Wood Fuel, Carbon Markets, and Black Carbon

By

Akhilesh Khopkar

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Approved by advisory committee:

Dr. Erin Sills (Committee Chair)
Dr. Robert Abt
Dr. Heather Cheshire

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Interest in controlling black carbon emissions is increasing due to better understanding of their role in climate change. Unlike other greenhouse gases (GHG), black carbon (BC) is primarily emitted in developing countries such as China and India. Thus, effective mitigation would have to involve developing countries currently participating in climate change mitigation primarily through “carbon offset” markets, both under Kyoto and through voluntary markets. This raises the question of how a market or some other funding mechanism for black carbon mitigation would interact with the existing initiatives to mitigate GHG. I focus specifically on the wood energy sector and the residential energy sector, examining the existing portfolio of projects that seek to mitigate climate change by modifying use of wood energy in the industrial sector and by modifying the use of wood energy and fossil fuel energy in the residential sector. I then consider the implications of these projects for BC emissions by applying BC emission factors. I utilize this assessment to consider how a market for BC might affect the existing carbon offset markets. I find that both spatial and temporal factors play a key role in the effective BC mitigation initiatives. I also find that inclusion of BC in the global carbon market could both change the spatial distribution of carbon market projects and either increase or decrease the financial value of those projects.
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I. INTRODUCTION

A. Rationale for Research

The topic of BC emissions has only recently caught the attention of global audiences with its implications toward global climate change, regional climatic fluctuations, changing of local precipitation and monsoon patterns, contribution to the accelerated melting of local glaciers and polar ice caps, and impact on respiratory health in the developing world (Kroeger, 2010). My research was driven by the fact that the diverse residential and industrial use of wood fuel in addition to fossil fuels has a key direct relationship to black carbon emissions. Furthermore, switching to cleaner burning fuels and technology in the residential sector is widely thought to be one of the most cost-effective ways to improve the welfare of some of the most vulnerable populations in developing countries: women and children (Baron, 2009). Because many of the residential scale projects that influence BC emissions involve switching to or from woodfuels, I also assessed industrial scale projects that involve this type of fuel switching. Hence, my goal is to research the relationship between wood fuel, fossil fuels, and black carbon emissions. Since black carbon mitigation has flown under the radar relative to other greenhouse gases such as CO₂ and methane, attempts, examples, and case studies of BC mitigation have been difficult to obtain.

There is an abundance of publicly available documented material of projects mitigating GHGs through global carbon market project design documents (PDDs), verification reports, and monitoring reports. Although current carbon market policies, projects, and the agreements that spawn those projects lack any mention of BC emissions or their relationship to wood fuel or fossil fuels, carbon market projects have strong implications for black carbon
emissions. I therefore identified BC implications in reference to carbon market projects involving the industrial and residential use of wood fuels along with other residential projects with implications for BC emissions. I then built a catalog of projects implemented through selected carbon market standards switching to or from wood fuel in the industrial or residential sector and residential scale projects switching current practices of coal or wood fuel combustion to other technologies such as improved cookstoves, residential biogas, and solar cookers. Once the projects were catalogued, I applied to the projects BC emissions factors gathered from various studies so that I could determine whether project activities increase, decrease, or have no change from the business-as-usual scenario. Finally, I synthesized my data with the goal of better understanding the results from the perspectives of global climate mitigation and the carbon offset market.

In the remainder of this introduction, I review the literature and describe BC, carbon markets (including the project registration process), and wood fuels. In following sections, I examine the methodology behind the characterization of carbon market projects' BC impact and the organization and spatial distribution of catalogued data. In Chapter 2, I present the methodology used in conducting the analysis. In Chapter 3, I present and discuss the results of my analysis. The final chapter I summarize my primary findings and introduce potential relevant policy implications.

B. Black Carbon

Also known as “soot,” BC is a product of incomplete combustion of fossil fuel, wood fuel and charcoal. Black carbon usually forms when insufficient oxygen is present for the complete oxidation of carbonaceous fuel to CO2 (Bond et al., 2004). In the process of
incomplete combustion, different forms of aerosols are emitted including BC, which warms the atmosphere and cools the ground, and organic carbon (OC), which cools both the atmosphere and ground (Roden et al., 2006). Global black carbon emissions originate from a variety of sources; open biomass burning is estimated to be responsible for 42%, residential burning 24%, transportation 24%, and industry/power 10% (with large regional differences) (Bond, 2007). The emissions originate in both industrialized countries (mostly from diesel emissions) and developing countries (from residential activities, crop management, and diesel emissions). Historically a higher percentage of BC emissions originated from developed countries; however, over the past century, technological advances have significantly mitigated these black carbon emissions (Baron, 2010). Therefore, the current major hurdle in BC mitigation is reducing emissions in the developing world (Bond, 2005). In 1996, 26% of global BC emissions originated from India and China alone with 40% of global emissions originating from Asia with the exclusion of Japan (Bond et al., 2004).

BC has several negative effects on regional and global environmental factors. When globally averaged, BC is estimated to exert a net positive radiative forcing (global warming effect) at the top of the atmosphere of as much as 60% of CO2 (Chung et al., 2005 and Ramanathan 2007); BC’s overall contribution to 20th century contribution to climate change is likely to be the second highest after CO2 on a global scale (Jacobson, 2002). On a regional level, the impact of BC emissions is even more critical. Regional BC over the Arctic and Himalayas is a “double whammy,” as BC present in the atmosphere absorbs sunlight, warming the atmosphere; subsequently, that same BC settles on ice as a result of rain and snow, causing accelerated melting of polar ice (Climate Change, 2011). The United Nations
Environmental Programme (UNEP) states in a recent report that reducing lower-atmospheric BC in Scandinavia, America, and Russia could reduce the melting of Arctic ice by as much as 2/3. Furthermore, the UNEP also believes that a reduction in worldwide BC emissions could halve the rate of warming by 2050. As regional BC settles on glaciers and polar ice, it darkens their surfaces, therefore decreasing surface albedo and causing accelerated glacial melt (Press Release, 2011). Food security in the Indo-Gangetic plane is endangered because many major rivers essential for livelihoods originate from the Himalayan Glaciers, which are suffering from accelerated melting (Baron, 2010). Localized climate forcing in Asia involves the decrease of Indian and Southeast Asian monsoon rainfall, resulting in a weaker hydrological cycle and reduced freshwater availability (Ramanathan et al., 2005; Ramanathan et al., 2008; Ramanathan and Feng, 2009). Additionally, a north-south shift in Chinese rainfall has also been observed, increasing drought in Northern China and flooding in Southern China (Menon et al., 2002; Ramanathan et al., 2005). It is important to note that in contrast to CO2, BC is a short-term warming agent, meaning that it only exists in the atmosphere between 1 and 2 weeks, whereas CO2 exists for decades at a time. Therefore, any reductions in BC emissions yield immediate benefits to the environment (Baron 2010). However, when considering a long-term climate change mitigation goal, CO2’s status in mitigation attempts cannot be overlooked.

i. BC in the Residential Sector

BC is also a major component of indoor air pollution caused by open fires and traditional cookstoves, as approximately 3 billion people in the worldwide residential sector rely on coal or biomass as their primary energy source for cooking and heating, accounting
for 13% of global energy consumption (About: HEDON, 2011). Indoor air pollution is a major cause of illness and mortality for people in the developing world, as indoor smoke is attributed to be the 8th highest factor in global burden of disease (Roden et al., 2006). The group of people most affected by indoor air pollution is women and children, for they are present while food is being cooked inside homes (Kroeger, 2010). Among the illnesses resulting from indoor air pollution are childhood pneumonia, lung cancer, bronchitis, and cardiovascular disease. 1.6 million premature deaths worldwide, including 900,000 among children under five (Bailis, 2009) and 400,000 in India alone, occur annually.

Use of improved cookstoves leads to more complete combustion and more efficient use of fuelwood. Compared to traditional cooking practices, improved stoves can lead to fuel savings of up to 67% (Smith, 2007). As less wood fuel is consumed due to increased efficiency, more forest carbon is maintained in long-term sinks rather than burned as fuel. CO2 emissions are calculated by considering the baseline wood consumption scenario and factoring in wood efficiency improvements. CO2 emissions factors based on approved laboratory tests are then applied to determine the level of CO2 mitigation (3Degrees, 2010). However, improved fuelwood efficiency does not always equal decreased BC emissions, an issue discussed later on in the paper. Improved residential fuelwood efficiency has positive implications for poverty alleviation and women’s empowerment. As combustion efficiency improves and less fuel is required, women will spend less time gathering fuelwood and less time cooking. This will enable them to focus on other vital activities such as earning extra income, eventually alleviating poverty. Furthermore, as less wood fuel is required for improved stoves and for industrial consumption, less pressure is put on forests, thus leading
to the conservation of biodiversity and reduced forest degradation. Therefore cookstoves maintain more carbon sinks by keeping more forests intact.

C. Wood Fuels

Through wood fuel, forests and trees provide a significant share of the global energy demand, both in developing and developed countries. Industrial users of wood fuel include iron and steel makers, cement factories, and heat and power generation plants (Nogueira, 1998); wood fuel’s use as a modern and environmentally suitable source of energy for industries such as brick manufacture and power generation is globally prevalent and further expanding (FAO, 1995). Primary household uses of wood fuel involve residential cooking and heating (Nogueira, 1998). In 1997, wood fuels accounted for more than 16 percent of total energy supply in developed countries including Sweden, Finland, Austria and other European Union countries (FAO, 1997). Recent international interest and agreements have highlighted the environmental advantages of bioenergy utilization, mainly referring to the CO2 cycle and GHG emission mitigation, creating an additional thrust for wood energy expansion (UN, 1997).

Antti Asikainen, Professor at the Finnish Forest Research Institute, believes that sustainable use of wood for energy is the second best means to alleviate climate change, just behind saving energy. Dr. Asikainen does not necessarily believe wood energy to be carbon neutral; however, he does believe it to be as carbon neutral as any fuel can be (Asikainen, 2011).

Various types of wood fuel include fuelwood, charcoal, sawdust, and pellets, each with its own unique properties and impacts on GHG emissions. Although fuelwood and charcoal have a common source, they have different markets and applications. Unlike fuelwood, charcoal is typically manufactured, transported, and sold commercially. Charcoal usually
competes with other commercially available fuels such as kerosene, electricity, and liquefied petroleum gas (LPG); therefore, its consumption depends greatly on its price relative to other fuels (Wood, 1985). Wood pellets are another source of wood fuel, created from the compacting of sawdust and waste from the manufacture of wood products. In general, the utilization of a specific source of wood energy greatly depends on the scarcity or availability of sources in that specific area. Wood fuel is unique to different sites and involves complex processes in which users encounter varying types and qualities of wood fuel derived from diverse sources and produced using different technologies. As well as being derived from various sources including natural forests, forest plantations and urban areas, wood fuels can be derived from byproducts of forest industries such as sawmills and particle board plants. These various types of wood fuels reach a contrasting group of users through numerous channels with household, industrial and commercial use in rural and urban areas.

D. Carbon Markets

The global carbon market is a mechanism through which governments, corporations, and individuals can purchase and trade CO2 emissions reduction credits with the intention of reducing their own carbon footprints. The global carbon market has two major parts: the voluntary market and the compliance market. The compliance market spurs from the Kyoto Protocol, which is a binding global agreement that requires industrialized nations to reduce their GHG emissions below a certain level.

i. The Kyoto Protocol and GHG Trading

The Kyoto Protocol is a global environmental agreement requiring developed countries
to limit or reduce their GHG emissions to set levels, thereby giving GHG emissions reductions economic value. As its primary feature, Kyoto sets binding targets for 37 industrialized countries and the European community for reducing GHG emissions. The targets over the five-year period 2008-2012 are five per cent below 1990 levels (Kyoto Protocol, 2011). The targets cover emissions of the six main greenhouse gases for which CO₂ equivalents are calculated: Carbon dioxide (CO₂), Methane (CH₄), Nitrous oxide (N₂O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF₆) (Kyoto Protocol, 2011). To simplify GHG trading, reductions of emissions are usually stated in CO₂ equivalents since it is the principal greenhouse gas. In calculating equivalents, Kyoto uses the global warming potential (GWP) on a 100-year time horizon, as recommended by the Intergovernmental Panel on Climate Change (Shine, 2007). To help developing countries and the private sector in meeting emissions targets, Kyoto includes market-based mechanisms such as the Clean Development Mechanism (CDM). Thus a new commodity was created for the tracking and trading of GHG emissions.

ii. The Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM) allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries (Clean Development Mechanism, 2011). Overseen by the CDM executive board, the CDM is considered by many to be a pioneering idea, the first global environmental investment and crediting scheme of its kind. Emissions reduction projects in developing countries earn certified emissions reductions (CERs). Each equivalent to one ton of CO₂, CERs can be traded, sold, and used by developed countries to meet a part of their emissions reduction target under Kyoto. This process
therefore stimulates sustainable development and emissions reductions while simultaneously giving developed nations flexibility in meeting emissions reduction targets. However, CDM projects have to go through a very rigorous registration and issuance process. This public process assures that the emissions reductions are real, measurable, verifiable, and additional. Additionality signifies that the emissions reductions achieved due to the project would not have otherwise occurred. This process will be discussed in detail in sections to follow.

iii. The Voluntary Market and the Verified Carbon Standard

The voluntary carbon market enables businesses, governments, non-government organizations (NGOs), or individuals to reduce their carbon footprints through verified emissions reductions that each equal one ton of CO₂. Trading volumes in the compliance market are much smaller because voluntary instruments -- rather than regulatory instruments -- create demand. The Verified Carbon Standard (VCS) also does not have any restrictions on the location of projects and thus can also have projects located in developed countries (CORE, 2011). The VCS is a quality assurance standard for projects to quantify GHG emissions reductions in the voluntary market. This independently verified standard requires a defined set of principles and requirements to ensure that emissions reductions are real, measurable, additional, permanent, and conservatively estimated (How It Works, 2011).


The Gold Standard is a carbon standard for the compliance market under the Kyoto protocol as well as the voluntary market, and is therefore considered “hybrid.” Funding for carbon credits under the Gold Standard comes from both the public and private sector with additional revenue from sponsorships and fees. The Gold Standard allows for parallel
submission of projects to the CDM CER as well as to the Gold Standard VER. Therefore, if rejected by CDM, a credit could be eligible under Gold Standard. An organization wishing to earn carbon credits under the Gold Standard must follow the same steps as the CDM but must supply additional information at various steps. Gold Standard credits for sale in the compliance market are issued and tracked in the CDM registry, whereas credits for sale in the voluntary market are issued and tracked in the Gold Standard registry (Gold Standard, 2011).

v. Project Design Documents and the Registration Process for the CDM and GS

Each project in the carbon market has a project life cycle with steps that are common to all successful projects. Projects first enter an initial planning phase where a project design document (PDD) is first drafted. After the Designated National Authority approves the PDD, the project is “At Validation”. A Designated Operational Entity (DOE), a third party institution, then examines the project before the project is registered. The project is subsequently “Registered” or “Terminated”. Project activities are then monitored before being Certified/Verified and VERs/CERs are issued (Blunk 2010).

The PDD is the main project document and the basis for evaluation and analysis of the project by the Designated National Authority, the public, or the carbon credit standard. It provides information about the project’s concept, category, methodology, additionality and leakage assessments, geographic locations, etc. In preparing the PDD, demonstrating the additionality of the project is key. A project is additional if GHG emission reduction would not have occurred in the absence of the project activity; therefore in the case of a stove project, a project that would have been implemented through the private sector in the absence of carbon financing would not be eligible. Furthermore, it is necessary to prove that carbon
financing was a planned part of the project before implementation. Also, a document such as a draft PDD is required in ensuring the acceptance of affected local groups due to project activity.

vi. The VCS Project Registration Process

Projects under the Verified Carbon Standard (VCS) also undergo a process of registration and VCU issuance similar to the one mentioned above for CDM and GS. All project plans must also be approved, validated, and verified by a validation/verification body. In the VCS, unlike the CDM, accredited 3rd party auditors or Validation/Verification Bodies (VVBs) validate, verify, and give final project approval on the same project; the VCS Association, the founding body of the VCS, does not review individual projects. The VVB completes a VCS Validation Report that includes a description of the project, method used to calculate the baseline, a monitoring plan, calculation of the GHG reduction, calculation of the environmental impact, and comments by stakeholders. When GHG emissions reductions have been verified and a VCU issued, project proponents open an account with a registry operator and must be linked to the central VCS Project Database so that consumers can trust and confirm the history of a VCU from issuance to retirement. All project types are allowed under the VCS as long as they are supported by a VCS methodology or a methodology under an approved GHG reduction program such as the CDM (CORE, 2011).

The VCS Project Description contains the information that a CDM or GS PDD contains\(^1\). The Project Description is only made available after a project has been validated, verified, and

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\(^1\)Although the VCS refers to its PDD as a Project Description, I refer to the VCS Project Description as PDD in this paper.
submitted to the registry administrator, who makes VCS project documents available to the public on the VCS Database (CORE, 2011).

vii. Other Considerations for CDM, GS, and VCS Projects

In the initial phase of the project registration process, standards look to evaluate their overall carbon market potential in addition to financial resources and availability and necessity of raw materials. After doing so, an assessment of whether the project meets CDM and voluntary market criteria is necessary. A list of project eligibility criteria is as follows:

1. Scale of the project activity: For CDM improved cookstove projects, only projects that are smaller than 180 GWh annual energy savings (small scale) are permitted for registration. There is no such requirement through the Gold Standard (Blunk, 2010) or for VCS projects (CORE, 2011).

2. Host country or state: The host country has created a Designated National Authority (DNA). The DNA determines whether the project contributes to the country’s sustainable development and subsequently issues a letter of approval (LoA). For the voluntary market there are no restrictions for host countries; thus any country is eligible as a host country for a VER project. Under the CDM, any country other than a non-Annex 1 country in the Kyoto Protocol can host a project (Blunk, 2010). In the case of the VCS, the DNA is not involved; instead, third-party auditors validate, verify, and give final project approval. In addition VCS does not require projects to have additional social or environmental benefits (CORE, 2011).

3. Type of project activity: The project must fit into a category specified by the carbon standard. Improved stove projects are placed in the end-use energy efficiency
category; biogas projects are placed in the methane avoidance category with a subcategory of domestic manure; fuel switching projects from fossil fuels such as coal, LPG, natural gas, or oil to biomass are in the biomass energy category. There are categories such as forest biomass, forest residues: other, and forest residues: sawmill waste which were of particular interest within the biomass energy subcategory. These fuel-switching projects were included in the database (Blunk, 2010). Under the VCS, improved stove projects are under the Energy Demand Sectoral Scope; projects switching from non-renewable to renewable biomass are under the Energy (renewable/non-renewable) Sectoral Scope (The VCS, 2011).

4. Greenhouse gases: The Kyoto Protocol identified six greenhouse gases for which projects are able to claim emissions reduction credits under the CDM. For stove projects (through the AMS-II. G methodology), however, the CDM only allows emissions reductions credits to be claimed through reductions in CO2. But, the GS takes into account CO2, CH4, and N2O in GHGs that can claim emissions reductions credits (Blunck, 2010).

5. Timeframe: A carbon market project can have a crediting period of either seven or ten years without being eligible for an extension or seven years with the possibility of two extensions for a total of 21 years (Blunk, 2010). For non-AFOLU projects under the VCS, projects have a maximum crediting period of ten years with the option to renew the project at most two times (CORE, 2011).

Emissions reductions can only be claimed and counted once. If an activity is registered under a standard other than GS, the GS can be used but only for emissions reductions that have not
been claimed under the other standard. Therefore, it is imperative that double counting be avoided (Blunk, 2010).
II. METHODOLOGY

In this section, I first discuss the criteria used in the selection of the carbon credit standards analyzed. I then explain the criteria of project selection within the selected carbon credit standards and then go on to explain the process by which I obtained projects meeting the selected criteria. Subsequently, I explain the process through which BC emissions factors are applied to the selected projects to determine whether those projects increase, decrease, or have a neutral effect on BC emissions. Finally, I explain the process gathering project attributes and viewing the spatial distribution of the projects.

A. Criteria for selection of carbon credit standard

In choosing the appropriate carbon credit standard to include in the database, it was necessary that both the compliance and voluntary markets be represented in order to diversify the catalogue. It was also important that the standard contained projects relevant to the research study being conducted (i.e. fuel switching projects to or from wood fuel; residential energy efficiency projects that will reduce or displace fossil fuel use through the use of improved cookstoves or biogas). In addition, the carbon credit standard had to contain credits of sufficiently high quality (i.e. limited additionality, leakages, incorrect assessment, and compromised sustainability) (Warringa, 2009). The emissions reductions measurement procedures or verification procedures also needed to be robust, with the credits registered in a transparent way in order to minimize double counting. Furthermore, checks on auditors and an evaluation for additionality were also vital factors in guaranteeing the reliability of the credits. In an evaluation of validation and verification reports and additionality tests of
various carbon credit standards done by the Dutch Government only the Gold Standard was on par with the CDM with additional sustainability assessments in the host country, which the CDM lacks (Warringa, 2009). Given these factors the report mentioned above advises the Dutch government to acquire credits verified by CDM or Gold Standard. Gold Standard is generally accepted as the standard with the most stringent quality criteria (Kollmuss, 2008). The Gold Standard, according to the WWF, is the highest standard in terms of carbon integrity, environmental integrity, and sustainable development benefits (Kollumss, 2008). The CDM additionality tool has been developed over several years and is used as a benchmark for comparison with other carbon credit standards (Kollmuss, 2008). The VCS also has robust additionality requirements such as its project-based additionality requirements that closely follow the CDM Additionality Tool procedures. These project-based additionality tests are outlined in VCS as minimum requirements for developing new methodologies (Introduction, 2011). Furthermore, the VCS meets a high standard in carbon verification and successfully addresses the issues of real and permanent carbon sequestration (Verified Carbon Standard, 2010). Thus, VCS, CDM, and GS were ultimately the chosen standards, giving me one standard on the voluntary market, one hybrid (containing voluntary and compliance credits), and one on the compliance market.
Is the standard on the compliance or voluntary carbon market? The global carbon market has two major parts: the voluntary market and the compliance market. The compliance market spurs from the Kyoto Protocol, a binding global agreement that requires industrialized nations to reduce their GHG emissions below a certain level. The voluntary market enables businesses, governments, NGOs, or individuals to reduce their carbon footprints created through either CDM or voluntary market (voluntary or verified emissions reductions). To qualify, the standard must be on the compliance market, voluntary market, or both.

Does the standard contain high quality carbon credits (i.e. does it have measures that prevent limited additionality, leakages, incorrect assessment, and compromised sustainability)? In addition the emissions reductions measurement procedures or verification procedures should be robust, with the credits registered in a transparent way in order to minimize double counting. Also, checks on auditors and an evaluation for additionality are also vital factors in guaranteeing the credibility of the credits.

Is there a registry or spreadsheet present that lists projects? If there is a registry or spreadsheet database listing projects under the label, the public should be able to access this registry or database. If the information is accessible to the public, does the database include projects relevant to the study?

Registry present: All of projects are approved and VERS/CERS are issued – GS and VCS

Spreadsheet with project listing present (some projects pending verification, some verified, some cancelled, some terminated) - CDM

Filter VCS catalog by keyword; Filter GS catalog by keyword in the "Project Name" and "Project Type" categories

Filter CDM spreadsheet database by status → type of project → subtype → methodology (please see below for detailed directions)

Comment [a1]: At end of next box: credibility could be changed to authenticity (as above) to alleviate repetition/confusion

Figure 1 - The process of building the BC project database
B. Criteria for Project Selection

The following are the types of projects that I searched for:

(a) Industrial fuel-switching projects involving wood: These projects could involve switching from fossil fuels such as natural gas, LPG, coal, and heavy fuel oil over to forest biomass; it could also include a switch from non-renewable native forest biomass to renewable forest biomass such as sawdust and sawmill waste. These criteria do not include switching to and from agricultural residues such as bagasse or rice husks if the project does not in some way involve forest biomass.

![Diagram](Figure 2 - Project selection criteria: industrial projects)

(b) Residential energy efficiency projects that will displace or reduce coal or wood fuel use with improved stoves, biogas, or solar cookers: Residential energy efficiency projects also have a secondary goal of the reduction of indoor air pollution; however, that does not necessarily mean BC reduction.
C. Process of Project Selection

The process of project selection first started with searches in various catalogues and listings without searching for a specific carbon market standard with a certain criteria in mind. I was specifically looking for improved cookstove projects and projects switching to and from wood fuel. I then became more acclimated to VCS (voluntary) and CDM (Kyoto compliance) projects since they were readily available and therefore decided to browse catalogues for VCS and CDM projects. Along the way, I found several carbon market projects under the Gold Standard and later discovered that this standard has projects covering both the compliance and voluntary markets.

With a certain project criteria in mind, I found several projects that met the criteria, however realizing that there could be several others that may not be captured in the locations I was searching. I therefore decided to browse registries to see if there were additional projects with my criteria that I was missing. In order to find projects fitting my criteria in the VCS and GS registries, I browsed the entire registry without using a filter since these registries were not nearly as large as the CDM registry. The VCS registry currently has 685 projects; the Gold Standard Registry has 317 projects in its VER registry and 189 in its CER registry. Going through the registry and browsing all the projects also made the process more accurate since
none of the projects or project types were overlooked. When browsing the VCS and Gold
standard registries, a number of the PDDs were available. A portion of the PDDs that were
unavailable was found after searching for the project on an Internet search engine. There
were several pieces of relevant information that the PDDs contained. This included
information about the host country, geographic location (enabled mapping the exact location
of the project – helpful for policy relevant analysis), scale of the project (residential, industrial,
etc. – this piece was relevant to the BC impact calculation), details about the type of fuel
switch in the project activity, tons of CO2 emissions avoided, number of stoves disseminated
by the project, a detailed description of the project, and duration of project activity.

i. Filtering the VCS Database

Table 1 - Ranks of keywords used in filtering VCS Database by number of favorable hits and accuracy

<table>
<thead>
<tr>
<th>Rank</th>
<th>Keyword</th>
<th>Favorable</th>
<th>Total</th>
<th>Accuracy</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ceramic</td>
<td>32</td>
<td>32</td>
<td>100%</td>
<td>32.00</td>
</tr>
<tr>
<td>2</td>
<td>fuel switching</td>
<td>28</td>
<td>31</td>
<td>90%</td>
<td>25.29</td>
</tr>
<tr>
<td>3</td>
<td>fuel switch</td>
<td>29</td>
<td>39</td>
<td>74%</td>
<td>21.56</td>
</tr>
<tr>
<td>4</td>
<td>switching fuel</td>
<td>4</td>
<td>4</td>
<td>100%</td>
<td>4.00</td>
</tr>
<tr>
<td>5</td>
<td>wood</td>
<td>2</td>
<td>4</td>
<td>50%</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>cookstove</td>
<td>1</td>
<td>1</td>
<td>100%</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>fuel-switching</td>
<td>1</td>
<td>1</td>
<td>100%</td>
<td>1.00</td>
</tr>
<tr>
<td>8</td>
<td>biomass</td>
<td>4</td>
<td>40</td>
<td>10%</td>
<td>0.40</td>
</tr>
</tbody>
</table>

There are three options when filtering projects in the VCS database: Keyword, Country, and Sectoral Scope. Filtering by country or Sectoral Scope was not the most efficient
way to find products since it yielded an excessive number of projects that did not meet the
project criteria. Therefore I came up with a list of keywords to filter the database. These
different keywords are displayed in the above table. I ranked these keywords by their ability
to yield favorable matches based on their level of accuracy in finding projects and also based
on the number of database hits. I obtained accuracy percentages by dividing database hits from that keyword by the total number of BC projects in the VCS database. One universal keyword yielding all the projects did not exist; thus, a combination of various keywords should be used in order to extract from the database all the projects that meet the project criteria. The keyword “ceramic” yields the strongest results; the keyword “biomass” yields the weakest results. When looking at results of key word search, it is important to view the descriptions of resulting projects to confirm that the projects do meet the criteria. This is especially true for searches using “biomass” since it is important to confirm that industrial-scale projects switching to or from the use of biomass involve forest biomass.

ii. Filtering the GS Database

There are several options available in filtering the GS project registry. However, the two most straightforward categories to filter the database are Project Name and Project Type. It is once again important to understand that it will take a few searches to find all of the projects to meet your criteria. It is therefore important to use combinations of keywords; in the case of the Gold Standard it is necessary to use a combination of keywords simultaneously in categories such as Project Name and Project Type. Below are the results of using various keyword searches filtering by “Project Name” and “Project Type.”

Table 2 - Effectiveness of keyword used in filtering GS Project Database by “Project Name”

<table>
<thead>
<tr>
<th>Filter by &quot;Project Name&quot;</th>
<th>Favorable</th>
<th>Total</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stove</td>
<td>48</td>
<td>48</td>
<td>100%</td>
</tr>
<tr>
<td>Cook</td>
<td>37</td>
<td>38</td>
<td>97%</td>
</tr>
<tr>
<td>Biogas</td>
<td>12</td>
<td>23</td>
<td>52%</td>
</tr>
<tr>
<td>Biomass</td>
<td>5</td>
<td>12</td>
<td>42%</td>
</tr>
<tr>
<td>Kitchen</td>
<td>2</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>Bio gas</td>
<td>1</td>
<td>1</td>
<td>100%</td>
</tr>
</tbody>
</table>
In filtering by Project Name, the keyword “stove” yielded the highest and most accurate results. Although “biomass” did not yield very many results and yielded many projects that do not meet the criteria, it is nevertheless an important keyword since it did find matching criteria that no other keyword found.

**Table 3 - Effectiveness of keywords used in filtering the GS Project Database by "Project Type"**

<table>
<thead>
<tr>
<th>Filter by &quot;Project Type&quot;</th>
<th>Favorable</th>
<th>Total</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Efficiency - Domestic</td>
<td>43</td>
<td>53</td>
<td>81%</td>
</tr>
<tr>
<td>Biogas-Heat</td>
<td>14</td>
<td>15</td>
<td>93%</td>
</tr>
<tr>
<td>Solar Thermal - Heat</td>
<td>3</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>16</td>
<td>19%</td>
</tr>
<tr>
<td>Energy Efficiency - Public Sector</td>
<td>3</td>
<td>3</td>
<td>100%</td>
</tr>
<tr>
<td>Biomass, or Liquid Biofuel – Heat</td>
<td>2</td>
<td>7</td>
<td>29%</td>
</tr>
<tr>
<td>Energy Efficiency - Commercial Sector</td>
<td>1</td>
<td>2</td>
<td>50%</td>
</tr>
</tbody>
</table>

The same process was applied to the Project Type category. The two most important categories here are “Energy Efficiency – Domestic” and “Biogas – Heat.” “Energy Efficiency – Domestic” found most of the improved cookstove projects; “Biogas – Heat” found most of the residential biogas projects. “Energy Efficiency – Domestic” from Project Type and keywords “stove,” “cook,” and “kitchen” are closely related; “Biogas-Heat” from Project Type and keywords “biogas,” “bio gas,” and “biodigester” are closely related.

### iii. Filtering the CDM Pipeline

The same process for finding projects could not be used for the CDM as there are approximately 7350 projects in the pipeline. To find CDM projects that met the criteria, I downloaded the CDM Pipeline spreadsheet. The CDM Pipeline spreadsheet contains all CDM projects that have been sent for validation/determination. The Pipeline contains projects that are registered, at validation, and those that have had their registration terminated. This was a
contrast from VCS/GS project registries where only registered projects were available. I chose to include CDM projects that were at validation and registered since doing so gave me a greater volume of diverse data. As mentioned earlier, projects at validation are those projects whose PDDs have been approved by the Designated National Authority but whose registration is pending approval by the third party Designated Operation Entity. I had to therefore find an effective method of filtering the projects by category and subcategory as they were listed in the database.

(a) Carbon market projects switching to wood fuel

1. Industrial biomass fuel-switching projects using forest biomass: This includes projects switching to or from wood energy. They could be switching out of or into fossil fuels such as LPG, natural gas, coal, or heavy fuel oil. The category of such projects is Biomass energy; the subcategories used to filter the projects are Forest biomass, Forest residues: other, and Forest residues: sawmill waste.

(b) Residential energy efficiency projects that will displace or reduce fossil fuel or wood fuel use with improved stoves, biogas, or solar cookers

1. Improved stove projects: The category for filtering improved stove projects is EE households (energy efficiency households); the subcategory within this category is stoves. This category of projects also included projects switching from residential coal
to biomass briquettes since they too had implications for residential BC emission and indoor air pollution.

2. Domestic residential biogas projects: These projects displace the residential use of fossil fuels and fuelwood with community and residential biodigesters with the goals of reducing wood and coal dependence and improving indoor air quality. The category for filtering residential biogas projects is Methane avoidance; the subcategory within this category is domestic manure.

3. Solar cooker projects: The category for filtering improved stove projects is Solar; the subcategory within this category is solar cooking.

The CDM pipeline spreadsheet contained two separate spreadsheets for individual projects and Program of Activities. The above steps were once again carried out for the Program of Activities spreadsheet.
Based on the registry and PDD data, I created an attribute table listing various aspects of each project with the goal of ultimately viewing the data including results of the BC emissions calculation on a spatial scale. These attributes included the project type (i.e. fuel switching, improved stove, biogas, etc.), BC impact (positive, negative, neutral – this attribute was obtained after the BC emissions calculation), scale (residential, industrial), market type (compliance, voluntary), methodology, and distribution by country. My goal was to cross tabulate various attributes and countries in order to determine relevant relationships for policy analysis focusing on regions relevant to BC emissions.

D. BC Calculation and Methodology

Before determining projects BC impact, I examined various literature calculating BC emissions factors and BC emissions inventories. I found that China contained the most data for emissions factors, total BC inventories, and future analyses of trends in BC formation. After examining this data, I hypothesized that although several developing countries with carbon market projects would have their own unique BC footprints, many could potentially have characteristics for BC emissions similar to China’s, where ¼ of the global BC emissions originate and BC emissions are poorly controlled in terms of Western standards (Streets, 2001). The largest contribution to BC emissions in China is the use of raw coal, coal briquettes, and biofuels in the residential sector. Greatly enhancing the emission of fine particles, these fuels are burned in small domestic stoves, cookers, and heaters without any emission controls (Streets, 2001). In 1995, 83% of BC emissions in China were from residential combustion of coal and biofuels. From this figure we can infer that BC emissions reductions from a residential- or domestic-scale carbon market project could potentially have a greater
impact on reducing BC than an industrial-scale project. The majority of BC emissions were distributed across the east-west heartland of China in regions where coal and biofuels are widely used for cooking and heating. It is projected that this number could fall 9% by 2020 despite a 50% increase in energy use, perhaps due to a transition to more advanced technologies (Streets, 2001).

The goal is to assess whether carbon offset projects within the project database are increasing, decreasing, or having no impact on emissions of BC. This is a challenging task since there are many unresolved questions regarding the formation of BC or “soot,” even for the simplest configurations and the purest fuels. It is important to understand that black carbon has a strong positive forcing and most organic carbon and other aerosols have a negative forcing. Therefore the greater the share of black carbon in soot, the higher the warming effect the soot creates. Thus, fossil-fuel soot warms more than solid biomass soot per unit mass since it has a greater fraction of BC (Jacobson, 2007). Biomass soot and fossil fuel soot combined have a strongly positive net global forcing (Flanner et al., 2009), while biomass soot from agricultural burning and forest fires has a net negative global forcing (Hansen et al., 2005; Jacobson, 2004). Furthermore, unlike CO2, but like other trace species such as NOx and CO, emissions of BC are quite dependent on the combustion process.

Although attempting to simplify the process of BC formation is no simple task, one is able to gain a better overall picture by understanding that particles of varied composition result from separate mechanisms and aspects of the combustion process. This causes emissions to vary even among apparently similar technologies. In addition, when trying to understand the relationship between black carbon and other products of incomplete
combustion such as carbon monoxide, it is important to recognize that the source, overall conditions, and control device all contribute. BC forms when not enough oxygen is present for complete oxidation of carbonaceous fuel to CO2.

In assessing the BC impact of the project’s fuel-switch as increasing, decreasing, or neutral, it is necessary to determine both a business-as-usual (BAU) and project fuel switching type and a BAU and project BC emissions factor. I first determined the BAU and project fuel-switching types based on the project’s description or the information in the PDD for each project in the database. The project database had several types of fuel switching and energy efficiency projects at both the industrial and residential scale. I found information on the fuel switching type of the project either in the PDD or in the description of the project in the registry. In the case of CDM, I used the CDM Pipeline spreadsheet along with individual PDDs in determining fuel switching. In most cases, if a project had an unavailable PDD, there was another project with similar parameters with an available PDD. I then grouped the BAU and project fuel switching types into general categories of project type for the sake of reducing the complexity of the database and simplifying the black carbon calculation. After doing so I had all the basic BAU and project fuel types and control devices necessary to perform the calculation.

The estimates for the BC emissions factors came from studies involving estimations of BC inventory such as the one performed in Bond et al. (2004). From these studies the BC emission factor was either already calculated or required a calculation based on a simple formula. The formula is as follows:

\[ EF_{BC} = EF_{PM} \times F_{1.0} \times F_{BC} \times F_{cont} \]
where $E_{BC}$ is the final BC emissions factor. The factors $E_{PM}$, $F_{1.0}$, $F_{BC}$, and $F_{cont}$ if available must be multiplied in order to determine the final BC emissions factor. Here $E_{PM}$ is the first component of the formula and determines the bulk particulate emissions factor in g/kg; once I determined the particulate matter emissions for the fuel source, I separated the fraction of particulate matter with diameters smaller than one micrometer. $F_{1.0}$ is the component used to do so. This component separates smaller particles including BC from larger particles such as ash and char. After I calculated fine particulate matter emissions, I separated the fine particulate matter that is BC. After finding the BC fine particulate matter emissions, I then accounted for BC emissions that escape the control device. To do so, I used the factor $F_{1.0}$. For a process without emissions control, such as open burning of fossil fuel or biomass, the $F_{1.0}$ factor is 1. Bond et al. 2004 compiles data on the factors in the BC emissions equation for a range of fuel combustion technologies, drawing on sources such as the International Energy Agency. I used the values that they reported to calculate BC emissions for the BAU and project technology for each category of projects. Based on all of the components, I obtained BC emissions factors for the project types in the database. I was then able to determine whether projects had a net increase or decrease in BC emissions.

I aggregated emission factors for certain sources when data were unavailable or when that source had the same end-use combustion properties as sources for which data was available. An example of such a sources is biogas. Biogas was aggregated with natural gas since end-use combustion properties were similar (Bond et al., 2004). Certain fuels such as ones with “smokeless” properties were not included in the emissions factors due to lack of information, magnitude, or existence of emissions (Bond et al., 2004). BC emissions factors
must be based on direct measurements for a few different reasons. BC is not predictable from overall balance of fuel and air provided to combustion and is governed by small-scale mixing rather than average composition. Basing estimations of BC emissions and emissions factors on measurements of other gases such as carbon monoxide and methane will be erroneous since any relationships between BC and other emitted gases are source-dependent (Bond et al., 2004).

F. GIS Mapping of Project Locations

The next objective of the project was to geographically map the project locations. This spatial analysis could be useful in determining where greater policy decision-making or marketing may be necessary in developing more projects that use carbon financing to mitigate BC emissions. Unlike CO2 and other GHGs, the greater impact of BC depends on the region where it is emitted. Examples of BC hotspots include those located in the vicinity of Himalayan Glaciers and Arctic Ice. Therefore, viewing the spatial distribution of projects could help determine where such projects could provide fundamental benefits in terms of regional climate change.

Each project’s PDD provides latitude and longitude coordinates of all project locations. Some projects cover only one location such as a manufacturing plant or a ceramic manufacturing center. Other projects cover multiple locations, with PDDs giving up to 50 latitude/longitude coordinates. Some PDDs only provide the name of the city, region, or province where project activities will be implemented rather than lat/long coordinates. When PDDs did not provide latitude/longitude coordinates, I acquired these by mapping project
locations in Google Earth. I then converted all latitude/longitude coordinates to decimal
degrees using a computer program.

I then merged the latitude/longitude spatial data that I had obtained from the PDDs
and Google Earth with the attribute table that I had created based on project registries and
PDDs. Next, I created maps of projects based on specific attributes. The various types of
maps included the following: direction of change in project BC emissions based on individual
locations of the projects (increasing, decreasing, neutral); level of project uncertainty based
on individual locations of the projects (moderate, high); project carbon standards (CDM, VCS,
GS); and distribution of BC projects per country (for this map I used a graduated color scheme
to display the contrast in number of projects by country).
III. RESULTS

A. Fuel-switch Types Represented in the Database

The database contains projects at both the industrial and residential scale. Improved cookstove projects, solar cooker projects, and wood to biogas projects are all included in residential scale projects. The most common types of projects in the database are improved cookstove projects, making up 27% of the database, and wood to biogas projects, making up 22% of the database. Projects switching from fossil fuel to solar, improved cookstove projects, and wood to biogas projects make up the residential portion of projects in the
database. Biogas and natural gas are comparable fuels, so for the sake of the BC impact calculation, biogas was given the same emissions factors for particulate matter, sub-micron particles, and black carbon emissions. Combustion of biogas and natural gas lead to negligible BC emissions. It is thus certain that projects switching from wood to biogas have a definite decrease in BC emissions. It is also certain that projects switching from fossil fuels to solar cookers decrease BC emissions from the BAU scenario, since solar cookers avoid GHG emissions all together. Improved cookstoves in theory improve combustion efficiency and decrease BC emissions. Whether this reduction in BC actually occurs is a separate question altogether and is discussed in a following section involving uncertainty.

There are also a broad variety of industrial scale projects in the catalogue. A common type of industrial-scale project switches from non-renewable to renewable biomass. Emissions reductions in these projects are achieved through the displacement of wood from areas without sustainable forest management to provide thermal energy from wood originating from areas with sustainable forest management (Menegalli, 2010). Projects employing renewable biomass also avoid GHG emissions by utilizing biomass that would have otherwise produced methane emissions through its disposal in landfills (EcoSecurities, 2005). These projects have neutral BC emissions since they are not switching control devices or fuel type. Rather, they are switching from wood extracted from natural forest biomes in Brazil to renewable biomass such as sawdust, sawmill waste, forest residues, etc. Another large variety of projects switch single fossil fuels such as coal, diesel, and fuel oil to renewable biomass. Projects switching from industrial coal encompass a wide range of technologies
including those with notable distinctions as stokers, those using coal beds, and other
technologies containing coal tar suitable to the formation of BC (Bond et al., 2004).

Other project types present are those switching from multiple fossil fuel sources at a
time to renewable biomass and those projects switching from consumption of power
originating from the regional or national grid to power consumption resulting from project
activities (renewable biomass in most cases). In China’s case and several other developing
countries, particulate emissions and BC levels from power generation are low since fossil-
fueled plants for power and electricity generation are equipped with technologies that inhibit
the emission of BC, and conditions tend to burn out any BC formed. All new power plants and
several large, old power plants use technologies to collect particulate matter (Streets, 2001).

Overall, industrial scale projects in the database have a wide variety of fuels,
combustors, and control devices in use, making it difficult to determine the direction of BC
change. However, because of the greater attention to the combustion process and emission
control, these facilities tend to have lower emissions than residential- or domestic-scale
projects as in the case of China (Streets, 2001).

B. Projects by Carbon Standard

![Projects by Label](image)

**Figure 9 - Distribution of projects by standard**
The VCS has a total of 685 registered projects (The VCS, 2011) out of which 39 were selected for the database; database projects therefore make up 5.69% of all VCS projects. The Gold Standard has a total of 319 projects in its VER registry and 189 in its CER registry (Gold Standard Registry, 2011), 52 of which are included in the database; database projects therefore make up 16.30% of all registered GS projects. The CDM has approximately 6,034 projects that were either registered or at validation (this number includes Program of Activities); database projects therefore make up 3.04% of CDM project that are either registered or at validation. After calculating the change in BC emissions, 87% of CDM projects in the database had decreasing BC emissions and 13% had increasing BC emissions. Also due to the high proportion of CDM projects in the database, CDM projects made up 75% of all projects in the database that had decreasing black carbon emissions and 73% of all projects with increasing BC emissions. 98% percent of GS projects saw decreasing BC emissions whereas only 2% of GS projects saw increases in BC emissions. 24% of projects decreasing BC emissions were GS projects, whereas 3% of database projects increasing BC emissions were GS. VCS projects mainly consisted of projects with neutral BC emissions and also those projects increasing BC emissions. 21% of VCS projects increased BC emissions whereas 77% were neutral, as VCS projects mainly consisted of projects switching from non-renewable to renewable biomass. 100% of neutral projects in the database were on the VCS standard.

<table>
<thead>
<tr>
<th></th>
<th>Decrease</th>
<th>Increase</th>
<th>Neutral</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDM</td>
<td>160</td>
<td>24</td>
<td>0</td>
<td>184</td>
</tr>
<tr>
<td>GS</td>
<td>51</td>
<td>1</td>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>VCS</td>
<td>1</td>
<td>8</td>
<td>30</td>
<td>39</td>
</tr>
<tr>
<td>Total</td>
<td>212</td>
<td>33</td>
<td>30</td>
<td>275</td>
</tr>
</tbody>
</table>

Table 5 - Distribution of project by standard cross tabulated by BC impact
There is currently only one project under the VCS standard that potentially mitigates BC emissions; there is also a high level of uncertainty associated with that project (improved cookstoves). The VCS also does not currently hold requirements for environmental or social benefits from project activities. Next we consider projects under the CDM. The rules governing the CDM for allowable GHG reduction mechanisms and permitted GHGs are well defined under the Kyoto Protocol and will only change if the successor of Kyoto has a provision for BC mitigation; although current operations of the CDM are fully functional, there is more uncertainty with CDM compared to the GS or VCS due largely to the fact that the Kyoto Protocol ends in 2012. Things could turn in the favor of BC mitigation through the CDM.
if the Kyoto Protocol spurs a successor that includes provisions for BC mitigation. Although a level of uncertainty persists, nearly all database projects under the GS mitigate or decrease BC emissions. In addition as mentioned earlier, BC mitigation has relevant implications for sustainable development through human health and poverty alleviation. Furthermore, the inclusion of warming agents such as BC in accounting for GHG emissions reductions seems more feasible as GS projects are not driven by a global agreement such as Kyoto. Given these factors, it could potentially be more feasible for the GS to consider BC mitigation projects than the VCS or CDM.

C. BC calculation

The following table displays the results of the BC calculation. If the $\Delta \text{EF}_{BC}$ is negative, the BAU BC is greater than the project BC and BC emissions for the fuel-switch type are decreasing. If the $\Delta \text{EF}_{BC}$ is positive, the BAU BC is less than the project BC and the BC emissions are therefore increasing. The case of native wood to renewable biomass is one where neither the combustion process nor the fuel type has changed, thereby yielding a $\Delta \text{EF}_{BC}$ of 0. Projects switching from the energy grid to renewable biomass and improved cookstove projects have high uncertainty based on the rationale from the Uncertainty section. Based on the calculation, 77% of the projects in the database are decreasing in BC, 12% are increasing, and 11% have neutral BC emissions.
Table 6 - Black carbon impact calculation - BAU EFBC is subtracted from Project EFBC to yield ΔEFBC

<table>
<thead>
<tr>
<th>Project Fuel-switch Type</th>
<th>BAU EFBC</th>
<th>Project EFBC</th>
<th>ΔEFBC</th>
<th>ΔBC</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal to biomass</td>
<td>0.9796</td>
<td>0.0662</td>
<td>-0.913</td>
<td>Decrease</td>
<td>Low</td>
</tr>
<tr>
<td>Diesel to biomass</td>
<td>0.7750</td>
<td>0.0662</td>
<td>-0.709</td>
<td>Decrease</td>
<td>Low</td>
</tr>
<tr>
<td>Fossil fuel to solar</td>
<td>0.7501</td>
<td>0.0000</td>
<td>-0.750</td>
<td>Decrease</td>
<td>Low</td>
</tr>
<tr>
<td>Grid to biomass</td>
<td>0.2621</td>
<td>0.0662</td>
<td>-0.196</td>
<td>Decrease</td>
<td>High</td>
</tr>
<tr>
<td>Improved cookstoves</td>
<td>0.7020</td>
<td>0.4140</td>
<td>-0.288</td>
<td>Decrease</td>
<td>High</td>
</tr>
<tr>
<td>Native wood to renewable biomass</td>
<td>0.0662</td>
<td>0.0662</td>
<td>0.000</td>
<td>Neutral</td>
<td>Low</td>
</tr>
<tr>
<td>Natural gas to renewable biomass</td>
<td>0.0001</td>
<td>0.0662</td>
<td>0.066</td>
<td>Increase</td>
<td>Low</td>
</tr>
<tr>
<td>Oil to renewable biomass</td>
<td>0.0012</td>
<td>0.0662</td>
<td>0.065</td>
<td>Increase</td>
<td>Low</td>
</tr>
<tr>
<td>Wood to biogas</td>
<td>0.7020</td>
<td>0.0001</td>
<td>-0.702</td>
<td>Decrease</td>
<td>Low</td>
</tr>
</tbody>
</table>

Figure 11 - Distribution of projects by BC impact
D. Countries Represented in the Database

Making up 22.18% of the project database, China has the highest percentage of projects followed by Brazil at 22.00% and India at 11.27%. In China residential projects switching from wood to biogas make up 47% of the projects; improved cookstove projects that are also residential level are second, with 21% of China’s projects. In Brazil the majority of projects are those switching from native wood to renewable biomass (54%) followed by those switching from oil to renewable biomass (20%). In India almost half of the projects are those switching from wood to biogas (48%) followed by a large chunk making up those switching from the power grid to energy generated from renewable biomass (16%). Improved
Cookstove projects are close behind, making up 13% of projects. The combustion of biogas has the same properties as the combustion of natural gas, therefore leading to very low BC emissions.

Figure 13 - Spatial distribution of projects by country
Although Brazil has 20% of the projects in the database, projects in India and China are more likely than those in Brazil to benefit from carbon standards adding value for BC mitigation due to the fact that projects switching from native forests to renewable biomass lead to a neutral BC impact. Since approximately half of India’s and China’s projects are switching from wood to biogas and a number of China’s projects are switching from fossil fuel to solar powered cookers, both India and China would benefit the most from a market for BC emissions.

Table 7 - Distribution of projects by country

<table>
<thead>
<tr>
<th>Country</th>
<th># Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>55</td>
</tr>
<tr>
<td>Chile</td>
<td>9</td>
</tr>
<tr>
<td>China</td>
<td>61</td>
</tr>
<tr>
<td>India</td>
<td>31</td>
</tr>
<tr>
<td>Kenya</td>
<td>13</td>
</tr>
<tr>
<td>Nepal</td>
<td>8</td>
</tr>
<tr>
<td>South Africa</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>89</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>275</strong></td>
</tr>
</tbody>
</table>
E. Uncertainty in accurate characterization of projects

In calculating emissions factors, authors including Bond et al. attempted to strike a balance between accuracy and the feasibility of representing existing inconsistencies. The emission factors often contain high uncertainty but represent best estimates based on reviewing the literature on combustion processes. Several different factors affect uncertainty in the calculation of emissions factors including speciation of particulate matter from small sources and measuring BC and OC fractions and the prevalence of different technologies (Bond et al., 2004). These uncertainties in characterizing projects as reducing BC emissions are present in both the residential and industrial sector.

i. Uncertainties with Improved Cookstove Projects and the Residential Sector

In the residential sector, BC emission factors for project types have varying levels of uncertainty. Improved cookstove projects have the highest level followed by wood to biogas projects and fossil fuel to solar projects. BC emissions from the combustion of residential biofuels have a strong dependence on combustion conditions such as the fuel type, moisture content, stove temperature, and burning rate (Streets, 2001). Improved cookstove projects in general have inconsistent results in reducing BC emissions. The results largely depend on the nature of improvements including the combustion characteristics of the improved stove. Some studies have shown that improved stoves have higher particulate matter emissions than traditional stoves (Zhang et. al., 2000), whereas others have shown the opposite (Venkataraman and Rao). Each project in each region contains improved stoves with unique characteristics. Also, emissions factors could be strongly affected by differences between field
and laboratory procedures since laboratory experiments strive for uniformity and consistency. However, lab conditions fail to reflect everyday field conditions as they do not reflect the variations in biofuels and cooking practices employed (Roden et al., 2006). Furthermore, it is also difficult to measure biofuel and cooking practice variation in remote areas where the lack of power restricts the ability to measure BC (Roden et al., 2006). Variables that control emissions factors and environmentally relevant factors such as EC/PM ratio need to be identified or quantified by region (Roden et. al, 2006).

Sufficient research has also not been conducted on BC emission from improved cookstoves as compared to traditional stoves. In one particular study conducted on 14 different stoves, 13 were traditional stoves and 1 was improved. The study involved laboratory trials where all of the stoves were given uniform combustion conditions including temperature, pressure, and relative humidity. In the study, the mass emission factor was the total factor in g/kg of particulate matter emissions. The experiment also measured emissions factors for BC, organic carbon, and CO2. No correlation was found between mass emissions and BC emissions (R2=0.0013), although the correlation between mass emissions and organic carbon was quite high (R2=0.934). There was also no correlation between CO2 emissions and BC emissions for an improved or traditional stove. The study therefore supported a key reason for which measurement of BC emissions is a complex area (Roden et al., 2006) since BC emissions cannot be estimated based on complementary CO2 emissions. CO2 emissions for the improved stove were well below the average, yet the improved stove displayed higher than average BC emissions (Streets, 2001). For these reasons, improved cookstove projects have a high degree of uncertainty.
ii. Uncertainties with the Industrial Sector

Predicting industrial BC emissions also involves a degree of uncertainty, which is particularly high for coal combustion where larger particles, organic compounds, and ash can have a negative effect on measurements (Streets, 2001). In almost all non-residential coal combustion facilities of significant size, particulate control devices are employed to prevent unacceptable smoke problems (Streets, 2001). Furthermore, statistical data on the distribution and performance of different kinds of industrial combustors are lacking, inhibiting the ability to confidently predict industrial BC emissions in the process (Streets, 2001). The uncertainty increases further when attempting to apply BC emissions characteristics to carbon market projects. Through project design documents, one is not able to identify exact and specific technologies used in various projects, and averages of BC emissions factors encompassing a broad range of combustion technologies are used in the comparison.

11% of the projects in the database switch from energy derived from the power grid to renewable biomass. Energy from the power grid originates from multiple sources including power plants fueled with a range of fossil fuels including coal, fuel oil, natural gas, LPG, and diesel. Grids across the world, developing countries included, have also begun to generate power by other means such as renewable energy and hydropower. For projects switching from grid-based energy, it was unclear what proportions of various fossil fuels and renewable energy sources produced energy from the power grid; therefore, application of emissions factors to this project would be impractical and inaccurate. For the sake of the BC emissions calculation, it was assumed that all projects using grid-based energy in their BAU scenario were using an equal proportion of all fossil fuels. This is likely to bias results for countries such
as Brazil, where nearly 45% of energy needs come from non-BC emitting renewable sources as of 2010 (Yapp, 2011). For this particular reason, a high level of uncertainty is associated with the application of emissions factors to projects switching from the power grid to renewable biomass.

Figure 15 - Spatial distribution of projects by uncertainty level
IV. CONCLUSION

As the level of development progresses, current practices and technologies emitting high levels of BC are being replaced with cleaner technologies with lower emission factors. Although reductions in emissions are partially offset by an increase in energy consumption due to a rising population and rising demand, the net effect is an overall decrease in emissions, especially those from fossil fuels (Bond et al., 2004). It has been observed that BC emissions can occur from various sectors and combustion types and at many scales. Nevertheless, it is clear that the combustion of coal and biofuels in domestic stoves, cookers, and heaters is responsible for a far greater share of BC emissions than the industrial sector (Streets, 2001), as 24% of global BC emissions originate from the residential sector, compared to 10% from industry. As households in developing countries move up the energy ladder, they will progressively emit less BC, as they will switch from their reliance on fuelwood and raw coal to energy sources such as electricity, LPG, natural gas, or other renewable energy sources. It would therefore be wise to accelerate the replacement of these polluting energy sources with renewable energy sources including solar, wind, biogas, and small-head hydro (Bond et al., 2004). However, it is not always possible to make an immediate transition for reasons such as low household incomes or the lack of social or government infrastructure. Thus, before it is possible to transition to cleaner fuels or technologies, individual and social practices along with government policies should target temporary solutions including improved cookstoves, biogas, and solar cookers to improve efficiency and cleaner combustion with the goal of preserving human and environmental health.
A. International BC Mitigation Efforts

A topic worth considering is the current international view and status of BC mitigation and the roles various countries are taking in reducing national emissions of BC. The importance of benefits resulting from BC mitigation must be considered by developed countries as well as developing countries in order to help limit global temperature rise in the near future and increase the chances of keeping temperature rise below two degrees Celsius in order to avoid extreme events. It is also important to realize that in limiting temperature increases below two degrees Celsius in the long run, immediate and sustained action to limit long-term climate change agents such as CO2 are also necessary while simultaneously attempting to limit short-term climate forcers. Studies such as Hansen et al.’s (2000) note that raising the profile of BC in the climate change debate could draw countries such as China and India closer to joining a global commitment to the reduction of greenhouse-gas emissions because they would simultaneously accrue significant local and regional air-quality benefits (Hansen et al., 2005).

While the carbon market could help scale up national or international programs such as the Indian National Cookstove Initiative or the Global Alliance for Clean Cookstoves, robust national or international policy responses are necessary if we are to see a noticeable reduction in global BC emissions. The Global Alliance for Clean Cookstoves is an international initiative through the public and private sector to mobilize $250 million specifically to reduce BC emissions and improve human health (Global Alliance, 2011). The UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone suggests that action could be catalyzed through not only the UN climate convention process but also, for example, via strengthening
existing national and regional air quality agreements (Press Release, 2011). Although it has become clear in recent years that several pollutants such as BC are contributing to global climate change, more global focus is still given to the mitigation of CO2. The Government of Sweden recently announced support for a comprehensive policy assessment coordinated by the UNEP to aid governments in taking fast action on short-lived climate forcers (Press Release, 2011). The Obama administration has also shown interest in exploring alternative methods of slowing Arctic warming that do not require United Nations-brokered treaties or complex cap-and-trade scenarios since current efforts to mitigate GHG emissions have stalled in Congress. Instead of an international treaty, Arctic Council nations such as Sweden also have been encouraged to adopt measures unilaterally to control BC emissions (Warrick & Eilperin, 2011). India and China, on the other hand, have a shared regional concern to avoid a rapid melting of the Himalayan glaciers and can focus specifically on the biomass burning activities that emit most of the region-relevant BC (Garderet, 2009).

B. BC and Carbon Markets

Carbon finance could be yet another mechanism among many to mitigate global BC emissions. The projects analyzed in this database exist among several other categories of projects with implications for BC emissions. For example, there are hundreds of renewable energy carbon market projects including wind power, hydropower, and landfill methane projects that displace BC-emitting fossils such as coal; however, these projects were not considered. As observed in the database, the CDM has both the highest number of projects overall and also the highest number of projects that have an impact on BC emissions. As the Kyoto Protocol ends in 2012, one cannot help but question the future status of the Clean
Development Mechanism. Since the commitment period of the Kyoto Protocol spans from January 1, 2008 to December 31, 2012, the CDM is associated with the period up until 2012. However, all aspects of the CDM including the registration process, certified emission reduction (CER) issuance and methodology approval are independent of set commitment periods, although emission reduction targets between countries are negotiated on a period-by-period basis. This implies that though there could be new negotiations for industrialized countries to continue reducing their GHG emissions beyond 2012 (the year the current commitment period ends), CDM projects and their life cycles would not be dependent upon the span or functioning of the newly set commitment period. Certain ad-hoc working groups are currently negotiating for sustained implementation of the UNFCCC. CDM could potentially continue through a second commitment period through the Kyoto Protocol. It is likely that due to the widespread participation in CDM, ongoing activities and the issuance of CERs are likely to continue or be transferred to a different instrument (CDM, 2011).

Although the CDM considers CO2 equivalents of six different GHGs for carbon credits, current methodologies for BC reduction mechanism such as improved cookstoves only credit reductions in CO2 (Blunck, 2010). In order to truly incorporate a GHG into a global multi-gas mitigation treaty, the overall residence of a GHG in the atmosphere is a factor to consider; as different GHGs have varied atmospheric lifetimes, global agreements consider the global warming potential (GWP) of a GHG. The GWP’s applicability to short-lived climate forcers such as BC complicate this process as GWP considers all gases on a 100-year scale. This measure proves difficult for BC, which is only in the atmosphere for one to two weeks. As a unit of BC with a global radiative forcing is a million times greater than CO2, the GWP for BC
has been calculated as 680 (Bond & Sun, 2005). GWP is also not favorable for BC because it gives equal weight to emissions without considering an emissions reductions target or the proximity to a target. The overall effects of short-lived species such as BC are not fully accounted for through this process since in the case of BC the same mass emissions from different locations can have markedly different climate effects. The GWP also gives equal weight to the entire life of a short-lived pollutant’s ability to warm the atmosphere. GWP fails to consider the fact that different GHGs will have varied atmospheric warming properties as time progresses since it does not consider an overall long-term target.

A carbon standard could incorporate BC in its GHG portfolio by using CO2 equivalents of BC through its current structure or through BC mitigation co-benefits such human health and poverty alleviation. These options could potentially be feasible to carbon credit standards on the voluntary carbon market. Unlike the CDM, GS and VCS place no limits on overall project scales of improved cookstove projects and also allow methodologies to count methane, sulfur, and nitrogen, leading to more GHG offset credits. The fact that GS VER projects or VCS projects are not governed by a global GHG mitigation agreement could make the inclusion of the global or regional climate benefits of BC through proposed methodologies more likely than through the compliance market. The Gold Standard or VCS could therefore factor CO2 equivalents for BC mitigation into the project’s overall carbon credits from GHG mitigation. Another approach of bringing BC into the mix is through its co-benefits; the GS currently requires a sustainability assessment of project co-benefits. For improved cookstove, biogas, and solar cooker projects, GS currently considers co-benefits such as improved indoor air quality and poverty alleviation in project sustainability assessment. The VCS does not
currently focus on environmental and social benefits but does allow co-benefits for factors including community and biodiversity to be added to attributes of VCUs, thereby enabling community, biodiversity and other benefits to be added to the attributes of VCUs. For example, several REDD projects under current development are being certified by the Climate Community and Biodiversity Standard (CORE, 2011). Several projects in the VCS Project Database have also been certified under the Social Carbon Standard, a carbon standard published in 2008 by the Ecologica Institute in Brazil, which establishes criteria for monitoring the social gains of projects (Carbon Offset Standards, 2011).

How then would the inclusion of BC offsets or co-benefits in voluntary or compliance markets affect current projects and the portfolio of new projects in those markets? As BC is increasingly discussed at the international and regulatory levels, we are likely to see higher demand for certified BC projects and proposals for projects that supply such credits (Garderet, 2009). If a successful BC mitigation scheme were to be implemented, several projects with potential BC mitigation implications would attempt to take advantage of the fact that they could gain value through their ability to mitigate BC. Whether the GWP or other measures are ultimately used, the methodology used to incorporate BC emissions should consider the time horizon and variation in regional impacts for BC (Garderet, 2009). Considering regional impacts of BC mitigation projects such as proximity to BC hot spots or proximity to areas with critical tipping points such as the Himalayan Glaciers or Polar Ice could potentially make those particular projects far more valuable than other locations.

One way to incorporate BC mitigation into the carbon market would be to sum the impact of a project’s BC impact with the impact of other GHGs. Summing credits for other
GHGs and BC could have varied impacts on the financial value of carbon market projects. Projects decreasing BC emissions would add value to the projects, which would therefore lead to an increase in credits from those projects. On the other hand, projects increasing BC emissions would reduce in value, therefore leading to a decrease of credits. Doing so could potentially attract projects to be included in the carbon market, however could deter other projects from inclusion. If the inclusion of BC mitigation had already been in the mix, the current portfolio of projects in the carbon market could also be markedly different with the inclusion of projects that would not have otherwise made it and the exclusion of certain projects that are currently registered or receiving credits. Instead of summing credits, another possible outcomes could involve the differentiation of carbon credits that also reduce BC in addition to other GHGs, which could potentially lead to the inclusion of a tiered system of carbon credits for different “qualities” of credits. In this scenario, projects mitigating BC could sell for a higher premium than other projects.

Either approach would require funds and capabilities for robust monitoring, reporting, and verification (MRV) of BC emissions for each project. In the case of residential-level projects such as improved cookstove projects with BC mitigation uncertainties, a reliable certification scheme for varying types of cookstoves disseminated through projects would be necessary. A greater requirement or emphasis on MRV or certification could potentially increase costs associated with effective BC mitigation, however BC mitigation’s ability to attain co-benefits such as human health should not be overlooked for its ability to add value and make the BC mitigation more cost effective.
V. REFERENCES


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