBF systems will continue to be voluntary but with greater expectation from stakeholders that pro-poor programs show quantifiable results using systematic procedures for monitoring, reporting, and verifying their outcomes.

Addressing climate and development needs of the global south will ultimately require a massive upscaling of public and private sector initiatives. The public sector has historically played the role of a catalyst by providing policy frameworks for private sector participation, and by lowering barriers to entry that ultimately spurs private investment. The private sector has been a conduit for capital flow that enables scalability of frameworks and climate strategies, and presumably are sources of innovation for both clean technologies and cost-effective financing and distribution. This has been the historic model for rural energy development in the Global South. The precipitous fall in the global price for carbon offsets during Kyoto Protocol's first commitment period has accelerated the discussion for new forms of development finance.

Markets, and in particular carbon markets, alone are an insufficient response to the collective needs of climate change and the development needs of the world. Yet, financing through traditional government aid and charities is an equally insufficient response. Governance over climate policy is shifting towards developing nations in the form of self-directed Intended Nationally Determined Contributions (INDC), and New Market-based Mechanisms such as regional and subnational carbon and RBF markets. As new power structures emerge over the governance of national and subnational climate finance, we move closer to a polycentric archetype of authority over development finance in which public-private initiatives continually adapt to the needs of complex systems, governments, and economies. The future of carbon and RBF markets must harnesses the multiple approaches used in climate adaption, mitigation, and sustainable development strategies.

Indeed, awareness and understanding of RBF systems will continue to grow as private and public actors refine and expand the pay-for-performance certification model. Following Green's (2013) theory of entrepreneurial authority, practitioners should seek to strengthen the "authority" of RBF markets by developing a reliable supply of credits as well as well as growing the demand needed to finance and purchase the credits (Green, 2013). Future research should seek to better understand the functional form of emerging private authority as it expands its influence in a "polycentric" landscape of environmental governance (Ostrom, 2010). The most pressing environmental issue of our day – global climate change – will require a full range of policy and economic tools in order to tackle the monumental energy and development challenges faced by industrialized and developing countries.

As new RBF markets emerge it will important to understand the consequences of changing methodological rules that underlie the "monitoring" aspect of these markets. As was found in this dissertation, small changes to methodological rules through standardization and simplification of monitoring rules can have large consequences on investment decisions and environmental outcomes. Possible future case studies could examine the effects of highly stringent methods versus simplified methods have on RBF markets, investment, and social and environmental outcomes. Research on RBF markets will contribute to the ongoing discussion around practical mechanisms for aiding the transition to "green" economies for the global south. Research should seek to understand why and why various MRV frameworks and new RBF markets are adopted by governments and nonstate actors, since these governance models will ultimately be used to oversee future global transfers of financing for initiatives aimed at tackling climate change and sustainable development. It remains to be seen whether RBF markets will become more deeply engrained into international compliance markets, such as through linked regional carbon markets, or whether RBF markets will remain strictly voluntary initiatives that support sustainable development through corporate and philanthropic leadership and individual action. Research should continue to identify the inherent variability and uncertainty resulting from decisions to standardize or simplify future RBF and carbon accounting methods, and this in turn must be used by policy makers when developing new models of governance for financial transfers and aid packages to the global south.

Given the fragmentation of carbon markets and the highly debated future framework for overseeing various regional and national climate and development initiatives, it will be important to continue research that seeks to understand the feasibility and efficacy of markets to spur rural energy access and sustainable development in the global south. Climate and development responses must be able to coexist and adapt to a dynamic global economy that fluctuates with changing patterns of technology innovation, political whims, and changing scientific understanding of our world. The malleability of metrics and market rules, with all of their potential drawbacks and consequences, may ultimately also be their greatest strength as we navigate and adapt to a complex and changing world.

WORKS CITED

Adler, E., & Haas, P. M. (1992). Conclusion: epistemic communities, world order, and the creation of a reflective research program. *International organization, 46*(01), 367-390.

Aguilar, S. (2007). Elements for a Robust Climate Regime Post-2012: Options for Mitigation. *Review of European Community & International Environmental Law, 16*(3), 356-367.

Aldy, J. E., & Stavins, R. N. (2012). Using the Market to Address Climate Change: Insights from Theory & Experience. *Daedalus, 141*(2), 45-60.

Arrow, K. J., Cropper, M. L., Eads, G. C., Hahn, R. W., Lave, L. B., Noll, R. G., . . . Smith, V. K. (2001). Is there a role for benefit-cost analysis in environmental, health, and safety regulation? *Environment and Development Economics, 2*(02), 195-221.

Asongu, S. A. (2013). How has mobile phone penetration stimulated financial development in Africa? *Journal of African Business, 14*(1), 7-18.

Aunan, K., Fang, J., Hu, T., Seip, H. M., & Vennemo, H. (2006). Climate change and air quality--measures with co-benefits in China. *Environ Sci Technol, 40*(16), 4822-4829.

Bachram, H. (2004). Climate fraud and carbon colonialism: the new trade in greenhouse gases. *Capitalism Nature Socialism, 15*(4), 5 - 20.

Bailis, R., Berrueta, V., Chengappa, C., Dutta, K., Edwards, R., Masera, O., . . . Smith, K. R. (2007). Performance testing for monitoring improved biomass stove interventions: experiences of the Household Energy and Health Project. *Energy for Sustainable Development*, 57-70.

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nature Climate Change*.

Baumgartner, J., Schauer, J. J., Ezzati, M., Lu, L., Cheng, C., Patz, J., & Bautista, L. E. (2011). Patterns and predictors of personal exposure to indoor air pollution from biomass combustion among women and children in rural China. *Indoor Air, 21*(6), 479-488.

BerkeleyAir. (2012). Stove Performance Inventory Report. In B. A. M. Group (Ed.).

Berrueta, V. M., Edwards, R. D., & Masera, O. R. (2008). Energy performance of wood-burning cookstoves in Michoacan, Mexico. *Renewable Energy, 33*(5), 859-870.

Bowker, G. C., & Star, S. L. (1999). *Sorting Things Out: Classification and Its Consequences*. Cambridge: MIT Press.

Briner, G., Kato, T., Konrad, S., & Hood, C. (2014). Taking Stock of the UNFCCC Process and its Inter-linkages. *a paper of the OECD/IEA Climate Change Experts Group, OECD, Paris*.

Bumpus, A. G. (2011). The Matter of Carbon: Understanding the Materiality of tCO2e in Carbon Offsets. *Antipode, 43*(3), 612-638. doi: 10.1111/j.1467-8330.2011.00879.x

Burnett, R. T., Pope, C. A., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., . . . Brauer, M. (2014). An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure.

Cao, G., Jokisalo, J., Feng, G., Duanmu, L., Vuolle, M., & Kurnitski, J. (2011). Simulation of the heating performance of the Kang system in one Chinese detached house using biomass. *Energy and Buildings, 43*(1), 189-199.

Carmody, P. (2013). A knowledge economy or an information society in Africa? Thintegration and the mobile phone revolution. *Information Technology for Development, 19*(1), 24-39.

Carter, E. M., Shan, M., Yang, X., Li, J., & Baumgartner, J. (2014). Pollutant Emissions and Energy Efficiency of Chinese Gasifier Cooking Stoves and Implications for Future Intervention Studies. *Environmental Science & Technology, 48*(11), 6461-6467.

Cashore, B., Auld, G., & Newsom, D. (2004). *Governing Through Markets: Forest Certification and the Emergence of Non-state Authority*. New Haven: Yale University Press

Chowdhury, Z., Edwards, R. D., Johnson, M., Shields, K. N., Allen, T., Canuz, E., & Smith, K. R. (2007). An inexpensive light-scattering particle monitor: field validation. *Journal of Environmental Monitoring, 9*(10), 1099-1106.

Cutler, A. C. (2010). The legitimacy of private transnational governance: experts and the transnational market for force. *Socio-Economic Review, 8*(1), 157-185.

Cutler, A. C., Haufler, V., & Porter, T. (1999). *Private authority and international affairs*: Suny Press.

Edwards, R. (2004). *August 2004 Summary: An Assessment of Programs to Promote Improved Household Stoves in China*. University of California, Berkeley. Berkeley.

Edwards, R. D., Liu, Y., He, G., Yin, Z., Sinton, J., Peabody, J., & Smith, K. R. (2007). Household CO and PM measured as part of a review of China's National Improved Stove Program. *Indoor Air, 17*(3), 189-203.

Ezzati, M., Mbinda, B. M., & Kammen, D. M. (2000). Comparison of Emissions and Residential Exposure from Traditional and Improved Cookstoves in Kenya. *Environmental Science & Technology, 34*(4), 578-583.

Flues, F., Michaelowa, A., & Michaelowa, K. (2008). *UN approval of greenhouse gas emission reduction projects in developing countries: The political economy of the CDM Executive Board*. Center for Comparative and International Studies. Zurich.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., . . . Myhre, G. (2007). Changes in atmospheric constituents and in radiative forcing. Chapter 2 *Climate Change 2007. The Physical Science Basis*.

Gieryn, T. F. (Ed.). (1995). *The Boundaries of Science*. Thousand Oaks, CA: Sage Publications.

Gordon, S. B., Bruce, N. G., Grigg, J., Hibberd, P. L., Kurmi, O. P., Lam, K.-b. H., . . . Martin Ii, W. J. (2014). Respiratory risks from household air pollution in low and middle income countries. *The Lancet Respiratory Medicine, 2*(10), 823-860.

Green, J. F. (2013). *Rethinking private authority: Agents and entrepreneurs in global environmental governance*: Princeton University Press.

Guo, S., Hu, M., Zamora, M. L., Peng, J., Shang, D., Zheng, J., . . . Zhang, R. (2014). Elucidating severe urban haze formation in China. *Proceedings of the National Academy of Sciences, 111*(49), 17373-17378.

Hagerman, S., Witter, R., Corson, C., Suarez, D., Maclin, E. M., Bourque, M., & Campbell, L. (2012). On the coattails of climate? Opportunities and threats of a warming Earth for biodiversity conservation. *Global Environmental Change, 22*(3), 724-735.

Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., . . . Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *The Lancet, 374*(9707), 2104-2114.

Hall, R. B., & Biersteker, T. J. (Eds.). (2002). *The emergence of private authority in global governance*. Cambridge: Cambridge University Press.

He, G., Ying, B., Liu, J., Gao, S., Shen, S., Balakrishnan, K., . . . Ezzati, M. (2005). Patterns of Household Concentrations of Multiple Indoor Air Pollutants in China. *Environmental Science & Technology, 39*(4), 991-998. doi: 10.1021/es049731f

IEA. (2011). Energy for All: Financing access for the poor *World Energy Outlook 2011*. Paris.

International Emissions Trading Association (IETA). (2005). Strengthening the CDM: IETA Position Paper for COP 11 and COP/MoP 1. Toronto.

IPCC. (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. In J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, M. K.

& J. C.A. (Eds.), (pp. 881). Cambridge, United Kingdom and New York, NY, USA: IPCC.

Jack, W., & Suri, T. (2011). Mobile money: the economics of M-PESA: National Bureau of Economic Research.

Jaffe, J., & Stavins, R. N. (2008). Linkage of tradable permit systems in international climate policy architecture: National Bureau of Economic Research.

Jasanoff, S. (1991). Cross-National Differences in Policy Implementation. *Evaluation Review, 15*(1), 103.

Jasanoff, S. (1994). *The Fifth Branch: Science Advisers as Policymakers*. Cambridge: Harvard University Press.

Jetter, J., Zhao, Y., Smith, K. R., Khan, B., Yelverton, T., DeCarlo, P., & Hays, M. D. (2012). Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. *Environmental Science & Technology, 46*(19), 10827-10834.

Johnson, M., Edwards, R., Alatorre, C., & Frenk, O. M. (2007). In-field greenhouse gas emissions from cookstoves in rural Mexican households. *Atmos. Environ.*

Jordan, A., van Asselt, H., Berkhout, F., Huitema, D., & Rayner, T. (2012). Understanding the Paradoxes of Multilevel Governing: Climate Change Policy in the European Union. *Global Environmental Politics, 12*(2), 43-66.

Kirkman, G. A., Seres, S., Haites, E., & Spalding-Fecher, R. (2012). *Benefits of the clean development mechanism 2012.* Paper presented at the United Nations Framework Convention on Climate Change. United Nations Climate Change Secretariat, Bonn.

Koch, N., Fuss, S., Grosjean, G., & Edenhofer, O. (2014). Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence. *Energy Policy, 73*, 676-685.

Kossoy, A., & Guigon, P. (2012). State and trends of the carbon market 2012: World Bank.

Kossoy, A., Oppermann, K., Platonova-Oquab, A., Suphachalasai, S., Höhne, N., Klein, N., . . . Wu, Q. (2014). State and Trends of Carbon Pricing 2014: World Bank.

Lee, C. M., Chandler, C., Lazarus, M., & Johnson, F. X. (2013). Assessing the climate impacts of cookstove projects: issues in emissions accounting: Stockholm Environment Institute.

Leigh-Star, S. (2010). This is Not a Boundary Object: Reflections on the Origin of a Concept. *Science, Technology & Human Values, 35*(5), 601-617.

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., . . . Andrews, K. G. (2013). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet, 380*(9859), 2224-2260.

Liu, J., Zheng, B., Aposhian, H. V., Zhou, Y., Chen, M.-L., Zhang, A., & Waalkes, M. P. (2002). Chronic Arsenic Poisoning from Burning High-Arsenic-Containing Coal in Guizhou, China. *Environmental Health Perspectives, 110*(2), 119-122.

Longino, H. E. (1990). *Science as social knowledge: Values and objectivity in scientific inquiry*: Princeton University Press.

MacKenzie, D. (2009). Making things the same: Gases, emission rights and the politics of carbon markets. *Accounting, Organizations and Society, 34*(3–4), 440-455.

Madill, A., Jordan, A., & Shirley, C. (2000). Objectivity and reliability in qualitative analysis: Realist, contextualist and radical constructionist epistemologies. *British Journal of Psychology, 91*(1), 1-20. doi: 10.1348/000712600161646

Meckling, J. (2011). *Carbon coalitions: Business, climate politics, and the rise of emissions trading*: MIT Press.

MEP. (2012). Ambient Air Quality Standards (Vol. GB 3095-2012). Beijing, China: Chinese Ministry of Environmental Protection, China State Council.

Michaelowa, A., F. Jotzo. (2005). Transaction costs, institutional rigidities and the size of the clean development mechanism. *Energy Policy, 33*(4), 511-523.

Miller, C. A. (2000). The dynamics of framing environmental values and policy: four models of societal processes. *Environmental Values, 9*(2), 211-233.

Miller, C. A. (2005). New Civic Epistemologies of Quantification: Making Sense of Indicators of Local and Global Sustainability. *Science, Technology & Human Values, 30*(3), 403.

Moreno, A., & Bareisaite, A. (2015). Scaling Up Access to Electricity: Pay-as-You-Go Plans in Off-Grid Energy Services *Live wire knowledge note series ; no. 34*. Washington, DC World Bank Group.

Mukunda, H., Dasappa, S., Paul, P., Rajan, N., Yagnaraman, M., Ravi Kumar, D., & Deogaonkar, M. (2010). Gasifier stoves–science, technology and field outreach. *Current Science, 98*(5), 627-638.

Myhre, G., Shindell, D., Bréon, F., Collins, W., Fuglestvedt, J., Huang, J., . . . Mendoza, B. (2013). Anthropogenic and natural radiative forcing: In. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment

Report of the Intergovernmental Panel on Climate Change (pp. 659-740). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Newell, P., & Paterson, M. (2010). *Climate capitalism: global warming and the transformation of the global economy*: Cambridge University Press.

Ostrom, E. (2010). Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*, *20*(4), 550-557.

Pellizzoni, L. (2011). Governing through disorder: Neoliberal environmental governance and social theory. *Global Environmental Change, 21*(3), 795-803.

Peters-Stanley, M., & Yin, D. (2013). Maneuvering the mosaic: state of the voluntary carbon markets 2013. *Forest Trends' Ecosystem Marketplace & Bloomberg New Energy Finance*.

Pope, C. A., III, Burnett, R. T., Krewski, D., Jerrett, M., Shi, Y., Calle, E. E., & 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), 941-948. doi: 10.1161/circulationaha.109.857888

Porter, T. M. (1995). *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. Princeton, NJ: Princeton Univ Press.

Ramanathan, V., & Carmichael, G. (2008). Global and regional climate changes due to black carbon. *Nature geoscience*, *1*(4), 221-227.

Ramaswamy, V., Boucher, O., Haigh, J., Hauglustaine, D., Haywood, J., Myhre, G., . . . Joos, F. (2001). *Radiative Forcing of Climate Change. In: Chapter 6 of the IPCC Third Assessment Report Climate Change 2001: The Scientific Basis*.

Ramaswamy, V., Boucher, O., Haigh, J., Hauglustaine, D., Haywood, J., Myhre, G., . . . Solomon, S. (Eds.). (2001). *Ch.6 Radiative Forcing of Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Raustiala, K. (2001). Nonstate actors in the global climate regime. In U. Luterbacher & D. F. Sprinz (Eds.), *International relations and global climate change* (Vol. 117, pp. 95-118): Massachusettes Institute of Technology.

Roden, C. A., Bond, T. C., Conway, S., Osorto Pinel, A. B., MacCarty, N., & Still, D. (2009). Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves. *Atmospheric Environment, 43*(6), 1170-1181.

Roden, C. A., Bond, T. C., Conway, S., & Pinel, A. B. O. (2006). Emission factors and real-time optical properties of particles emitted from traditional wood burning cookstoves. *Environmental science & technology, 40*(21), 6750-6757.

Rolffs, P., Byrne, R., & Ockwell, D. (2014). Financing sustainable energy for all: pay-as-you-go vs. traditional solar finance approaches in Kenya. Working Paper. The STEPS Centre, Brighton.

Rowlands, I. H. (2001). *Classical Theories of International Relations*. Cambridge: MIT Press.

Rowlands, I. H. (2001). Classical theories of international relations *International relations and global climate change* (pp. 43-65): MIT Press.

Ruiz-Mercado, I., Canuz, E., & Smith, K. R. (2012). Temperature dataloggers as stove use monitors (SUMs): Field methods and signal analysis. *Biomass and Bioenergy, 47*(0), 459-468.

Ruiz-Mercado, I., Masera, O., Zamora, H., & Smith, K. R. (2011). Adoption and sustained use of improved cookstoves. *Energy Policy, 39*(12), 7557-7566.

Sasser, E., Hemby, J., Adler, K., Anenberg, S., Bailey, C., Brockman, L., . . . Witosky, M. (2012). *Report to Congress on Black Carbon*. U.S. Environmental Protection Agency.

Schennach, S. M. (2000). The economics of pollution permit banking in the context of Title IV of the 1990 Clean Air Act Amendments. *Journal of Environmental Economics and Management, 40*(3), 189-210.

Shrestha, R. M., & Timilsina, G. R. (2002). The additionality criterion for identifying clean development mechanism projects under the Kyoto Protocol. *Energy Policy, 30*(1), 73-79.

Simon, G. L., Bailis, R., Baumgartner, J., Hyman, J., & Laurent, A. (2014). Current debates and future research needs in the clean cookstove sector. *Energy for Sustainable Development*(20), 49-57.

Simon, G. L., Bumpus, A. G., & Mann, P. (2012). Win-win scenarios at the climate–development interface: Challenges and opportunities for stove replacement programs through carbon finance. *Global Environmental Change, 22*(1), 275-287.

Smith, K. R. (1996). The Natural Debt: North and South. In A. H.-S. Thomas W. Giambelluca (Ed.), *Climate Change: Developing Southern Hemisphere Perspectives*: John Wiley & Sons.

Smith, K. R., A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn (2014). Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 709-754). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Smith, K. R., & Haigler, E. (2008). Co-Benefits of Climate Mitigation and Health Protection in Energy Systems: Scoping Methods. *Annual Review of Public Health, 29*(1), 11-25.

Smith, K. R., & Mehta, S. (2003). The burden of disease from indoor air pollution in developing countries: comparison of estimates. *International Journal of Hygiene and Environmental Health, 206*(4-5), 279-289.

Smith, K. R., Shuhua, G., Kun, H., & Daxiong, Q. (1993). One hundred million improved cookstoves in China: How was it done? *World Development, 21*(6), 941-961.

Smith, K. R., Uma, R., Kishore, V. V. N., Zhang, J., Joshi, V., & Khalil, M. A. K. (2000). Greenhouse implications of household stoves: an analysis for India. *Annu. Rev. Energy Environ., 25*, 741.

Somanathan, E. (2008). What do we expect from an international climate agreement? A perspective from a low-income country: Discussion Paper 08-27, Harvard Project on International Climate Agreements, Belfer Center for Science and International Affairs, Harvard Kennedy School, December.

Spalding-Fecher, R. (2013). National policies and the CDM rules: options for the future. *Carbon Limits for the Swedish Energy Agency, Oslo*.

Spash, C. L. (2010). The brave new world of carbon trading. *New Political Economy, 15*(2), 169-195.

Stavins, R. N. (1998). What can we learn from the grand policy experiment? Lessons from SO 2 allowance trading. *The Journal of Economic Perspectives*, 69-88.

Strange, S. (1996). *The Retreat of the state : the diffusion of power in the world economy*. New York: Cambridge University Press.

Stripple, J., & Lövbrand, E. (2008). *Verification as Justification: Private Standard-Setting and Regulation in the Global Carbon Market*. Paper presented at the ISA's 49th Annual Convention, Bridging Multiple Divides, San Francisco.

Sutter, C., & Parreno, J. C. (2007). Does the current Clean Development Mechanism (CDM) deliver its sustainable development claim? *Climatic Change*(84), 75-90.

Wara, M. (2007). Is the global carbon market working? *Nature, 445*, 595-596.

Warnecke, C. (2014). Can CDM monitoring requirements be reduced while maintaining environmental integrity? *Climate Policy, 14*(4), 443-466.

WHO. (2004). Environmental Health Criteria 213, Carbon Monoxide.

WHO. (2006a). Fuel for life: household energy and health.

WHO. (2006b). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global Update 2005.

WorldBank. (2013). China: Accelerating Household Access to Clean Cooking and Heating. *East Asia and Pacific Clean Stove Initiative Series.* . Washington, DC: World Bank.

Zhang, J., Smith, K. R., Ma, Y., Ye, S., Jiang, F., Qi, W., . . . Thorneloe, S. A. (2000). Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. *Atmospheric Environment, 34*(26), 4537-4549.

Zhang, Z., & Smith, K. R. (2007). Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions. *Environmental Health Perspectives, 115*(6), 848-855.

Zheng, B., Ding, Z., Huang, R., Zhu, J., Yu, X., Wang, A., . . . Su, H. (1999). Issues of health and disease relating to coal use in southwestern China. *International Journal of Coal Geology, 40*(2-3), 119-132.

Zhuang, Z., Li, Y., Chen, B., & Guo, J. (2009). Chinese kang as a domestic heating system in rural northern China—A review. *Energy and Buildings, 41*(1), 111-119.

APPENDICES

Appendix 1 Kitchen schematic for HAP Monitoring

Figure 2a. Configuration #1 – Attached Kitchen (part of main house but separate from living room)

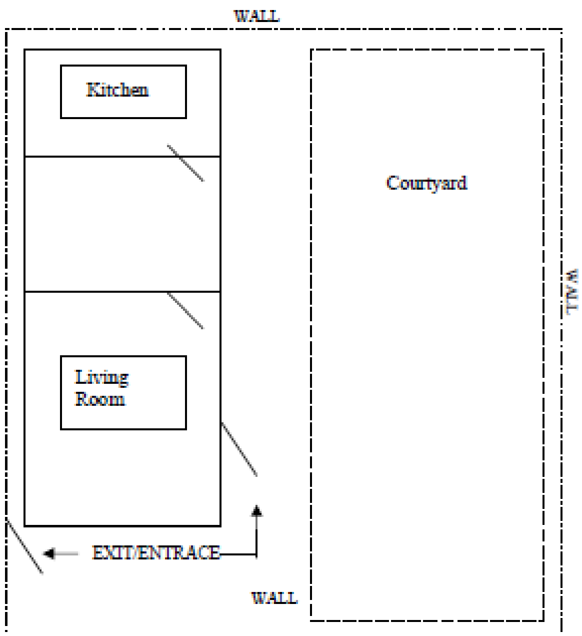
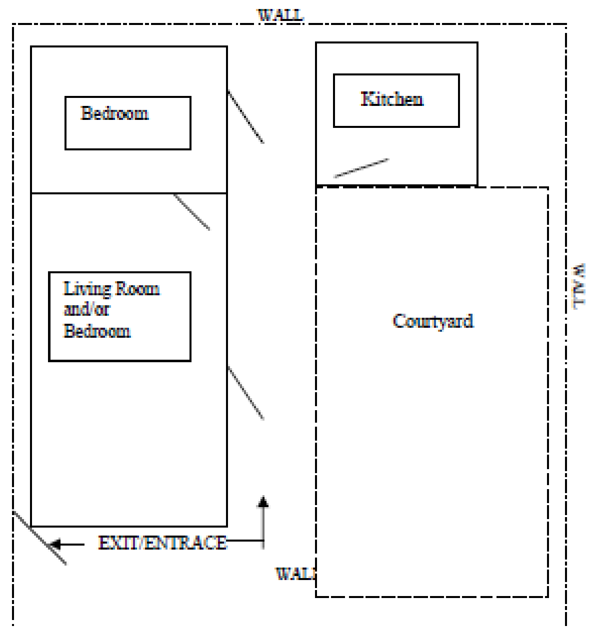


Figure 2b. Configuration #2 – Separate Kitchen



Appendix 2 $PM_{2.5}$ Adjustment Factor using UCB vs. Gravimetric Filter

The UCB Particle Monitor was calibrated with pine wood smoke by Berkeley Air Monitoring Group in Berkeley, CA USA. To account for differences in fuel smoke found in this study, adjustment factors derived from linear regression between co-located gravimetric filter and UCB devices were applied to final UCB results. Separate adjustment factors were applied based on either coal or biomass fuel. Data from each fuel type was pooled for separate and attached kitchens.

Linear regression for coal fuel resulted in the relationship y = 4.1322x (R^2 = 0.8858) and for biomass fuel y = 5.2716x (R^2 = 0.8797) (Figures 1A and 1B, respectively). Four homes using biomass fuels with net negative gravimetric filter weights were removed. One outlier home using biomass fuels and two outlier homes using coal fuels were removed due to abnormally high UCB:Gravimetric ratios that were radically inconsistent with ratios in other households. Equipment troubleshooting based on battery and pump ID stratification, rotameter used, and field assistant deployed did not reveal abnormal trends.

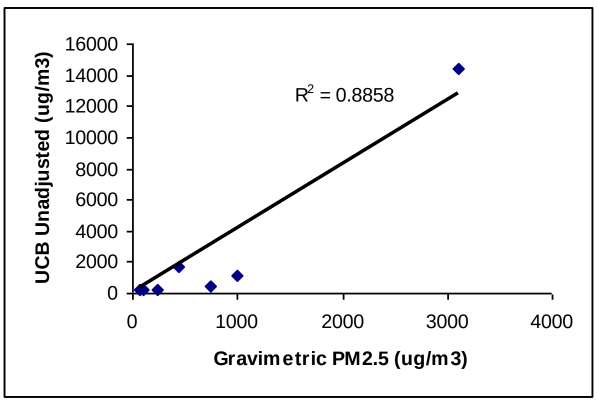


Figure 3 Coal Stove (Pre-Intervention): Relationship between UCB Particle Monitor concentrations (µg/m^3) and gravimetric filter $PM_{2.5}$ concentrations (µg/m^3) (N = 6).

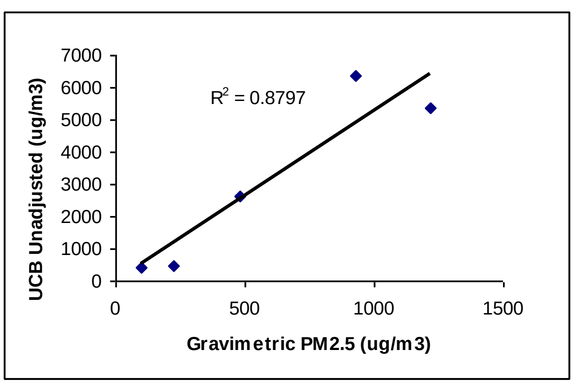


Figure 4 Biomass Stove (Post-Intervention): Relationship between UCB Particle Monitor concentrations (µg/m3) and gravimetric filter PM2.5 concentrations (µg/m3) (N = 5).

Appendix 3 Instrument Monitoring Form for Household Air Pollution Measurements

	Instrument ID	**Programmed Start Date** (dd_mon_yyyy)	**Programmed Start Time** (hh:mm)	**Initial Photoelec** (mV)	**Initial Battery** (Volts)	**Final Photoelec** (mV)	**Final Battery** (Volts)	**HOBO Post Channel #1**		**HOBO Post Channel #2**	
UCB #1											
UCB #2											
HOBO #1								Max	Min	Max	Min
HOBO #2								Max	Min	Max	Min

SAMPLING	**UCB_PM #1**			**UCB_PM #2**			**HOBO_CO #1**			**HOBO_CO #2**		
Instrument ID												
Location	ID	Ht.(cm)	Dist(cm)	ID	Ht.(cm)	Dist(cm)	ID	Ht.(cm)	Dist(cm)	ID	Ht.(cm)	Dist(cm)
Initial Zeroing Time (In Bag)	to			to								
Actual Sample Start Date (dd_Mon_yyyy)												
Actual Sample Start Time (hh:mm)												
Final Check ID# & On/Off												
Actual Sample Stop Date (dd_Mon_yyyy)												
Actual Sample Stop Time (hh:mm)												
Final Zeroing Time (In Bag)	to			to								

Gravimetric						
Check Filter Air Escape Yes No						
Date (dd/Mon/yyyy):			**ID (County/Village/HH/Location): _________-_________-_________-_________**			
INSTRUMENTS						
Microenvironment:	**Kitchen**		**Outdoor**		**Other__________________**	
1. SKC Pump	****DUR (pump duration) = 48 hours **** *Set (a) run time to 2880min; (b) pump duration to 576min (1min flow/5min)*					
Pump Serial Number						
Battery ID Number						
Initial SKC Flow Rate (l/min)						
Initial Rotameter Flow rate						
Pump Start Date/Time	Date:	Time:	Date:	Time:	Date:	Time:
Final Rotameter Flow Rate						
Pump Stop Date/Time	Date:	Time:	Date:	Time:	Date:	Time:
Total Run Time (min)						
Total Flow Time (min)						
Total Volume (m^3)						
2. BGI Cyclone						
* Filter ID *						
Cyclone ID Number						
Cassette ID Number						

Appendix 4 Rotameter Calibration Form

Pre-Sampling Round **Sampling Round #: _______________**

Date: ___ / ___ / ___ Rotameter ID: _____________ Sampling Conducted By: __________
Calibration Flow: ________ LPM

	Calibration Chamber Readout (LPM)	Avg. Flow (6 flows)
+5%		
+ +2 %		
Base		
-2%		
-5%		

Result: flow (lpm) = slope * flow (rota) + intercept

Slope = _______________ Intercept = ________________ r^2 = ________________

Base: ______________ Flow (lpm) = ___________ Avg Flow (lpm)

Acceptable Range (+/- 5 %) = (________, ________) Avg.

Post-Sampling Round **Sampling Round #: _______________**

Date: ___ / ___ / ___ Rotameter ID: _____________ Sampling Conducted By: __________
Calibrate Flow: ________ LPM

	Calibration Chamber Readout (LPM)	Avg. Flow (6 flows)
+5%		
+ +2 %		
Base		
-2%		
-5%		

Result: flow (lpm) = slope * flow (rota) + intercept

Slope = _______________ Intercept = ________________ r^2 = ________________

Base: ______________ Flow (lpm) = ___________ Avg Flow (lpm)

Acceptable Range (+/- 5 %) = (________, ________) Avg.

Observations: ____

____

Appendix 5 Kitchen Survey for Household Air Pollution Measurements

Kitchen Survey

The program is aimed to promote the scale of using high-efficiency and low-emission Biomass Stoves in China, realizing the goals of energy conservation, emission reduction, indoor air quality improvement, health promotion and environmental protection. By participating in this survey, you will help us to improve JinQilin Stove. Thank you for your making time for us. All of the information we collect will be kept private. If willing to help us, could you sign your name below?

Interview Date：_______________ (Format：D/M/Y, 16/5/2008)   Signature：_____________
Address：_____________________________ Telephone

	Section A： Family Status	
	Questionnaire：	**Answer**
1	How many family members who are living in your household?	
2	How many children under 10 years old live in your household?	
3	What is your highest level of education attained? 1. Primary school 2. Middle school 3. High school 4. University 5. Other	1. Husband: ___________ 2. Wife: ___________
4	What is your household's main source of income?	1. Farming 2. Livestock breeding 3. Migrant workers 4. Business 5. Other(specify)
5	If willing to answer, what is your average annual household income?	
	Section B： JinQilin Stove Purchase Status	
6	Do you have a JinQilin Stove?	1.Yes 2.No
7	How many months have you had the stove?	
8	Are you still using the stove now？	1.Yes 2.No
9	What's the usage of this stove you are using?	1. Cooking 2.Heating forage 3. Heating 4. Boiling Water 5. **Other usages：**
10	How many people do you cook for per meal?	Morning： Noon： Evening：
11	How does the new stove compare to old cooking habits？（tick "√" on the options）	1.Cooking time： more/less/same 2.Fuel use more/less/same 3.Fuel expense： more/less/same 4.Ease of use： more/less/same 5.Amount of Smoke more/less/same 6.Coughing & eye irritation: more/less/same 7. Other：
12	What can be done to improve JinQilin stoves?	Describe in details：

Stove types *(Tick " √" Primary Stove Used)*	**Fuel & Cost**	**Fuel Use（Day Month Year）** (Please choose a time unit above to tick" √ " to show the amount used per D/M/Y)			
		Fuel Used Before buying JinQilin Stoves		*Fuel Used After buying JinQilin Stoves*	
		Non-Heating	Heating	Non-Heating	Heating
□New Biomass Stoves	Biomass（kg）				
	Spent (RMB)				
□Old Biomass Stoves	Biomass（kg）				
	Spent (RMB)				
□Coal Stove	Coal（kg）				
	Spent (RMB)				
□Electric Stoves	Electricity (kw)				
	Spent (RMB)				
□Biogas	Gas (m^3)				
	Spent (RMB)				
□Coal Boiler	Coal (kg)				
	Spent (RMB)				
□Biomass Boiler	Biomass（Kg）				
	Spent (RMB)				
□Other	(Kg)				
	Spent (RMB)				

The amount of heating months/yr: ________________

Notes：Please specify the categories of biomass: tree branches, wood, corncobs, briquettes, cattle dung, and straw.