Climate Credit Pilot Project (C2P2):

Surya Methodology for Deriving Climate Credits for improved solid biofuel cookstoves

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Technical Summary

Project Surya (www.projectsurya.org) is initiating a major pilot project to explore if rewarding women directly with funds from carbon markets for using improved stoves and solar lighting will significantly enhance women’s ability to sustain adoption of these energy efficient technologies. The secondary goal of the project is to establish a stable carbon market-based revenue source by developing a methodology that awards climate credits for reductions in non-carbon dioxide climate pollutants (including black carbon), in addition to reductions in carbon dioxide, for the use of improved cookstoves. By accounting for reductions in non-CO\textsubscript{2} climate pollutants, along with reductions in CO\textsubscript{2}, each household can triple the financial returns generated from a carbon market, thereby creating sufficient revenue to sustainably scale up this model.

This ambitious initiative, called the Climate Credit Pilot Project, or C2P2, will be launched on 1st April, 2014 in India. The core institutions of Project Surya are the University of California at San Diego, The Energy and Resources Institute (TERI) at New Delhi, and Nexleaf Analytics at Los Angeles, with over a dozen collaborating institutions around the world.

When completed, C2P2 will have established a new protocol for awarding climate credits for advanced cookstoves that use solid biofuels. It will have also established a revolutionary way, through the use of cell phone monitoring of compliance, to reward women in villages directly for mitigating emissions of CO\textsubscript{2} and other climate warming pollutants. For the first time we have integrated all of the available simulated data on climate forcing of black carbon, organic carbon and ozone with field data collected by Surya and estimated the climate credit for non-CO\textsubscript{2} climate pollutants. The estimates from this integrated attempt are summarized below:

- **The Surya Forced Draft stove manufactured in India,** will annually mitigate 1.8 tonnes of CO\textsubscript{2} from avoided deforestation and 3.5 (1.5 to 5.9) tonnes of equivalent CO\textsubscript{2} (also referred to as CO\textsubscript{2} equivalent, or CO\textsubscript{2e}, in this document), due to mitigated emissions of black carbon, organic carbon, ozone precursor gases. The estimate is based on a 40-year timeframe for translating the impact of black carbon into CO\textsubscript{2} equivalents.

- **C2P2 use the mean value of 3.5 tonnes of CO\textsubscript{2e} due to mitigated emissions of black carbon, organic carbon, ozone precursor gases. Therefore each woman can potentially generate 5.3 tonnes of CO\textsubscript{2e} in climate credits each year if she uses the Surya Forced Draft Stove for all her cooking needs.**

- **C2P2 will deploy up to 5000 stoves, and will adopt $6/tonne of CO\textsubscript{2e} for each climate credit. Each woman will therefore generate climate credits valued at up to $32 a year.**

- **Assuming a life time of 5 years, the 5000 stoves will save about 150 lives. The valuation of each stove based on the lives saved is $1300.**

- **In addition, the co-benefits to mitigation of global warming will amount to an average of 133,000 tonnes of CO\textsubscript{2e} for the 5 year life time of each stove. At an estimated value of $6/tonne of CO\textsubscript{2e} each woman participating in C2P2 will earn, during the 5 year life time, $99 to $231, thus contributing to the sustainability of her family and that of the planet.**
Traditional mud stove (left) and improved cookstove with sensor (right).
Background and C2P2 Strategy:

Reducing harmful emissions from traditional solid biofuel (firewood, dung and crop residues) cookstoves is at the forefront of global efforts to improve the lives of roughly 3 billion worldwide who depend on biofuels for their basic needs. Surya, through its field work – deploying advanced stoves and advanced soot monitoring systems (Ramanathan et al., 2011), has published several peer reviewed papers that document the extent of the pollution from the stoves, their impacts on indoor human exposure and ambient levels of soot (also known as black carbon), and the cooking technology that can drastically reduce black carbon emissions (Rehman et al., 2011; Praveen et al., 2011; Kar et al., 2012). This technology is the forced draft solid bio-fuel (FD_SB) stoves. Alternatives to FD_SB stoves include gas stoves and electric induction cookstoves, which are amongst the cleanest technologies. However, their fuel costs are prohibitive and there is no reliable supply and supply chain to deliver the required energy. FD_SB stoves are likely the best option until a more cost-effective and feasible solution becomes available for large-scale adoption. FD_SB stoves are relatively cheaper but still unaffordable for a majority of the underserved, at a cost of approximately $80 (USD) (which includes the cost of delivery).

Surya is working very aggressively and actively on scale-up strategies. One such strategy is to develop practical and sustainable methods for providing carbon credits for mitigation of CO₂ emissions and emissions of other global and regional warming pollutants, black carbon and ozone precursors. Accordingly, it has launched C2P2 to develop the methodology that combines the best available science with innovative technologies developed by Surya and deploys them in the field. In parallel it is teaming up with social scientists to understand the market potential of advanced cookstoves and ways to adapt them better to local needs and wants. The first attempt at this market-based research can be seen in the Surya publication “How do people in rural India perceive improved stoves and clean fuel? Evidence from Uttar Pradesh and Uttarakhand”, published in International Journal of Environmental and Public health (Bhojvaid et al., 2014).

The implementation activities for the pilot phase have already begun (February 2014) and will run for 24 months. C2P2’s metrics for success are the following:

- The demonstrated ability to autonomously monitor stove usage by women in villages (about 5000 homes) and send them monetary credits directly through a rural bank for mitigating emissions of global warming pollutants.
- Development of a methodology that can be adopted by a leading carbon market entity, and registration of Surya to receive climate credits in order to potentially scale up to millions of homes.

The Surya Climate Credit methodology is being developed by integrating available knowledge from peer reviewed publications with data collected by the Surya team on air pollution levels, compliance on the use of clean technologies, and types and amount of fuel consumed. Our starting point is the most recent IPCC-AR5 (2013) report.

There are three key components to the development of climate credits, addressed by the Surya methodology, and briefly summarized here.

First, the methodology accounts for the inclusion of short lived climate pollutants (including cooling agents). In addition to CO₂, burning of firewood leads to emissions of:

a. Black carbon, brown carbon and other organic aerosols
b. Ozone precursors such as CO, non-Methane volatile organics (VOCs)
c. Methane

All of the above, except ‘other organic aerosols’, lead to net warming.
The Surya Climate Credit methodology explicitly accounts for the cooling effect of organic aerosols.

Black carbon, brown carbon, ozone precursors and methane are referred to as Short Lived Climate Pollutants (SLCPs). There are two independent avenues for getting climate credits directly to the users of improved biofuel stoves:
1. The first is the traditional approach of getting credits for mitigating CO$_2$ emissions through reductions in the consumption of firewood, and by using renewable fuels instead of fossil fuels.
2. The second avenue involves mitigation of SLCPs.

We describe the scientific basis as well as the procedures adopted by C2P2 for estimating climate credits for following both avenues: CO$_2$ mitigation and SLCPs mitigation. As far as possible we adopt region (Indo-Gangetic) specific values using data collected by the Surya team. However, in translating our data in terms of global warming potentials for SLCPs, we adopt as much as possible the data published in IPCC-AR5 working group report (Chapters 7 and 8) as well as other recent international reports published in 2013. Towards the end of this report, we also summarize sustainability co-benefits from the use of improved stoves through: i) reduction of air-pollution related mortalities; ii) improvement in agriculture yields; iii) reduction in Himalayan glaciers melting.

The second component is the time horizon that is used for translating the impact of SLCPs into CO$_2$ equivalents. IPCC started in the 1990s with a time horizon of 100 yrs. IPCC-AR5 now uses a variety of time scales ranging from 20 Yrs to 100 Yrs. Several recent studies (e.g., Meinhausen et al., 2009; Ramanathan and Xu, 2010; UNEP-WMO 2011; IPCC-AR5, 2013) have shown that if current growth rates of greenhouse gases continue unabated, the warming (from pre-industrial times) can exceed 2°C by mid-century. A primary advantage of SLCPs is that they can significantly mitigate near-term warming, making it possible to avoid the 2°C. Based on such considerations, we choose a time scale of 40 Yrs.

The third component is the duration that women receive climate credits: Should women receive climate credits for several years or for the full 40 years (i.e. the time horizon used for evaluating the impact)? This question cannot be definitively answered, and will depend on when the women, without the intervention, would have switched to cleaner cooking technologies. In C2P2, women will be rewarded with climate credits for up to the two year duration of the pilot. Our recommendation is for allowing the users to claim credits until they recover the cost of the stove.

In order to scale up, Surya will be registered in the voluntary carbon market.
1. Estimating Climate Credits for direct CO₂ reduction

C2P2’s estimate for direct CO₂ emission reduction (as opposed to reduction of SLCPs) is based on the reduction of woody biomass (non-renewable biomass), reproduces the methodology/protocol laid down by the Clean Development Mechanism publication: *AMS-II.G Small Scale Methodology Energy efficiency measures in thermal applications of non-renewable biomass Version 6.0*, published on 21 February 2014 (AMS-II, 2014)

It is assumed that in the absence of the project activity, the baseline scenario would be the projected use of fossil fuels to meet similar thermal energy needs as those provided by the project devices.

Emission reductions are calculated as:

\[ ER_y = \sum_i ER_{y,i} \]

Where:
- \( i \) = indices for the situation where more than one type of project device is introduced to replace the pre-project devices. In case of C2P2 just one project device FD_SB is used to replace the pre-project device, hence ‘\( i = 1 \)’.
- \( ER_y \) = Emission reductions during year \( y \) in t CO₂e
- \( ER_{y,i} \) = Emission reductions by project device of type \( i \) during year \( y \) in t CO₂e.

For household cook stoves

\[ ER_y = \sum_{a=1}^{a=y} B_{y,\text{saving},i,a} \times N_{y,i,a} \times \frac{\mu_y}{365} \times f_{\text{NRB},y} \times N_{\text{CV},\text{biomass}} \times EF_{\text{projected fossil fuel}} - LE_y \]

- Equation (1)

Where,
- \( a \) = ‘\( a \)’ is the indices for the age (in years) of the cook stoves that are operating in the year ‘\( y \)’ of the crediting period. At any year ‘\( y \)’ of the crediting period (e.g. \( y = 1,2,3,...,7 \) or \( 10 \)) there will be a population of \( N_{y,i,a} \) operational devices of type ‘\( i \)’ with age varying from \( a=1 \) (the cook stove installed during the current year \( y \)) up to the age \( a=y \) (the cook stove installed during the first year of the crediting period). However, in case of C2P2, the length of the crediting period is two years, and the lifetime of the cook stove is assumed to be five years (much longer as compared to the crediting period) with no efficiency losses over the crediting period. As a result, all cook stoves deployed (forced draft stoves made of stainless steel) under the project may be considered equivalent with no significant adjustments required for the monitoring plan.
- \( B_{y,\text{saving},i,a} \) = Quantity of woody biomass that is saved in tonnes per cook stove device of type \( i \) and age \( a \) in year \( y \). However, in case of C2P2, all cook stoves deployed are of one particular type (FD_SB) with no significant difference in efficiencies. As a result, in the current context, the variable
By savings,i,a may be replaced by ‘By,savings’.

\[ f_{\text{NRB}},y = \text{Fraction of woody biomass saved by the project activity in year } y \text{ that can be established as non-renewable biomass using survey methods or government data or default country specific fraction of non-renewable woody biomass (f_{\text{NRB}}) values available on the CDM website. In the current context government data is being used.} \]

\[ \text{NCV}_{\text{biomass}} = \text{Net calorific value of the non-renewable woody biomass that is substituted [joules/kg of fuel burned]} \]

\[ \text{EF}_{\text{projected fossil fuel}} = \text{Emission factor for the fossil fuels projected to be used for substitution of non-renewable woody biomass by similar consumers. Use a value of 81.6 t CO}_2/\text{TJ}^1 \]

\[ N_{y,i,a} = \text{Number of project devices of type } i \text{ and age } a \text{ operating in year } y. \]

However, in case of C2P2, there is just one type of improved cook stove (FD_SB) with no significant difference in efficiencies arising due to age. Hence, the variable \( N_{y,i,a} \) may be replaced by \( N_y \) defined as ‘number of project devices operating in year ‘y’.

\[ \mu_{y,i} = \text{Number of days of utilization of the project device during the year ‘y’. Its value has been considered as 350} \]

\[ \text{LE}_y = \text{Leakage emissions in the year } y. \text{ However, as per section 4.3 of AMS-II, leakage related to the non-renewable woody biomass saved by the project activity has been adjusted by multiplying } B_{y,savings,i,a} (B_{y,savings} in this case) \text{ by a net to gross adjustment factor of 0.95, in which case ex post surveys, of users and the areas from which this woody biomass is sourced, is not required. As a result this variable (LE_y) is not required, and may be removed from the equation for calculating ER_y.} \]

Based on the aforementioned changes, the equation for calculation of emission reductions is:

\[ \text{ER}_y = B_{y,savings} \times N_y \times \frac{\mu_y}{365} \times f_{\text{NRB},y} \times \text{NCV}_{\text{biomass}} \times \text{EF}_{\text{projected fossil fuel}} \]

- Equation (2)

**Step 1: Reduction in fuel wood consumption (By,savings)**

\( B_{y,savings} \) for cook stoves is estimated using Option 2 defined on paragraph 17 of AMS-II.G version 6.0. The equation is:

\[ B_{y,savings,i,a} = B_{old,i} \times \left(1 - \frac{\eta_{old}}{\eta_{new,i,a-1} \times \eta_{y,i,a}} \right) \]

- Equation (3)

Where,

\[ ^1 \text{This value represents the emission factor of the substitution fuels likely to be used by similar users, on a weighted average basis. It is assumed that the mix of present and future fuels used would consist of a solid fossil fuel (lowest in the ladder of fuel choices), a liquid fossil fuel (represents a progression over solid fuel in the ladder of fuel use choices) and a gaseous fuel (represents a progression over liquid fuel in the ladder of fuel use choices). Thus a 50 per cent weight is assigned to coal as the alternative solid fossil fuel (96 t CO}_2/\text{TJ) and a 25 per cent weight is assigned to both liquid and gaseous fuels (71.5 t CO}_2/\text{TJ for kerosene and 63.0 t CO}_2/\text{TJ for liquefied petroleum gas (LPG).} \]
Quantity of woody biomass that is saved in tonnes per cook stove device of type \( i \) and age \( a \) in year \( y \). In the current context, as mentioned above, ‘\( B_{y,savings,i,a} \)’ may be replaced by ‘\( B_y, savings \)’.

\( B_{old,i} \) = Annual quantity of woody biomass that would be used in the absence of the project activity to generate thermal energy equivalent to that provided by the project device type \( i \), if the project device operates throughout the year \( y \). However, since only one project device is being deployed, the variable \( B_{old,i} \) may be replaced by \( B_{old} \). Further, following option (a) of the methodology (provided in paragraph 19 of AMS-II (AMS-II, 2014), \( B_{old} \) is calculated as the product of the number of appliances multiplied by the estimate of average annual consumption of biomass per appliance (tonnes/year) derived from historical data/ survey of local usage. Subsequently, in order to account for leakages in \( B_{y,savings} \), \( B_{old} \) is multiplied by a net to gross adjustment factor of 0.95 applied in accordance with section 4.3 of AMS-II (AMS-II, 2014).

Details are provided in equation (5).

\( \eta_{old} \) = Efficiency of the pre-project device (fraction). A default value of 0.10 is used in accordance with paragraph 17, section 4.2 of AMS-II (AMS-II, 2014).

\( \eta_{new,i,a} \) = Thermal efficiency of the device of type \( i \) being deployed as part of the project activity (fraction), using the WBT protocol carried out in accordance with national standards (if available) or international standards or guidelines. Further, since only one type of device is being deployed with no reported losses in efficiency over time, the variable \( \eta_{new,i,a} \) may be replaced by \( \eta_{new} \).

\( \eta_{y,i,a} \) = Factor to consider the efficiency loss of the project device type \( i \) due to its aging at the year \( y \). However, in case of C2P2, no loss of efficiency is assumed and as a result, the value of \( \eta_{y,i,a} \) is assumed to be one.

Based on the aforementioned modifications, equation (3) may be modified as:

\[
B_{y,savings} = B_{old} \times \left(1 - \frac{\eta_{old}}{\eta_{new}}\right)
\]

- Equation (4)

In equation (4), the value of \( B_{old} \) is adjusted by multiplying a net to gross adjustment factor of 0.95 applied in accordance with section 4.3 of AMS-II. The equation for calculation of \( B_{old} \) is:

\[
B_{old} = LAF \times Q_{biomass}
\]

- Equation (5)

Where:

\( B_{old} \) = Quantity of biomass used by each appliance in the absence of the project activity in tonnes/ year. The average cooking energy demand per household in India is 11 MJ per day (Venkataraman et al., 2010). With the assumption that food is prepared in 350 out of 365 days in a year, the total energy requirement is 3850 MJ per year. We adopt default mud stove efficiency of 10% (AMS-II, 2014). The net calorific value (fuel wood chemical energy) of biomass (NCV biomass) is 15 MJ/ kg for seasoned wood (Smith et al., 2000; IPCC default value for wood fuel, wet basis), i.e. only 1.5 (10% of 15 MJ/kg) MJ of chemical energy per kg of wood actually reached the cooking pot. The base-line annual wood consumption for the traditional mud stove is 2567 kg (3850 MJ per year / 1.5 MJ)

\( Q_{biomass} \) = Average annual biomass consumption per appliance (tonnes/ year).
LAF = Gross Adjustment factor of 0.95 applied in accordance with paragraph 30 of AMS-II. to account for leakages, in which case surveys are not required (AMS-II, 2014).

Applying values to equation (5), the value of \( B_{\text{old}} \) works out as 2439 kg/year or 2.4 tonnes/year.

\[
B_{\text{old}} = 0.95 \times 2567 \text{ kg/year} = 2439 \text{ kg/year}
\]

This amounts to 7.0 kg of fuel consumption per day for a traditional stove. This is an average value which will vary with time, family size, ease of wood availability etc.

The forced draft stove adopted by Surya (designed by TERI and manufactured in India by a commercial entity Phoenix Udyog Pvt. Ltd.) has a stove efficiency of 38.6% (as per test certificate issued by Government of India), i.e, 5.5 (0.368 of 15 MJ/kg) MJ of chemical energy per kg of wood actually reaches the cooking pot. Using, equation (4) and putting requisite values of \( B_{\text{old}} \) and \( B_{\text{new}} \) as 0.10 and 0.386 respectively, the value of \( B_{\text{y,savings}} \) works out to 1.8 tonnes. The working is provided as below:

\[
B_{\text{y,savings}} = 2439 \times \left(1 - \frac{0.10}{0.386}\right)
\]

Or, \( B_{\text{y,savings}} = 1807 \text{ kg/year} \)

Or, \( B_{\text{y,savings}} = 1807 \text{ tonnes of fuel saved annually using the forced draft stove} \)

This amounts to a fuel savings of 5.2 kg/day, resulting in a daily fuel consumption of 1.8 kg per day (reduced from 7 kg per day).

- **1.8 tonnes (metric ton) of woody biomass is saved per device annually.**

Step 2: Fraction of Non-renewable fuelwood (\( f_{\text{NRB,y}} \)):

As this protocol only considers the avoided emission from non-renewable biofuel that is consumed in the absence of C2P2, the fraction of woody biomass saved by the project activity in a year that can be established as non-renewable biomass (\( f_{\text{NRB}} \)) needs to be estimated.

\[
f_{\text{NRB}} = \frac{\text{NRB}}{(\text{NRB}+\text{DRB})}
\]

where:
- \( \text{NRB} \): Non_Renewable Biomass
- \( \text{DRB} \): Demonstratably Renewable woody Biomass
Annual wood consumption in absence of C2P2= NRB+ DRB

- The f_{NRB} is calculated based on the State of Forest Report of Forest Survey of India, 2011 (FSI, 2011) and the value calculated was 0.88 for Uttar Pradesh. The basis of this calculation is as follows:
  - Annual fuelwood consumption for Uttar Pradesh (in million tonnes) (NRB+DRB) = 19.063 (Table 7.4.7, Chapter 7, FSI, 2011)
  - Annual estimated production of fuelwood in Uttar Pradesh (in million tonnes) (DRB) = Annual estimated production of fuelwood from forests + Annual estimated production of fuelwood from Trees Outside Forests (TOF) = 0.008 + 2.253 = 2.261 (Table 7.4.2 & 7.4.3, Chapter 7, FSI, 2011)
  - Therefore, f_{NRB} Uttar Pradesh = (19.063 - 2.261)/19.063 = 0.88

These Uttar Pradesh values are also consistent with UNFCC published approved f_{NRB} values listed for 26 countries, which range from 0.65 to 1.00, with an average of 0.88.

- *Fraction of non-renewable biomass is: 0.88*

### Step 3: Emission factor for fossil fuels:

Following UNFCC protocol, we assume that in the absence of the project activity, the baseline scenario is the use of fossil fuels for meeting similar thermal energy needs. The 4-II methodology sets the emission factor for the substitution of non-renewable biomass by similar consumers (EF_{projected_fossil_fuel}) to be 81.6 tCO₂/TJ (AMS-II, 2014). This represents the emission factor of the substitution fuels likely to be used by similar users, on a weighted average basis. A 50% weight is assigned to coal as the alternative solid fossil fuel (96 t CO₂/TJ) and a 25% weight is assigned to both liquid and gaseous fuels (71.5 t CO₂/TJ for kerosene and 63.0 t CO₂/TJ for liquefied petroleum gas (LPG).

The emission reduction (ER_y) in a year in tonne CO₂ per device, as per equation (2) is:

\[
ER_y = B_{y,savings} \times N_y \times \frac{81.6}{965} \times f_{NRB,y} \times NCV_{biomass} \times EF_{projected_fossil_fuel}
\]

Or, \( ER_y = 1.8 \text{ tonnes} \times 1 \times \frac{230}{365} \times 0.88 \times \left( \frac{12 MJ \times 10^{-3}}{\text{tonne}} \right) \times 81.6 \text{ tonne CO}_2/\text{TJ} \)

Or, \( ER_y = 1.84 \text{ tonnes CO}_2 \text{ equivalent} \)

- The proposed project will avoid 1.84 tonnes CO₂ per year per improved stove device.

### 2. Estimating climate credits for SLCPs from biofuel cookstoves
We will rely on three recent assessments for our estimates of climate credits for mitigation of SLCPs emissions from improved cookstoves (ICs) deployed under Surya: 1) IPCC-AR5 Working Group I report of IPCC (2013). Hereafter this will be referred to as IPCC-AR5 (2013). 2) Bond et al (2013). 3) UNEP-WMO report on Black Carbon and Ozone (2011). Hereafter this is referred to as UNEP-WMO (2011). Where needed, we fill missing region-specific input data with data collected by the Surya field studies (Rehman et al., 2010; Ramanathan et al., 2011; Praveen et al., 2011; Kar et al., 2012) and satellite assimilation studies by the Ramanathan group (Ramanathan and Carmichael, 2008; Chung, Ramanathan, and Decremer, 2012; Bahadur et al., 2012). It should be noted that the primary source of data used here for global mean values is from IPCC-AR5 (2013) and Streets et al. (2013) for India-specific values. We will revert to the other sources only when relevant data are not given in IPCC-AR5 (2013).

The C2P2 improved forced draft cookstoves (FD_SB stoves) also reduce emissions of warming particulates (in this case black carbon, or BC), ozone precursors (methane, CO, and non-methane volatile organic compounds, NMVOCs) and methane. The ozone precursors produce ozone in the troposphere (first 8 to 16 km above the surface depending on latitude). Ozone in the troposphere is an important greenhouse gas. Reductions in SLCPs equivalent to \( \text{CO}_2 \) are determined through the so-called global warming potential (GWP). Focusing on cookstove emissions, we also account for the GWP of the co-emitted organics aerosols. Organics are emitted as primary aerosols (component of the cookstove smoke) as well as Voluntary organics (VOCs) gases which subsequently form secondary organic aerosols (SOAs). Most studies assume that organics aerosols primarily scatter (reflect) solar radiation and lead to cooling, thus offsetting some of the warming effect of black carbon. However, recent data (last 5 years) including Surya data has shown that some of the organics aerosols also absorb solar radiation; these aerosols are referred to as Brown Carbon. Brown carbon data for cook stoves have been measured perhaps for the first time (Figure below) under Surya studies (Praveen et al., 2011) and its global/regional radiative forcing were given for the first time in Chung, Ramanathan, and Decremer (2013). The organic aerosols also lead to cooling by interacting with clouds and this aerosol-cloud interaction (using IPCC-AR5 terminology) cooling effect is treated by following IPCC-AR5 (2013).

![Brown Carbon Absorption in wood burning cookstove smoke: Surya Data, Praveen et al, 2012. The Y-axis is normalized absorption coefficient. The two red lines indicate the behavior of black carbon absorption from fossil fuel burning. The black lines indicate biomass burning (open circles) and mix of Biomass and fossil fuel burning. The increase in absorption at shorter Wavelengths is due to brown carbon.](image)

We will follow the so-called Global Warming Potential (GWP) approach of IPCC and adopt the definition of GWP given by IPCC. GWP is defined as the ratio of the time-integrated radiative
forcing from a pulse release of 1kg of a pollutant (e.g. methane) relative to that of 1kg of Carbon Dioxide (see Appendix for the equations and steps to derive the GWP of various pollutants). Global Warming Potential (GWP) is a metric based upon radiative properties of well-mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given well-mixed greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame. The GWP metric, while originally defined for GHGs, is now applied to climate effects of aerosols as well (IPCC-AR5, 2013; Bond et al., 2013).

The first step is to estimate the radiative forcing for a given emission amount of the pollutant. For species that have life times much less than a year (all aerosols fall under this category), the emission amount is the annual mean emissions and the radiative forcing is the annual mean forcing. This is very convenient since most published estimates are for annual mean radiative forcing and annual mean emissions of BC and organic carbon (OC).

2.1: Black and Organic Carbon and Ozone from Biofuel Cooking

2.1.a Estimating the forcing efficiency of BC and OC

Two fundamental parameters enter into the GWP for BC: Radiative Forcing, RF_BC, [Wm⁻²] and the emission, E_BC (Gg/Year). The three major sources for BC are: Fossil Fuel, solid Bio-fuel used for residential purposes (cooking is the dominant sector) and open biomass burning (crops and forest fires). RF_BC and E_BC are the most challenging quantities among various climate forcing terms to either measure or model and there has been much debate on the numbers (see Bond et al, 2013, UNEP-WMO 2011 and IPCC-AR5 2013). For example, the bottom up global emission, E-BC, used by IPCC models have a 14-fold uncertainty range of 2000 to 29000 Gg Yr⁻1 (see abstract of Bond et al, 2013).

RF_BC has three components:

1) RF_BC (ATM) is the forcing due to absorption of solar radiation by BC in the atmosphere; 2) RF_BC (SUR) is the forcing due to absorption of solar radiation by BC deposited on snow and sea ice; 3) RF_BC (clouds) This is the change in the RF resulting from changes in cloud properties caused by black carbon.

RF_BC: Recognizing the difficulties involved in a bottom-up modeling approach given the 14-fold uncertainty in BC emissions, Chung et al (2007) developed an assimilation technique to integrate satellite observations of aerosol extinction (absorption + scattering), optical depth (AOD) and ground based observations of absorption optical depths (AAOD) and used models to fill in gaps between observations. Ramanathan and Carmichael (2008) used this data to estimate an observationally constrained RF_BC (for all sources of BC) of 0.9Wm⁻² for a period of 5 years centered around 2005. This estimate was about a factor of 2 to 3 greater than the estimates available then. Bond et al (2013) undertook a comprehensive assessment of all available forcing values and arrived at an estimate of 0.88Wm⁻² (for all sources of BC) as of 2005, identical to the values given in Ramanathan and Carmichael (2008) value of 0.9 Wm⁻². However, the quantity required by IPCC is not the forcing for all sources of BC, but just the forcing due to the pre-industrial (PI) to the present-day (PD) value, which is about 80% of that for the ‘all sources of BC’, and it is 0.71 Wm⁻² for Bond et al. (2013) and is within 10% of the value that can be inferred
from Ramanathan and Carmichael, 2008. The basic inference is that there is convergence for the direct forcing estimate for BC.

With respect to RF(SUR), it is so regionally dependent that we adopt the value given in Streets et al. (2013) for India, which is not too much different from the global values (within 50%). The RF(CLOUDS) has to be treated carefully since the observed liquid(low stratus, stratocumulus and trade cumulus) cloud fraction for the Indo-Gangetic Plains is much smaller (factor of 2 to 3) that global averages used in Bond et al and IPCC-AR5, as shown in Figure below. The observed cloud fraction for the India region varies from 0.05 to 0.2 compared with the 0.3 (30%) low cloud fraction for global averages. It is particularly low (<0.1) during the dry season when aerosols reach their peak values.

When we weight the monthly cloud fraction with the monthly absorption optical depth, we get a weighted cloud fraction less than 0.1 for the effective cloud fraction which is less than global average cloud fraction of 0.3 by a factor of 3 or more. We scale the global RF (Clouds) given by Bond et al and IPCC-AR5 for the CLOUDS effect of organics, by 1/3 to estimate the India-specific value for RF_OC (CLOUDS).

**Satellite (MISR) derived monthly mean Climatology Cloud fraction and Aerosol column optical properties over IGP region, India during 2000-2012**

![Graphs showing monthly mean Climatology Cloud fraction and Aerosol column optical properties over IGP region, India during 2000-2012](image)

The last issue we have to deal with is the low bias in the BC emission, E, used in IPCC models as identified by Bond et al. (2013). This study concluded that models using the published estimate of
E\textsubscript{BC} (annual mean emission of BC) yield very low BC forcing and recommends scaling up the present day emission of 7.5 Tg/Yr (and 6.1 Tg/yr for PD-PI; the present day minus preindustrial emission) used in most all models, by a factor of 2.2 to 16.95 Tg/Year (and 13.9 for PD\_PI) to be consistent with the observationally determined BC forcing of 0.9 Wm\textsuperscript{-2} by Ramanathan and Carmichael (2008) and Bond et al. (2013). The main issue is most IPCC models use the emission of 7.5Tg/Yr for PD. It is for this reason, we are examining the forcing normalized by the emission E. fortunately, this normalized forcing or forcing efficiency is the more relevant quantity for our purposes.

The fundamental quantity that enters in GWP is the ratio, R\_FE, of the forcing, F, to emission, E, (both annual mean values) and we will refer to it as forcing efficiency. The ratio of R\_FE and the e-folding life time, Tau, is the actual definition of forcing efficiency but when Tau is much shorter than 1 year (which is the case for BC), it is R- FE that determines GWP. The Table below compares this efficiency for BC and OC, both for global mean for all sources of BC (fossil fuel, biofuel and open biomass burning) and for Biofuel emissions in India. It is the Indian biofuel emissions case that is relevant for our purposes.

For C2P2 we are interested in biofuel emissions in India’s residential sector. The only recent study we are aware of that gives the forcing value using updated emission inventory for India is the Streets et al. (2013) study using the NASA-GISS model. Another reason for choosing this study is that this study gives forcing values after letting the model atmospheric variables adjust to the forcing, i.e, it gives the Effective Radiative Forcing, which is the preferred quantity as per IPCC-AR5-2013. However, we discuss this data in the context of published values since the global data are discussed in detail in published assessments. The Table reveals following:

- The BC forcing values agree within 20% between various global values and with India-specific values for biofuel.
- The OC forcing (without CLOUDS) values between various models are within a factor of two and have the same negative sign: Cooling. However, the assessments as well as the India-specific do not include Brown Carbon, the inclusion of which (based on one study) reduces the organics cooling effect (without CLOUDS) to near zero.
- The OC forcing due to alteration of clouds( CLOUDS) has a net cooling effect in global average case; but for the India specific case, the cooling effects become very small whether we adopt the Global Mean assessments with India-specific cloud parameters or the India specific model studies.

Based on the comparison shown in Table 1, we adopt the India-specific Residential Biofuel estimates published by Streets et al. (2013) for C2P2. However, we will continue the comparison for a few more steps to illustrate the fact that, all three approaches, Bond et al. (2013), IPCC-AR5, and Streets et al. (2013) all yield values for tons of CO\textsubscript{2} equivalent mitigation that are within 50% of each other.
Table 1: Comparison of published values of the Ratio, $R$, of annual mean Radiative Forcing (F) and annual mean emission, $E$ (Terra gram/year; Tg/Yr). The yellow shaded values denote the values adopted in this study. We consider two cases, with and without Brown Carbon.

<table>
<thead>
<tr>
<th>References</th>
<th>$R_{FE}$ [Wm$^{-2}$/Tg/Yr]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ratio of R and E</td>
<td>PD:Present Day; PI: Pre Industrial. Sources: FF is fossil fuel; BF is biofuel; OB is open biomass burning</td>
</tr>
<tr>
<td>Global: BC Bond et al. 2013</td>
<td>0.08</td>
<td>Includes all forcing: RF_BC(ATM+SUR+CLOUDS) Includes all sectors: FF; BF; OB. Emission is Bond’s scaled PD-PI emission: 13.9Tg/Yr</td>
</tr>
<tr>
<td>Global: BC IPCC-AR5(2013)</td>
<td>0.1</td>
<td>Includes only RF_BC(ATM+SUR) and that too for only FF and BF. Clouds effects are not included. PD-PI Emission is: 4.2Tg/Year</td>
</tr>
<tr>
<td>Global: BC UNEP-WMO(2011); Chung, Ramanathan, and Decremer (2012)</td>
<td>0.1</td>
<td>Includes RF_BC (ATM+SUR+CLOUDS) for FF; BF;OB. PD_PI Emission is 6.1Tg/Year. Allows for larger efficacy of BC deposition on snow and sea ice.</td>
</tr>
<tr>
<td>India: BC from Biofuel Streets et al, 2013</td>
<td>0.06 to 0.12</td>
<td>Includes only RF_BC(ATM). Observationally based estimate which does not require emission inventory. The efficiency is 0.06 if we use Bond et al.’s scaled emission of 13.9Tg/Year and 0.12 with unscaled emission of PD-PI 6.2 Tg/year.</td>
</tr>
<tr>
<td>Global: OC; direct only Bond et al, 2013</td>
<td>-0.004</td>
<td>Ignores Brown Carbon. Includes only direct forcing of atmosphere, i.e, RF_OC(ATM). Uses Scaled PD_PI emission of 81 Tg/Yr as per Bond et al.</td>
</tr>
<tr>
<td>Global: OC; direct only IPCC-AR5 (2013)</td>
<td>-0.009</td>
<td>Ignores Brown Carbon. Includes only direct forcing, i.e, RF_BC(ATM) of FF and BF. Uses PD_PI emission of 14 Tg/Yr[Bond et al]</td>
</tr>
<tr>
<td>Global: OC; direct only UNEP-WMO (2013)</td>
<td>-0.006</td>
<td>Ignores Brown Carbon. Includes only direct forcing, i.e, RF_BC(ATM) of FF; BF; OB. PD-PI emission is 33Tg/Yr[Bond et al]</td>
</tr>
<tr>
<td>Global &amp; India: OC including brown carbon; direct only Chung, Ramanathan, and Decremer (2012)</td>
<td>0</td>
<td>Includes Brown Carbon. Only Direct forcing, i.e, RF_OC(ATM). Brown carbon warming effects nearly cancels out cooling by all other organic aerosols.</td>
</tr>
<tr>
<td>India: OC from Biofuel Streets et al, 2013</td>
<td>-0.004</td>
<td>Ignores Brown Carbon. Only direct forcing, but effective forcing: RF-OC(ATM). OC emission is 1.9Tg/Year. Global climate model simulation of effective radiative forcing, ERF.</td>
</tr>
<tr>
<td>Region</td>
<td>Sectors</td>
<td>Clouds</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Global: OC, all sectors; Clouds Bond et al, 2013</td>
<td>-0.009</td>
<td>RF_OC[CLOUDS]. Uses Scaled PD_PI emission of 81 Tg/Yr as per Bond et al.</td>
</tr>
<tr>
<td>Global: OC; all sectors; Clouds IPCC-AR5 (2013)</td>
<td>-0.005</td>
<td>RF_OC[CLOUDS]. Uses All-aerosol-cloud effects of -0.45 Wm$^{-2}$ to infer the organics aerosol contribution to negative forcing.</td>
</tr>
<tr>
<td>India: OC; all sectors; Clouds. Inferred from Bond et al., 2013</td>
<td>-0.003</td>
<td>The Global RF_OC(CLOUDS) given above is scaled with observed cloud fraction over Indo-Gangetic Plains of India.</td>
</tr>
<tr>
<td>India: OC; all sectors; Clouds, Inferred from IPCC-AR5 (2013)</td>
<td>-0.002</td>
<td>The Global RF_OC(CLOUDS) given above is scaled with observed cloud fraction over Indo-Gangetic Plains of India.</td>
</tr>
<tr>
<td>India: OC+BC; Biofuel; Clouds. Streets et al, 2013</td>
<td>+0.001</td>
<td>RF_BC+OC[CLOUDS] as simulated by the climate model in Streets et al. The change in forcing from interaction of BC and OC with clouds is a small Positive value of 0.003 Wm$^{-2}$. Divided by BC+OC emission of 2.49 Tg/year to get +0.001.</td>
</tr>
</tbody>
</table>
2.1.B Determination of GWP-20 yrs and GWP-40 Yrs from Solid Biofuel Cook stoves (BC+OC)

The data given in Table 1 can be used to derive GWP for Cook Stove emissions of BC and OC. The individual GWP values are given in Table 2. The BC GWP values are in the range of 3200 to 4400. The IPCC global value of 4000 for Fossil+Biofuel is similar to the India-specific Biofuel value of 4400 from Streets et al. (2013). The OC [ATM] without Brown Carbon ranges from -160 to -360 and the India value of Streets et al. (2013) for residential biofuel is -160. The addition of Brown Carbon based on Chung et al. (2012), reduces the negative value of OC[ATM] to near zero. For RF_OC(CLOUDS), the global values of Bond et al. (2013) and IPCC-AR5 ranges are respectively -360 and -200, while the India-specific value of Streets et al. (2013) is a very low value of +40(warming). However, when we scale the global studies value with India-specific observed cloud fraction, the Bond et al. (2013) and IPCC-AR5 reduces to -120 and -80.

<table>
<thead>
<tr>
<th>References</th>
<th>GWP-20 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RF BC[ATM+SUR+CLOUDS]</strong></td>
<td></td>
</tr>
<tr>
<td>Global: BC . Bond et al. 2013</td>
<td>3200</td>
</tr>
<tr>
<td>Global: BC . IPCC-AR5 (2013)</td>
<td>4000</td>
</tr>
<tr>
<td>Global: BC; UNEP-WMO (2011)</td>
<td>4000</td>
</tr>
<tr>
<td><strong>India: BC from Biofuel. Streets et al, 2013</strong></td>
<td>4400</td>
</tr>
<tr>
<td><em>This is Effective Radiative Forcing.</em></td>
<td></td>
</tr>
<tr>
<td><strong>RF OC[ATM]</strong></td>
<td></td>
</tr>
<tr>
<td>Global: OC; direct only. Bond et al, 2013</td>
<td>-160</td>
</tr>
<tr>
<td>Global: OC; direct only. IPCC-AR5 (2013)</td>
<td>-360</td>
</tr>
<tr>
<td>Global: OC; direct only. UNEP-WMO (2013)</td>
<td>-240</td>
</tr>
<tr>
<td>Global: OC including brown carbon; direct only Chung, Ramanathan, and Decremer (2012)</td>
<td>0</td>
</tr>
<tr>
<td><strong>India: OC from Biofuel. Streets et al, 2013</strong></td>
<td>-160</td>
</tr>
<tr>
<td><strong>India: OC from Biofuel. Streets et al, 2013; with Brown Carbon from chung et al, 2012</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>RF OC[CLOUDS]</strong></td>
<td></td>
</tr>
<tr>
<td>Global: OC, all sectors . Bond et al, 2013</td>
<td>-360</td>
</tr>
<tr>
<td>Global: OC; all sectors . IPCC-AR5 (2013)</td>
<td>-200</td>
</tr>
<tr>
<td>India:OC; all sectors; Inferred from Bond et al, 2013</td>
<td>-120</td>
</tr>
<tr>
<td>India: OC; all sectors; Inferred from IPCC-AR5 (2013)</td>
<td>-80</td>
</tr>
<tr>
<td><strong>India:OC+BC;Biofuel; Clouds. Streets et al, 2013</strong></td>
<td>+40</td>
</tr>
</tbody>
</table>

The next step is to combine the data in Table 2, using the relative emissions of BC and OC from Biofuels in the residential sector. We use the most recent estimates of emissions (See figure below) for India as reported in Streets et al. (2013). Using the data for residential biofuel emissions of BC and OC (figure below), we infer the ratio of OC/BC=4 for Indian residential biofuel.
Emissions distributions in 2008 for China and India at 0.1° × 0.1° spatial resolution. Reproduced from Streets et al, 2013.

We combine the BC and OC values in table 2, using the ratio of (OC/BC)=4 to obtain the GWP for cook stove emissions of BC and OC for India. We let

\[ \text{GWP}_{\text{Biofuel}}(\text{BC and OC}) = \text{GWP}(\text{BC}) + 4 \times \text{GWP}(\text{OC}). \]

To get the CO2 equivalent emissions, we let:

\[ \text{CO}_2 \text{e} = E_{\text{BC}} \times \text{GWP}_{\text{Biofuel}}(\text{BC+OC}) \]
Table 3: GWP for Biofuel emissions of BC and OC for Indian Residential Sector. Value within bracket does not include Brown Carbon

<table>
<thead>
<tr>
<th>References</th>
<th>GWP-20 yrs</th>
<th>GWP-20 scaled with emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferred from Global results in Bond et al., 2013</td>
<td>2100</td>
<td>4600 (2400-5300)</td>
</tr>
<tr>
<td></td>
<td>(1100-2700)</td>
<td></td>
</tr>
<tr>
<td>Inferred from Global Results of IPCC-AR5 (2013)</td>
<td>2200</td>
<td>2200 (1800-3700)</td>
</tr>
<tr>
<td></td>
<td>(1800-3700)</td>
<td></td>
</tr>
<tr>
<td>Streets et al., 2013</td>
<td>3900-4600</td>
<td>3900-4600</td>
</tr>
</tbody>
</table>

The entry under GWP-Scaled with emission (last column in Table) requires explanation. It is same as the GWP in the middle column for IPCC-AR5 and Streets et al. For Bond et al., however, we needed to multiply GWP with a factor of 2.2 for the following reason: The emission used in the suite of models used in Bond et al. (as well as in IPCC) use Bond et al. (2004) emission inventory which has 7.54 Tg/Year for BC. To account for the large BC forcing inferred from observations, Bond et al recommend scaling the emission by a factor of 2.2 to 16.95 Tg/Yr. The India biofuel fraction is 0.41 of global total emissions. As a result, the Indian Residential emission of 0.31 Tg/Yr in the Bond et al. (2004) has to be multiplied by a factor of 2.2 to 0.69 Tg/Yr. This implies in turn, the published emission factor of BC from cook stoves has to be multiplied by 2.2. Since in what follows, we are using published emission factor, the GWP of Bond et al. has to be multiplied by 2.2.

The ‘central’ value in the Table is for the case for which the cloud fraction is adjusted to India-specific values. The lower range uses global cloud mean cloud fraction and ignored brown carbon, which is the case adopted in all estimates of GWP in the literature. For the Streets et al value, the lower vale is the value that is inferred from their study without many modifications. In the upper range, we add the brown carbon forcing to the values given in their paper.

The main inference from Table 3 is that the GWP_20 inferred from Streets et al study for Indian residential fuel (3900-4600) is consistent with the value inferred from Bond et al (4600) and IPCC_AR5 (3700), particularly given the factor of 2 or more uncertainty in emission inventory and comparable uncertainty in the atmospheric concentrations of BC and OC and their interactions with clouds (another factor of 2). In what follows, C2P2 will adopt the GWP-20 Yr value of 3900 (1800-5300). The central value is from Streets et al, while the range is basically the lowest and highest values shown In Table 3. The 40-year GWP value is 0.54 of the 20-year value

- For the C2P2 time frame of 40 years, the GWP-40 Yrs for BC and OC from Residential use of biofuels in India is: 2100 (1100-2900).

This number above has to be multiplied by BC emission reduction to obtain the CO2 equivalent tonnes.

We caution that the value of 2100 (1100-2900) is valid only for India, and that too only for residential combustion of solid biofuels in traditional stoves. Its extension to other regions will require recalculation using region-specific values.
Solid biofuel Cookstoves also emit significant amounts of CO and VOCs and trace amounts of methane which together produce ozone in the lower atmosphere and amplify the BC warming. While Streets et al. (2013) do not show the ozone forcing in their graphs and Tables, they discuss its effect in the text and cite their earlier study to point out that the inclusion of ozone will amplify the net BC+OC warming by 30%. We obtain the same 30% if we individually account for the effects of CO, VOCs and Methane (see supplement for other co-emitted species). This leads to the following conclusion:

- **For the C2P2 time frame of 40 years, the GWP-40 Yrs for BC, OC and Ozone from Residential use of biofuels in India is: 2700.**

  The number above has to be multiplied by BC emission reduction to obtain the CO2 equivalent tonnes, since changes due to OC and ozone are scaled to BC emissions using region appropriate ratios of BC and OC emissions and BC forcing to Ozone forcing ratios.

### 2.1.C Appropriate Metric for Climate Credits: GWP or GTP or Efficacy of Warming

The concept of GWP was originally developed in the 1990s for comparing the warming due to various greenhouse gases. Their life times were invariably over 10 years and as a result their forcing was smoothly varying over the global with similar spatial gradients. This is not the case for BC and OC whose forcing is regionally concentrated. In addition, the vertical variations of the forcing is much steeper for BC compared with CO2 and other gases. Such spatial gradients and vertical gradients influence climate change in addition to the global mean forcing and these sort of changes are not factored into GWP concept, which relies primarily on the forcing at the top-of-the-atmosphere. As a result, the applicability of GWP concept to short lived climate pollutants has been modified through the so-called efficacy of warming (Hansen et al, 2005) and the Global Temperature Potential, GTP(Shine et al, 2005; IPCC-AR4 2007). The efficacy, EFCY is basically the following ratio: EFCY= DT BC/RF BC/DT CO2/RF CO2. DT BC is the warming due to BC and RF BC is radiative forcing for BC. The ratio [DT/DF] for BC determines the efficiency of BC forcing to warm the climate and EFCY is simply the ratio of BC efficiency compared with CO2 efficiency. Global climate models indicate (Hansen et al, 2005) suggest that EFCY for BC is 0.6, i.e, BC is about 60% as efficient as CO2 in warming the climate. Jacobson (2010) arrives at a similar ratio. The GTP is a different approach with the same goal but it is highly dependent on assumptions and models etc and is typically smaller than the GWP by a factor of 2 to 3.

In our study, we follow the EFCY approach, and scale the GWP results above with the efficacy factor of 0.6. We also note the following: 1) The Streets et al BC forcing allows for the atmospheric response to the imposed forcing over a period of 30 years and is closer to GTP rather than GWP estimates. 2) The concepts such as GTP and efficacy focuses solely on surface warming. In the regional context of India, the BC induced temperature change aloft (above 3 km) is twice as large as surface warming (Ramanathan et al., 2005, 2007) and the warming aloft contributes the most to melting of Himalayan glaciers. Nevertheless, we scale the GWP values estimated above with the efficacy factor of 0.6 and refer this to GWPe. The letter e in GWPe denotes efficacy. So, the final numbers we use for climate credits estimate are summarized below:

- **For the C2P2 time frame of 40 years, the GWPe-40 Yrs for BC, OC and Ozone from Residential use of biofuels in India is: 1500 (800-2100). The corresponding number for 20-Yrs is 3600.**
2.1.D Determination of BC emissions reduction from C2P2 stoves

Carbon credits will be awarded based on the total mass of equivalent CO2 mitigated by use of an improved cook stove compared to the current scenario. As such, we need to determine the emissions (mass based) for both the baseline, currently used mud-stoves and the improved stoves. Ideally we would develop a matrix of emission factors combining stove models (mud stove, natural draft, forced draft) and fuel types (wood chips, crop residue, dung etc) to accommodate variations between users. This matrix should be further refined in the future by considering the region of use (high altitude mountains vs. river plains), as this may impact emissions even though the stove model and fuel type are held constant.

Based upon information currently available, we can estimate the BC reduction for a single stove.

**BC Emissions Reductions (ERBC)**

Emissions Reductions of BC, in units of kg BC (kg). The ideal equation to calculate the reductions in BC emissions when switching from a mud stove (MS) to an improved stove (IC) is:

$$\text{ER}_{\text{BC}} = \text{BC}_{\text{MS}} - \text{BC}_{\text{IC}}$$

where:

- $\text{BC}_{\text{MS}}$: BC emitted by the mud stove (for a specified period of time)
- $\text{BC}_{\text{IC}}$: BC emitted by improved cookstove (for a specified period of time)

$$\text{ER}_{\text{BC}} = (\text{Ef}_{\text{MS}} \cdot \text{F}_{\text{MS}}) - (\text{Ef}_{\text{IC}} \cdot \text{F}_{\text{IC}})$$

where:

- $\text{Ef}_{\text{IC}}$: is the emission factor for improved cook stoves (g BC/kg fuel).
- $\text{F}_{\text{IC}}$ is the mass of fuel consumed by the improved stove (kg fuel).
- $\text{Ef}_{\text{MS}}$ is the emission factor for mud stoves (g BC/kg fuel).
- $\text{F}_{\text{MS}}$ is the mass of fuel consumed by the mud stove (kg fuel).

$\text{Ef}_{\text{MS}}$ is the BC Emission factor for mud stoves. The average value of published emission factors for mud stoves (Table 4), is 0.9 g BC / kg fuel. However, the 0.9 g/kg value is inconsistent with the updated Streets et al. (2013) total emission of 0.49 Tg/yr of BC (see Figure above) from residential biofuel combustion. The 0.9 g/kg is consistent with the older Bond et al (2004) values of 0.31 Tg/yr of BC for India, biofuels. To be more consistent with more recently calculated values (0.49 Tg/yr), the emission factor used is 1.4g BC/kg of fuel, which is in agreement with the upper range of the values shown in the Table below. We adopt a range of 0.9g/kg to 1.4 g/kg for the emission factor in this study. See Table 4 below for citations and emission factors.
Table 4: Published Emission factor estimates for mud stoves

<table>
<thead>
<tr>
<th>Citation</th>
<th>Emission Factor BC (g BC / kg fuel)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lu et al, 2012*</td>
<td>1.1 g / kg</td>
<td>Wood</td>
</tr>
<tr>
<td>Just et al, 2012</td>
<td>0.7 g / kg</td>
<td>3 stone fire; Dry fuel</td>
</tr>
<tr>
<td>Roden et al, 2006</td>
<td>1.5 ± 0.3 g / kg</td>
<td>Field data, Honduras</td>
</tr>
<tr>
<td>Venkataraman et al, 2010</td>
<td>0.6 ± 0.15 g / kg</td>
<td>Wood</td>
</tr>
<tr>
<td>MacCarty et al (2008)</td>
<td>0.88 g / kg</td>
<td>Laboratory data, Wood</td>
</tr>
<tr>
<td>Habib et al (2008)</td>
<td>0.5 ± 0.1 g / kg</td>
<td>Wood</td>
</tr>
</tbody>
</table>

Table: Compilation of emission factors for mud stoves (\(E_{fMS}\))

*The net BC emission factor for residential usage of biofuel (biomass) as per Lu et al., 2012 is 55.4 (19.3–146.7) g / GJ for 2010. Assuming, that biofuel is woody biomass with average "energy density" of 19.8 MJ per kg, i.e. 0.0198 GJ per kg, the emission factor can be expressed as 1.1 g of BC per kg of wood.

\(E_{fIC}\): There are two ways to estimate \(E_{fIC}\)

1) The most straightforward method is to use field measurements and unscripted cooking (normal for the region). Unfortunately, such data are not available, at least for India. Laboratory data can be substituted for field data, however such laboratory data usually does not correspond well to field conditions (e.g. data collected in the USA, under idealized conditions, underestimates BC emissions in the field because of variable moisture content of the fuel in villages in India).

2) The second method, referred to as the Surya method, estimates \(R_{BC}\) as follows:

\[
E_{fIC} = E_{fMS} \times (1 - F_{BC})
\]

\(F_{BC}\) is the fractional reduction in BC concentrations between improved stoves (IC) and mud stoves (MS).

\[
F_{BC} = ((BC_{MS} - BC_{AMB}) - (BC_{IC} - BC_{AMB})) / (BC_{MS} - BC_{AMB})
\]

Where:

- \(BC_{MS}\) : Concentration of BC in household when using mud stove.
- \(BC_{AMB}\) : Ambient BC concentration when stove not in use.
- \(BC_{IC}\) : Concentration of BC in household when using IC.
The paper by Kar et al. (2012) establishes the BC concentrations for the mud stoves as well as forced draft stoves under the Controlled Cooking Test (CCT), a better representation of actual conditions compared to the laboratory-based WBT. We use data from Kar et al. (2012) for BC concentrations:

\[ F_{BC} = \frac{(127.55 - 3.7) - (18.7 - 3.7))}{(127.55 - 3.7)} = 0.88 \]

And the Effective Emission factor for IC as:

\[ E_{f_{IC}} = E_{f_{MS}} \times (1 - F_{BC}) = 0.9g \text{ BC to 1.44g BC/kg fuel} \times (1 - 0.88) \]
\[ = 0.11 \text{ to } 0.17 g \text{ BC/kg fuel} \]

There are two ways to obtain the fuel consumption.

1) The first method uses published numbers.

**F**<sub>MS</sub>, the base-line annual wood consumption for the traditional mud stove, is estimated at 2439 kg/year, or 7.0 kg/day (methodology described above).

**F**<sub>IC</sub>, the wood consumption for the improved stove, is estimated at 632 kg/year, or 1.8 kg/day (methodology described above).

Using this method, we get a total reduction of BC of:

\[ E_{R_{BC}} = (E_{f_{MS}} \times F_{MS}) - (E_{f_{IC}} \times F_{IC}) \]
\[ = (0.9 \text{ to } 1.4 \text{ g BC/kg fuel} \times 2439 \text{ kg fuel}) - (0.11 \text{ to } 0.17 \text{ g BC/kg fuel} \times 632 \text{ kg}) \]
\[ = 2700 \pm 600 \text{ (i.e. with a range of 2100 to 3300) g BC} \]

2) The second method relies on measurements from the field.

\[ F_{MS} = F_{CMS} \times D_{day} \times N \]

- F<sub>CMS</sub> is the rate of fuel consumption (kg fuel/minute cooking)
- D<sub>MS</sub> is the duration of cooking per day (minute cooking/day)
- N is the number of days of cooking per year.

Project Surya has established the rate of fuel consumption, FC (kg fuel/minute cooking) in the Project Surya target area (Bahadur et al., 2013):

- FC<sub>MS</sub> (Mud stove) = 1.06 kg/hour = 0.018 kg fuel/min cooking
- FC<sub>IC</sub> (Improved (FD) stove) = 0.47 kg/hour = 0.0078 kg fuel/min cooking

We also know from the Project Surya field data that for a typical day of cooking, the FD stove requires 303 minutes of use for every 336 minutes of use of the mud stove (Bahadur et al., 2013).

\[ F_{MS} = F_{CMS} \times D_{MS} \times N \]
\[ = 0.018 \text{ kg fuel/minute cooking} \times 336 \text{ min cooking/day} \times 350 \text{ days/year} = 2117 \text{ kg/year} \]

This is 13% lower than the published value, stated above (2439 kg/year),
\[ F_{1C} = FC_{1C} \times D_{1C} \times N \]
\[ = 0.0078 \text{ kg fuel / min cooking} \times 303 \text{ min cooking/day} \times 350 \text{ days/year} = 827 \text{ kg/year} \]

This value is 30% higher than the calculated value, stated above for \( F_{1C} \) of 632 kg / year.

Using these values, we get

\[ ER_{BC} = (E_{FMS} \times F_{MS}) - (E_{IC} \times F_{IC}) \]
\[ = (0.9 \text{ to } 1.4 \text{ g BC / kg fuel} \times 2117 \text{ kg fuel}) - (0.11 \text{ to } 0.17 \text{ g BC / kg fuel} \times 827 \text{ kg}) \]
\[ = 2300 \text{ (1800-2800) g BC} \]
\[ = 2300 \pm 500 \text{ (i.e. with a range of 1800 to 2800) g BC} \]

The Project Surya value is 15% lower than the calculated value for \( ER_{BC} \) using published values derived in option 1, making the estimate of emissions reductions used more conservative.

The advantage of the Project Surya option (option 2) for calculating fuel consumption is that it allows us to provide more accurate values on a house by house basis, because it relies on cooking duration from a house, which can be measured from each house as the improved stoves are equipped with sensors in the field to measure cooking duration (see next section). The next step is the method Surya has developed to monitor the duration of cooking with improved stoves, which is described in the next sub-section.

**In summary:**

- **The primary finding is, if a household uses the C2P2 stove for all their cooking needs for a full year, it would have mitigated 2.3 (1.8 to 2.8) kg of BC/yr. This value can be adapted on a house-by-house basis using the Project Surya method.**
- **Using the GWPe_40 yrs value of 1500 (800 to 2100) the Climate Credit will be: 3.5 (1.5 to 5.9) tonnes CO\(_2\)e per year.**

**2.1.E: Monitoring the duration of use of the improved stoves**

The Cookstove Temperature Monitoring System (figure to left) is an inexpensive wireless sensor system that enables remote verification of the number of times a stove is used for cooking and the duration of each use (Graham et al., to be published). The system has been under continuous testing in the laboratory and field for more than two years and has allowed researchers to unobtrusively monitor cookstove usage in a variety of homes and conditions. The system uses a temperature sensor (that attaches to the stove) that is connected to an inexpensive Android phone. The mobile phone software collects short streams of temperature data at regular intervals from the sensor and wirelessly uploads the data to the cloud server using local cellular networks or WiFi connections. Once the server receives temperature data, the System automatically applies the algorithms to compute cooking duration and makes the results available via a web page.
The thermistor-based temperature sensor can be attached to either the FD stove body or to a probe (as pictured in the figure; a “J-bar”) for easy placement on different units of the same FD type.

Development of the cooking time algorithm occurred in the Nexleaf laboratory and consisted of a series of modified Water Boiling Tests of different duration and intensity on a TERI-SPT 0610 (The Energy and Resources Institute, New Delhi, India; featured in the figure above) micro-gasification FC, designed and distributed to replace traditional mud stoves in India. The FD body and “J-bar” were monitored for temperature changes during tests and fuel consisted of uniform wood chips of different types (oak, pine, hickory) where moisture content was known. The TERI FD stove tested in this study responded to cooking in a repeatable and predictable way, allowing the construction of robust algorithms to determine cooking time. A recursive partitioning and regression tree analysis (rpart version 3.1-50; Therneau and Atkinson, 2002) was used to construct a “decision tree” to run on the back-end to determine when cooking was occurring based on the time series temperatures of the FD body or J-bar. Laboratory results indicated that cooking time measured in this way had an absolute cross-validated error rate of 2.0% and the classification correctly identified cooking 97.2% of the time and correctly identified “not cooking” 98.4% of the time.

Field verification of the system occurred over the course of 17 continuous days in 2 rural households in the Jagdishpur block of Uttar Pradesh, India. Households that had previously participated in trial cookstove intervention programs were chosen as representative of households that had experience with and owned their own TERI FD stove. Temperatures were recorded on the J-bar in each household and the time of the beginning of cooking, the last fuel addition, and the removal of cooking pot were recorded by a trained, local volunteers. Cooking was unscripted and varied with family practice and meals prepared.

Calculations of cooking time in the field using the decision tree algorithm agreed well with the observed time in the field (Figure below; Deming Regression correlation coefficient of .90). Calculated cooking time averaged 1.4 ± 0.6 h (n=31) and the observed cooking time averaged 1.5 ± 0.6 h for each event, indicating no strong measurement bias between the calculation and human observation. The average difference between calculated and observed cooking time was 0.03 ± 0.31 h (the absolute value difference averaged 0.23 ± 0.20h) with a maximum error of 0.83 h. The total amount of calculated cooking time was 44.3 h and total observed cooking time was 45.3.

In the pilot phase of our study, we will be deploying this system in 250 homes that own a TERI stove. Using the removable “J-bar” will allow for repeatable comparisons among different households without the need to model the temperature responses of the specific stove.

Scaling up to the remaining 2000 homes in this study will require built-in temperature sensors and may have to accommodate different models of FD stove. Because the FD stove body temperature predictably reflected cooking dynamics, a standardized location on the body of any model of FD stove can be determined in the laboratory and used for the built-in monitoring of the temperature signal of cooking events. Working with a built-in thermostat attached to a timer circuit further simplifies and reduces the cost of monitoring cooking duration and we have begun...
investigation into this approach (e.g., a single thermostat threshold of 64°C was determined to be optimal for classifying time into “cooking” or “not cooking” with a 2.3% over-estimation of cooking time over all laboratory cooking conditions tested).

2.2: Monetary Credits through voluntary carbon markets.

Transactions in the voluntary carbon markets (VCM) are not required by regulation, instead, demand is driven by companies and individuals that take responsibility for offsetting their own emissions, as well as entities that purchase “pre-compliance” offsets before emissions reductions are required by regulation. These voluntary markets co-exist with compliance markets driven by regulated caps on greenhouse gas emissions. The volume of carbon credits transacted voluntarily in 2011 represents less than a 0.1% share of the global carbon markets. What the voluntary carbon markets lack in size, they make up for in flexibility – spinning off innovations in project finance, monitoring, and methodologies that also inform regulatory market mechanisms.

Climate credits can be voluntarily purchased in one of two ways – through a private exchange or on the decentralized “over-the-counter” (OTC) market, where buyers and sellers engage directly through a broker or online retail “storefront.” The OTC market is driven by both “purely voluntary” and “pre-compliance” buyers. Purely voluntary buyers purchase credits to offset their individual or organization’s emissions and are driven by a variety of considerations related to corporate social responsibility (CSR) and ethics or reputational risk. The voluntary carbon market remains illiquid – meaning that ready buyers are not always at hand; one or a few market players can dramatically influence pricing; and prices are highly stratified and often unpredictable, even within similar classes of offset. The details of payment and offset delivery vary tremendously from one project to the next, as do the projects’ design, risk, start date and other factors that contribute to their eventual price.

Clean cook stoves have received substantial media attention and NGO and institutional support recently, within and beyond the carbon markets. Organizations like the Global Alliance for Clean Cookstoves have brought to the world’s attention the large-scale adverse health impacts and environmental pressures caused by burning biomass fuel for indoor cooking, and the hardships placed on women and children who spend the most time collecting biomass and inhaling indoor smoke. Cookstove credits are therefore especially attractive, as corporate offsetters consider these to be a catch-all that unite environmental, humanitarian, and in some cases investment opportunities under the umbrella of one purchase.

In 2011, the volume-weighted average price for OTC credits on the voluntary markets rose was $6.2/\text{tCO}_2$. This price helps to benchmark the value of global OTC trades. Compared to this baseline, clean cookstove projects achieved an above market price average of $13.2/\text{t CO}_2$. It remains to be seen however, as larger volumes of cookstove credits come online (particularly in Africa), if this premium pricing can be retained. For the monetary values estimated in this document, we use $6/\text{t CO}_2$ to be earned from the climate credits.

2.2.A Determination of Carbon and Climate credits

With the information collected thus far in this section, the carbon and climate credits credits can be estimated for each end user. The estimates below assume use of the C2P2 stoves for all domestic cooking needs for a full year. We adopt the value of $6/\text{[CO}_2\text{e Tonnes]}$ for the climate credits.

A. Mitigated CO$_2$ emissions from fuel savings with the Improved stove and the
avoided use of fossil fuels: 1.8 tonnes/Year

*Earned Carbon Credits for CO₂ mitigation: $11/Year*

B. Mitigated BC (including OC and Ozone) emissions: 3.5 (1.5 to 5.9) Tonnes of CO₂e/year

*Earned climate Credits for BC mitigation: $21 ($9 to $35)/year*

The upper value of $35 is obtained if we used India-appropriate values for meteorological parameters and adopted new data on brown carbon warming effect. The lower value of $9 is obtained if we adopt the global average values for the meteorological parameters and ignore brown carbon absorption.

We use the mean value for mitigated BC of 3.5 tonnes/year. Summing the two mitigated credits, we obtain $32 per stove per year.

2.2.B Benefits from Progress in Sustainability

The improved stoves will contribute in a major way towards achieving sustainability goals through the following avenues:

**Health:**

The Global Burden of Disease estimates a million lives or lost each year from indoor smoke from cooking and heating. There are about 150 million homes using mud stoves and thus every 5000 stoves leads to 33 deaths. Assuming a life time of 5 years for each stove, the 5000 Forced Draft stoves would save 150 lives.

As per World bank’s S. Asia estimates, the Value of a Statistical Life is about $300,000 (USD). Using the values for BC and OC emissions and mitigation of pollution by the improved stoves presented here, the valuation of each improved stove (assuming full use for a year) due to saved life is $1300/year.

**Water:**

a. **Himalayan Glaciers:** It has been estimated (Ramanathan et al, 2007; Flanner et al, 2010; Menon et al, 2010 and others; see UNEP-WMO for references) that BC heating of the elevated atmosphere and the deposition effects on snow contribute about 50% or more to melting of glaciers in the Himalayas. Residential biofuel combustion contributes about 25% to 50% of the black carbon effects.

b. **Monsoon Rainfall:** OC leads to dimming of the surface which contributes to reduction of monsoon rainfall (Ganguly et al, 2012). Residential biofuel use contributes as much as 70% of the total OC emission in India.

**Agriculture:**

Ozone is a major destroyer of crops leading to millions of crop destruction in India alone (UNEP-WMO 2011). Reduction of CO from cookstoves will contribute to reduction of ozone concentrations.

**Human wellbeing:**
In addition to the above, women and children spend hours collecting fuel. The Surya FD stoves reduces fuel consumption by a factor of two, significantly reducing the burden on women and children.

_in short the benefits to society and sustainability goals of India far outweigh the costs incurred in the Carbon/climate credits ($32/Year) or the cost of the stoves ($80). At $1300/stove for derived health benefits, it alone is a factor of 3 to 6 larger than the cost of the carbon/climate credits or that of the improved stoves. In addition, the 5000 stoves would offset the emission of an average of 133,000 tonnes of CO₂e._
3. End-to-end trial of cellphone-based carbon credit system for financing cookstoves

The pilot phase of C2P2 will be started in up to 5000 homes located in the Indo-Gangetic Plains and the Himalayan regions of India. The focus of the pilot study is on evolving a value chain linking end users, rural banks and carbon incentives provisioning. The details of instrumentation to be deployed, measurements that are made, and detailed calculations are provided here.

1. Overview
   a. **Temperature sensors and cellphones will be deployed in households.** Data will be continuously collected from each household, and uploaded to Nexleaf’s servers.
   b. **Automatically estimate cooking duration and stove type (duration, stove type):** Nexleaf servers will extract the duration of cooking and fuel consumption automatically.
   c. **Collect additional data through manual survey in the field from a subset of homes:** Fuel type, fuel weight, stove type, items cooked, kitchen type, cooking duration.
   d. **Send cooking data to Scripps and TERI for auditing:** Scripps/C4 and TERI will access data from Nexleaf servers (house number, location, date, time, cooking duration, stove type) for each house and each cooking event for independent evaluation of the total climate credits on a monthly basis.
   e. **Estimate BC emissions:** Cooking duration data will be used to calculate the BC emissions for that cooking event on Nexleaf’s servers. Estimate the reduction in emissions for houses that use improved stoves, based on the cooking duration.
   f. **Estimate climate credit value:** Use the BC emissions data per household, to calculate the daily dollar amount earned by that house.
   g. **Send monetary value to bank or to end-user’s cellphone:** The dollar equivalent for the reduction in emissions should either be sent to the bank or directly back to the end-user’s cellphone. In Kenya we can explore use of m-pesa (via Vodafone group) or other initiatives like Airtel Mobile Money to send money back to end-users.

2. Methods:
   *Deployment Locations: India (IGP and Himalayan Region)*

2a) **Temperature sensors and cellphones deployed in households**
*Monitoring Improved Stoves:* Sensors will be attached to improved stoves using the J-bar. This approach has been validated in laboratory and field experiments (Graham et al., to be published).

2b) **Automatically estimate cooking duration and stove type (duration, stove type):**
Nexleaf is publishing a methodology for automatically extracting cooking duration and fuel consumption from a temperature data stream (Graham et al., to be published). This methodology is implemented on the Nexleaf server and will be applied automatically to all temperature data collected from stoves to calculate cooking duration and fuel consumption.

2c) **Collect additional data through manual survey in the field:** In addition to the direct measurements via cell-phones, the fuel type, fuel weight, stove type, items cooked, kitchen type, cooking duration will be tabulated through field surveys in a subset of homes. This information will be used to validate the automated SLCP and CO₂ mitigation estimated on the server.
4. Surya Climate Credit Implementation Model

**Step 1:** The Surya Climate Change Mitigation Fund (SC²MF), jointly managed by TERI and UCSD, shall be established at the start of the pilot phase. The fund will act as an interface between the technology dissemination and climate credit tracking system. At one end, it will mobilize the women through their SHGs and local partner NGOs and collaborate with local financial institutions to facilitate stove financing in order to persuade women to participate in the project. On the other hand, it will manage the mechanism for stove usage tracking; evaluate the climate credits with support from Voluntary Carbon Registries (VCR) and subsequently transfer these credits to each beneficiary’s bank account.

**Step 2:** Next important step is identifying and collaborating with credible financial institutions (FI) operational in the project areas. The FI will facilitate stove financing to interested end-users. The criteria of selecting the FI will be as under,

- It should be operational in the project area with necessary network and infrastructure to serve the rural population living the area.
- The FI policies and its stove financing mechanism comply with the relevant guidelines and regulations of Reserve Bank of India.
- If women Self Help Groups (SHGs) are operational in the area, it would be desirable if the FI is already connected and serving to the SHG network in that area.

**Step 3:** Credible NGOs active in the local areas who are working closely with the women SHGs shall be taken on board. The partnership with these NGOs will be important as they already have a rapport with the local community, village panchayat. This can expedite the process of mobilizing the SHGs and women end-users in general. NGO’s major roles and responsibilities involve,

- Mobilizing the women SHGs to initiate the project activities in the area (Necessary support and resources for this purpose shall be extended through the SC²MF team in field).
- Discuss and finalize the cookstove awareness and promotion campaign designed by SC²MF for this area and execute the same in a systematic manner. This shall also include the demonstration of cookstoves and trial runs of the stoves in selected households. A point of consideration here is that, in most rural households the end-users of the stove are women but the decision to buy the stove is made by household heads (customers are mostly men). The awareness and promotion shall be thus designed keeping these facts in mind.
- In the next step, NGO shall identify interested women who are ready to invest in the cookstove and participate in the project. However, as per the FI’s requirements, minimum 5 women members from any SHG should be ready to purchase the stove in order to avail the stove finance facility from the FI.
- Also, for non-SHG members or individual customers, option will be given to purchase the stove by paying upfront the full price of stove and then enrol for climate credits under the project.
- The NGO will then help the interested SHGs in passing a resolution and submitting the loan application to the FI.

**Step 4:** When the local branch of the FI gets the application, it will verify and complete the loan formalities. After completing the formalities, the FI shall avail the loan to the SHG and inform about the same to the local partner NGO and SC²MF field staff.
**Step 5:** Once the loan is approved, the local partner NGO will contact the stove manufacturer who will supply the stove through its local sales agent, also known as Energy Enterprise (EE). As there are no such energy enterprises for forced draft cookstove manufacturers, TERI has taken a lead in creation of local energy enterprises that will serve as a “last mile” sales and service outlets for the cookstoves deployed under C2P2. TERI builds capacity, and facilitates linkage with manufacturers to local entrepreneurial youth who invested in shop space, interiors and inventory for these physical retail sales and service outlets for clean energy technologies including cookstoves under DFIR-TERI clean energy partnership. EE is selected based on their past business experience in local markets, credit worthiness, conduct in society and recommendations from eminent/responsible citizens in that area.

EE serves two critical purpose that often hinder scale up of stove usage - post dissemination maintenance & service and availability user finance. It is often not viable for manufacturers to incur travel/salary expenses to maintain service network in rural areas (unless assured of minimum customer density) and prospective customers are not willing to purchase stoves till they are assured of prompt after sales service. Further, non-usage of a product due to service issues can lead to non-payment of loan installments, thereby discouraging stove financing. This energy enterprise model is expected to be financially sustainable in long run as entrepreneurs operate on margins (instead of salary/project support) and earn revenue from sales and service of multiple clean energy products. Presence of a local service network also encourages stove finance as banks are assured of service during the credit period.

![Figure 1: LaBL Energy Enterprise Presence- National](image)

TERI aims to facilitate establishment of 500 such energy enterprises (45 currently operational across six states) by 2015; selected and established under TERI-DfID programme for clean energy access in rural areas that will sell clean cooking technologies and provide prompt and reliable post-sales service at fair price. Manufacturers of all quality clean energy products can tap
into this network of TERI supported retail outlets to introduce/ sell/ provide post sales service for their products.

Figure 2: LaBL Energy Enterprise Presence- Uttar Pradesh

EE’s role in this project would be to ensure the sales and after sales service of the offered cookstoves. EE shall install the cookstove in households already approved by FI or individual buyers (NGO to coordinate the process) and provide initial training to the end users. EE will also coordination with the manufacturer and other elements in the supply chain and manage the supply and demand in their service area.

**Step 6:** Once the stove is installed in the households, next steps will be to track the stove usage in each participant’s household and calculate the climate credits earned by each women. The incentives so estimated for each stove will then be credited to corresponding women’s bank account.

**Stove Usage Tracking**

Tracking the individual stove usage is one of the most important activities under C2P2. As depicted in the Climate Credit Tracking System of Figure 1, this process will first involve the collection of stove usage data through TERI’s data logger inbuilt in the stove charge controller. This collection will be carried out in association with the Village Oversight Committee which will act as a data filtering mechanism. The data so gathered will then be validated by Nexleaf’s more reliable temperature sensor assembly connected to a sample of stoves registered under the project. This data will then go to UCSD where, with support from the VCRs, it will be processed to calculate the climate credits (CO₂ and SLCP credits).
**Village Oversight Committee (VOC)**

This will be a 5-6 member local body constituting of representatives from the village panchayat, local partner NGOs and youth volunteers. The purpose of forming a VOC is two-fold.

1. **Awareness and Motivation**- The senior members of the committee, during regular village level meetings, will highlight the importance of improved cookstoves in terms of women and child health and environmental protection. SC²MF field staff will train the VOC on C2P2 objectives and expected outcomes and seek regular feedback based on the village level meets. To keep the women end-users motivated, SC²MF along with the VOC will award “Paryavaran Mitra” (Friend of Environment) certificates to regular stove users on quarterly basis. This will be in addition to the carbon credit incentives credited to end-users accounts.

2. **Volunteer Visits to track stove usage**- Youth volunteers of the committee will be responsible for making bi-weekly visits to households participating in the project and collect stove usage data from the data logger inbuilt in the stove as well as through an interview schedule. These volunteers will also help in repair and maintenance of stoves through the local EEs, in case such need arises.

**Stove in-built data logger**

This data logger is a circuit assembly in-built in the stove to track the usage of power pack that runs the fan (forced draft). The system is a cheap and low maintenance solution to track stove usage at a large scale. Village volunteers will be trained to perform this task (Refer Annexure 3: Data Logger Manual) for regular update of stove use by women.

**Nexleaf Temperature Sensor**

Nexleaf Analytics’ temperature sensor is a more accurate way of determining stove usage and shall help in triangulation of the stove usage tracking process. (Refer Annexure 4 for Sensor Technology and Usage Manual).

**Climate Credit**

Once the data is gathered and validated, it will be submitted to UCSD for computing the climate credits. Based on the stove usage data, UCSD will come up with the carbon offset estimates (direct CO₂ offsets provided by TERI) as per the methodology described in earlier sections. These estimates will be sent to the Voluntary Carbon Registries (VCRs) like American Carbon Registry (ACR) and SGS to convert the carbon offsets into climate credits. The figure in USD obtained for each stove, based on prevailing rates in the carbon markets, will be sent to the SC²MF which will then convert it into INR at current rates and transfer to corresponding user’s bank account.

**International Oversight Committee (IOC)**

The International Oversight Committee (IOC) will constitute of eminent scientists and in the field of Climate Sciences, Technology and Environment along with renowned Development professionals and Policy makers. IOC shall advice the SC²MF on strategic issues along with regular feedback on the functioning of C2P2.

**Table 1: Stove Costing and EMI structure (This will vary from state to state in India as per applicable tax laws and is detailed for the state of Uttar Pradesh)**
1 USD = 60 INR

<table>
<thead>
<tr>
<th></th>
<th>INR</th>
<th>USD</th>
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<tbody>
<tr>
<td>Stove Price for end-users</td>
<td>4,200</td>
<td>70</td>
</tr>
<tr>
<td>External Viability Gap Funding</td>
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<tr>
<td>Net Price of Stove for End User</td>
<td>3,400</td>
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<td>Upfront payment by End Users</td>
<td>500</td>
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<td>End User Financing</td>
<td>2,900</td>
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<td>EMI payable (24 month tenure @13% p.a.)</td>
<td>138</td>
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<tr>
<td>C2P2 Incentives (this will vary based on usage)</td>
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<td>1</td>
</tr>
<tr>
<td><strong>End User's monthly net repayment</strong></td>
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<td>1.2</td>
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<table>
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<th>Integrated Domestic Energy System (COOKSTOVE+LIGHT+MOBILE CHARGING)</th>
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<td>1 USD=</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDES Price for end-users</td>
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<td><strong>End User's monthly net repayment</strong></td>
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</tr>
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</table>

The actual working mechanism to make this operational shall be discussed with financial institutions in each of the project area and finalized accordingly.

**Appendix 1: Global Warming Potentials**

The GWP is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas:

\[
GWP(x) = \frac{\int_0^{TH} a_x \cdot [x(t)] \, dt}{\int_0^{TH} a_r \cdot [r(t)] \, dt}
\]
where TH is the time horizon over which the calculation is considered; \(a_x\) is the radiative efficiency due to a unit increase in atmospheric abundance of the substance (i.e., Wm\(^{-2}\)kg\(^{-1}\)) and \([x(t)]\) is the time-dependent decay in abundance of the substance following an instantaneous release of it at time t=0. The denominator contains the corresponding quantities for the reference gas (i.e., \(\text{CO}_2\)). The radiative efficiencies \(a_x\) and \(a_r\) are not necessarily constant over time. While the absorption of infrared radiation by many greenhouse gases varies linearly with their abundance, a few important ones display non-linear behaviour for current and likely future abundances (e.g., \(\text{CO}_2\), \(\text{CH}_4\), and \(\text{N}_2\text{O}\)). For those gases, the relative radiative forcing will depend upon abundance and hence upon the future scenario adopted.

The denominator is AGWP, the absolute GWP of \(\text{CO}_2\). It can be calculated for any time period. In order to calculate the relative GWP of any climate forcer, the additional information needed is the forcing efficiency, which corresponds to the change in radiative forcing caused by a pulse emission of 1kg of the pollutant, i.e. \(d(\text{forcing})/d(\text{mass})\). For these calculations, forcing/mass is used as an approximation. Global averages are used, but these can be updated for regional numbers. Second, a time threshold needs to be established. The IPCC uses GWP20 and GWP100 (20 yrs and 100 yrs), we will also use an additional horizon of 37 yrs, i.e. the time till 2050 (estimated horizon for a +2K temperature change, BAU). Note that if the study period is delayed, this time will need to be appropriately decreased, i.e. to GWP36 in 2014 and so on. The final parameter that needs to be specified is the e-folding time for the pollutant.

The GWP is then calculated using the definite integral

\[
\text{GWP} = \left(Fe \times \int \exp\left(-\frac{t}{\tau}\right)dt\right)/\text{AGWP}
\]

Where \(\tau\) is the e-folding time in years for the pollutant of interest, \(Fe\) is the forcing efficiency of the pollutant, in W m\(^{-2}\)kg\(^{-1}\).

The forcing efficiency \(Fe\) can be estimated as the ratio between the average net radiative forcing and the average atmospheric burden of the pollutant of interest. As an example, using the Ramanathan and Carmichael (2008) scenario for Black Carbon,

- BC radiative forcing = 0.9 W m\(^{-2}\)
- BC emission rate = 8 Tg yr\(^{-1}\)
- Average BC burden = 8 Tg yr\(^{-1}\) x \(\tau\) yr = 8\(\tau\) x \(10^9\) Kg
- \(Fe = \frac{1.125}{\tau} \times 10^{-10}\) W m\(^{-2}\) kg\(^{-1}\)

AGWP is the CO2 absolute global warming potential in W m\(^{-2}\) kg\(^{-1}\) yr, calculated using the Bern CO2 life cycle model, and

The limits of integration are between 0 and [20,37,100] depending on which GWP is being calculated.

**Appendix-2: Co-emitted GHGs | Methane; ozone precursors (CO and VOCs)**

In addition to particulate emissions, the incomplete combustion of complex biomass in cookstoves produces gas-phase emissions, not all of which are carbon neutral. According to the IPCC, reductions in four gas phase emissions should be considered when evaluating the GWP mitigation from implementing a clean cookstove project. These are – Carbon Monoxide (CO) which can be as high as 15% of the total CO2 emission in a traditional cookstove and a large contributor to localized air pollution; Methane (CH4) which is a part of the Kyoto accord and a very potent GHG with an atmospheric lifetime of 12 years; Non-Methane Volatile Organic Compounds (NMVOCs) that contribute to climate forcing by providing a pathway for ozone formation; and Nitrous Oxide (N2O) which is also a powerful greenhouse gas and a part of the Kyoto accord.
Due to the relatively long lifetime of these gases, calculating the GWP is more complex than that of particulates. Here we present the GWP100 as determined in the IPCC report. This can be used as a conservative estimate at this stage.

In a series of laboratory tests, McCarty et al. (2008) established the gas-phase emissions per Kg of wood used in both the traditional and forced draft stoves. These can be combined with the burn rates and scaled similarly to BC as described in Section 2.1 (Step 2) to determine the mitigation per minute of forced draft use; and then converted to equivalent CO2 credits

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emission, g/Kg wood (traditional)</th>
<th>Emission, g/Kg wood (forced draft)</th>
<th>Emission, g/min (traditional)</th>
<th>Emission, g/min (forced draft)</th>
<th>Mitigation, g/min of FD stove use</th>
<th>GWP-40</th>
<th>Eq.CO2/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>117.35</td>
<td>6.14</td>
<td>1.76</td>
<td>0.06</td>
<td>1.77</td>
<td>1.9</td>
<td>3.38</td>
</tr>
<tr>
<td>CH4</td>
<td>1.90</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.03</td>
<td>45</td>
<td>0.74</td>
</tr>
<tr>
<td>NMVOC</td>
<td>4.44</td>
<td>2.45</td>
<td>0.07</td>
<td>0.02</td>
<td>0.05</td>
<td>12</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>Total GHG</strong></td>
<td><strong>123.69</strong></td>
<td><strong>8.59</strong></td>
<td><strong>1.85</strong></td>
<td><strong>0.08</strong></td>
<td><strong>1.85</strong></td>
<td><strong>4.66</strong></td>
<td></td>
</tr>
</tbody>
</table>

Therefore, approximately 4.66 g CO₂ equivalents are mitigated per minute by using the forced-draft stove. Again, using a daily cooking time of 3 hours, this corresponds to an additional 4.66 * 180 * 350 = 294 Kg CO₂ equivalent/year, or approximately 0.3 tons CO₂/year. Use of 40-yr would have increased these numbers by a factor of 2 to 0.6 tons/year which is about 20% of the BC mitigation effects.


State of Forest Report of Forest Survey of India (FSI), 2011.


