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India's Clean Energy Initiative and Black Carbon Emissions: Data and Tests

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ABSTRACT

In India, residential sector represents the largest single source of black carbon (BC) emissions from the use of cow dung cake, wood or coal, in heating stoves, Chullah's and Kerosene lamp and its radiative forcing is a significant source of uncertainty for health and climate impact. A descriptive assessment was carried out through regression analysis to evaluate the relationship between socioeconomic variables, fuel use, leading causes of biomass fuel use, possible impact of BC, mitigation Measures and barriers to implementing clean fuel initiatives in 900 Households during April to June, 2015. It also looks at changes in this fuel use before and after clean energy program was introduced in India. Per household/month consumption of firewood in rural areas was 154.4 kg. Monthly per household consumption of LPG is 10.3 kg, and a household with access to LPG spends Rs. 218.54 per month on an average. LPG was the primary source of fuel for cooking in 65% of urban households. Firewood and kerosene are reported as primary sources of cooking fuel in 17% and 6% of the households, has been reported in urban households. The results of the model suggest that there is both room optimism and pessimism. One perspective on the data results suggests that there is a good chance that India will grow its way out of the cookstove conundrum; that is there is reasonably good evidence to suggest that fuelwood use may initially increase but the fall at still low NSDP levels.

1.Introduction

Black Carbon (BC) is a constituent of $PM_{2.5}$ together with organic carbon (OC), sulfate ($SO4^{-2}$), nitrate (NO^{-}_{3}), etc. which contributes the adverse impacts on human health, ecosystems, etc. The main sources of BC include residential and commercial combustion and transport, which accounted for 80% of anthropogenic emissions in 2005[1]. Other important sources include industrial processes and the burning of agricultural waste. Kerosene lamps may also be a significant source [2]. BC has short atmospheric lifetime and is referred to as SLCPs. It is also inert and can be transported over great distances [3,4,5]. BC affects the optical properties of the atmosphere when suspended, and is recognized as the second most important anthropogenic forcing agent for climate change after carbon dioxide (CO_2) [6, 7]. Therefore, the benefit of BC control for air quality is obvious. BC has the warming effect not only by absorbing heat in the atmosphere but also by reducing albedo over snowand ice [8, 9]. On the other hand, BC is emitted along with light-scattering OC whose reduction has an adverse effect from the climate point of view [10]. Therefore, the net effect of practical BC reduction on climate is complicated and obscure.

India has highest rank in South Asian black carbon emissions at 64% with other countries Pakistan, Sri Lanka, Bangladesh, Nepal and Bhutan. In India, residential (Households) sector represents the largest single source of black carbon emissions from the use of cow dung cake, wood or coal, in heating stoves, Chullah's and Kerosene lamp. Approximately 72% of all households in India rely on traditional energies for their cooking needs. Reducing atmospheric concentrations of black carbon in India can result in improved public health (premature deaths) and a slowing of the rate of near-term climate change. The acute respiratory infections, the leading cause of childhood mortality in India, were almost twice as likely in households in India that used only biomass for cooking and heating as in households using cleaner fuels [11]. The actual impact of black carbon could not quantify in India and need a greater research studies on impact of black carbon.

In part due to this uncertainty, the government of India has taken several initiatives such as black carbon research initiative under the National Carbonaceous Aerosols Programme (NCAP) in 2011; use of CNG in vehicles; Sustainable Transport (BRT System); Off Grid/Decentralized Renewable Energy; National Programme on Improved Chulhas (NPIC) in 1985–1986 and then National Biomass Cookstoves Initiative (NBCI) in 2009 with some improved technology to reduce or mitigate household emissions and improvement of health status. But these initiatives have limitations, for example NBCI is not achieving their 100% targets due to inadequate technology, awareness among households, fuel availability, inadequate laboratory infrastructure and human capital.

Recognizing the need to make progress on BC reductions or mitigation from residential area and allied sector, this paper examines national action, options for national action, co-benefits of implementing certain measures, and factors

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affected these programs. The study aims to answer the following questions:

- What are the main sources, impacts and mitigation options for black carbon in South Asia (India)?
- What are the factors that can help/hinder clean cookstoves?
- How much have those factors affected the implementation of previous cookstoves programs over time and across India?
- What lessons can be learned from an analysis of promoting and inhibiting factors?

2.0 Material and Methods

In developing countries, black carbon is primarily emitted from "domestic use." A large part of the developing countries' population lives under the poverty line and hence are unable to afford cooking methods or technologies that result in complete combustion of the fuel. Poverty and the associated combustion practices contribute heavily to expanding the black carbon emissions in developing countries. An assessment model is developed (Fig.1) to answer the sources, impacts and mitigation of BC India.

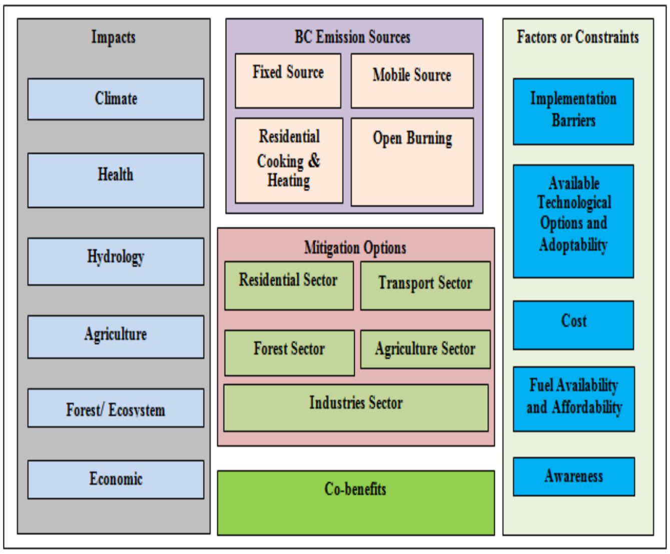

Figure 1. Assessment Framework

Secondary data was collected from various sources like research paper, study reports, Census of India and other government data for selection of study area. And also about 900 Households were selected randomly in thirty six selected villages (25 households/village) in Sitapur, Patna and Murshidabad districts of IGP in April to June, 2015. Each Household was interviewed by pre-design questionnaire to understand fuel consumption pattern or type of fuel being used, health impacts, barriers related to clean fuel accessibility and adoptability among users in IGP.

3.0 Secondary and Primary Data Analysis

3.1 Sources of Black Carbon

On a global basis, approximately 20% of black carbon is emitted from burning biofuels, 40% from fossil fuels, and 40% from open biomass burning [6]. In India, it is estimated that biofuel use for cooking in the residential sector accounts for 40% of all black carbon emissions (**Fig.2**). Additional emissions from the residential sector include emissions from heating and lighting, but emissions factors for these activities are uncertain [12]. Open biomass burning of agricultural waste and forests accounts for 24% of all black carbon emissions in India, while transportation and industry contribute 21% and 15%, respectively [13].

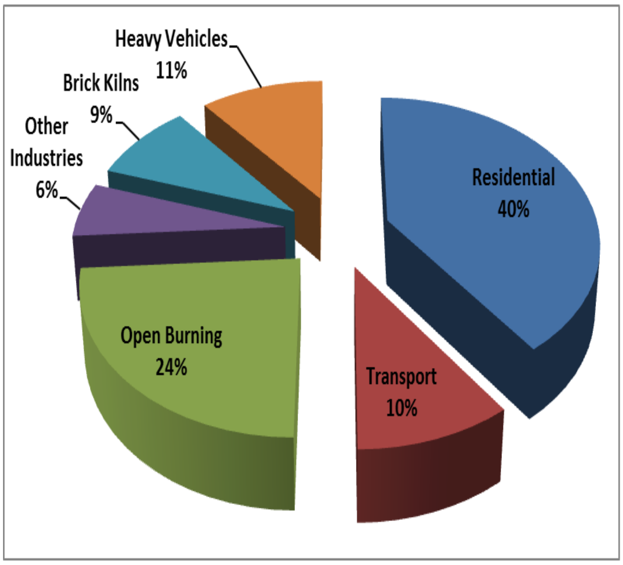

Figure 2. Sectoral black carbon emissions in India.

It is estimated that biofuel use for cooking in the residential sector major source of black carbon emissions. Firewood was primary cooking fuel and LPG [14]. All-India sample data indicated that firewood is primary energy source for cooking in 49% of households, whereas LPG in only 29% of households. Crop residue (9%) and Dung cakes (8%) exhibit considerable significance in the cooking fuel as the primary cooking fuel (**Fig.3**).

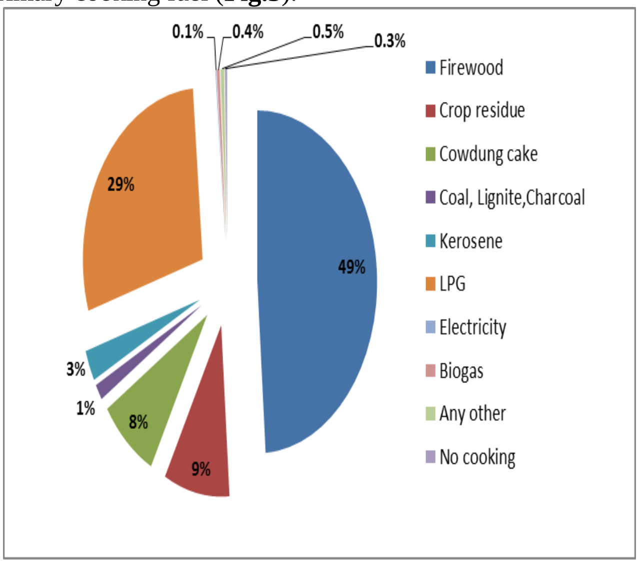

Figure 3. Percentage of Indian Households using various sources of household energy.

The below bar charts (**Figure 4a & 4b**) present a simple illustration of how firewood and LPG use varied between the years 2005-2011. As is clear from the chart, there is significant variation across different states and years. For instance, Tripura typically has the highest levels of use of firewood, while the UTs typically have the highest levels of LPG use in 2011. At the other end of the spectrum, Punjab typically has the lowest levels of firewood use, while Bihar typically has the lowest levels of LPG use in 2011. Further, the years with the highest levels of use of firewood and LPG are 2004-05 and year 2009-10 respectively. The years with the lowest levels use of firewood and LPG are 2009-10 and 2004-05 respectively. Descriptive data for the firewood and LPG are reported in Table 1.

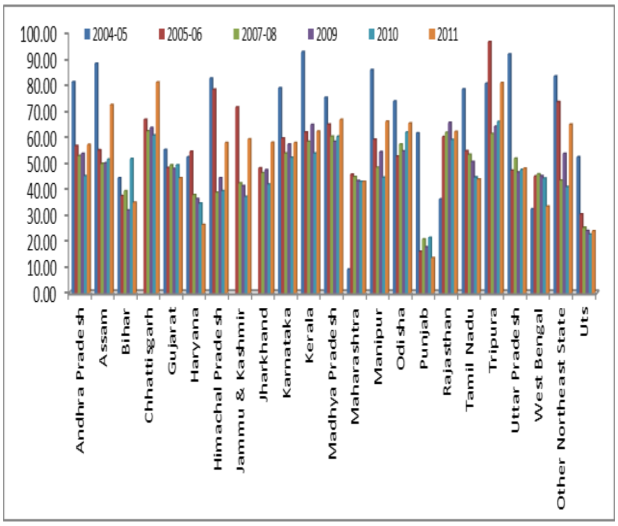

Figure 4a. Percentage of Firewood Consumption from 2004-05 to 2011.

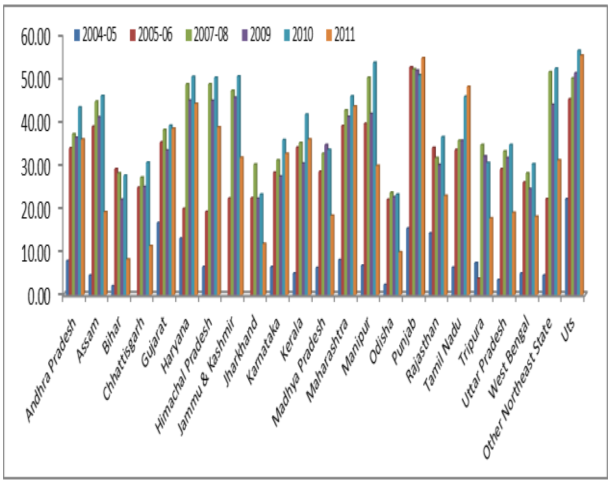

Figure 4b. Percentage of LPG Consumption from 2004-05 to 2011.

The survey results indicate that 80-95% households in rural areas rely on traditional cooking fuels such as firewood, coal, coke, and dung cakes in study area which is almost similar to national and state fuel consumption pattern. Firewood was the primary energy source for cooking in 74% of rural households in Sitapur, followed by crop residue (10.61%), cow dung cake (10.31%), whereas LPG was the primary cooking fuel in only 4.38% of rural households. Coal, kerosene and biogas exhibit considerable significance in the cooking fuel as 0.05%, 0.13% and 0.11% respectively (Fig. 5). In Patna, cow dung cake was the primary source of fuel for cooking in 59.44% rural households. Firewood, crop residue, LPG, kerosene, coal and biogas were reported as primary sources of cooking fuel in 18.62 %, 11.35%, 6.26%, 0.37%, 1.10% and 0.74% of the urban households respectively. While in Murshidabad, crop residue was the primary source of fuel for cooking in 57.62% rural households followed by cow dung cake (21.0%), firewood (13.24%), LPG (2.30%), coal (2.29%), biogas (0.11%) and kerosene (0.10%).

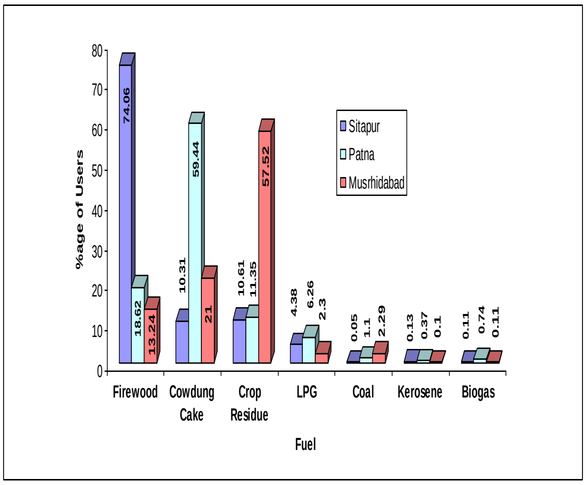

Figure 5. Energy Pattern in Sampled Districts.

Table 1. Percentage of Firewood and LPG Consumption from 2004-05 to 2011.

States/UTs	Firewood						LPG					
	2004-05	2005-06	2007-08	2009	2010	2011	2004-05	2005-06	2007-08	2009	2010	2011
Andhra Pradesh	80.85	56.40	52.50	53.35	44.85	56.80	7.75	33.75	37.00	36.20	43.17	35.80
Assam	87.96	54.70	49.50	49.72	51.21	72.10	4.46	38.70	44.50	40.92	45.83	19.00
Bihar	44.03	37.16	39.00	31.62	51.36	34.70	1.97	28.93	28.00	21.87	27.44	8.10
Chhattisgarh	NA*	66.48	62.00	63.30	60.38	80.80	NA	24.68	27.00	24.85	30.46	11.20
Gujarat	54.91	47.97	49.00	47.60	49.01	44.00	16.51	35.10	38.00	33.23	38.95	38.30
Haryana	52.10	54.20	37.50	36.07	34.25	26.10	12.91	19.80	48.50	44.77	50.28	44.00
Himachal Pradesh	82.30	78.00	38.50	44.05	39.02	57.50	6.37	19.10	48.50	44.65	50.04	38.60
Jammu & Kashmir	NA	71.20	42.00	41.02	36.81	58.90	NA	22.20	47.00	45.42	50.32	31.60
Jharkhand	NA	47.84	46.00	47.10	41.54	57.60	NA	22.23	30.00	22.10	23.10	11.70
Karnataka	78.58	59.25	53.50	57.00	51.86	57.50	6.35	28.15	31.00	27.25	35.65	32.50
Kerala	92.42	61.60	58.00	64.43	53.49	61.90	4.86	33.95	35.00	30.22	41.55	35.80
Madhya Pradesh	74.90	64.59	60.00	57.96	59.90	66.40	6.14	28.32	32.50	34.53	33.42	18.20
Maharashtra	9.00	45.40	44.50	42.94	42.61	42.60	8.00	38.90	42.50	40.98	45.70	43.40
Manipur	85.50	58.76	48.00	54.01	44.29	65.70	6.66	39.44	50.00	41.68	53.45	29.70
Odisha	73.47	52.38	57.00	54.26	61.57	65.00	2.27	21.89	23.50	22.47	23.05	9.80
Punjab	61.24	15.80	20.50	17.50	21.13	13.40	15.26	52.42	52.00	51.70	50.59	54.50
Rajasthan	35.91	59.79	61.50	65.30	58.74	61.80	14.14	33.85	31.50	29.90	36.32	22.80
Tamil Nadu	78.09	54.45	53.00	50.30	44.30	43.50	6.23	33.36	35.50	35.50	45.62	47.90
Tripura	80.35	96.20	61.00	63.77	65.67	80.50	7.29	3.70	34.50	31.86	30.41	17.60
Uttar Pradesh	91.52	46.95	51.50	46.25	47.19	47.70	3.35	28.95	33.00	31.48	34.55	18.90
West Bengal	32.13	44.69	45.50	44.77	43.85	33.10	4.87	25.88	28.00	24.39	30.10	18.00
Other Northeast State	83.11	73.19	43.10	53.41	40.60	64.52	4.40	22.04	51.30	43.76	52.13	31.00
UTs	52.04	30.18	25.00	23.77	22.40	23.69	22.00	45.04	49.86	51.05	56.27	55.13

Note: NA*- Data not available, Other Northeast States (Arunachal Pradesh, Mizoram, Nagaland, Meghalaya and Sikkim) and UTs: - Union Territories (Delhi, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep, Pondicherry and Andaman & Nicobar Islands).

In all districts, per household per month consumption of firewood in rural areas was 154.4 kg. Monthly per household consumption of LPG is 10.3 kg, and a household with access to LPG spends Rs. 218.54 per month on an average. LPG was the primary source of fuel for cooking in 65% of urban households. Firewood and kerosene are reported as primary sources of cooking fuel in 17% and 6% of the households, has been reported in urban households. The percentage distribution of households by primary energy source for cooking is presented in **Fig. 6.** This is clearly observed between rural and urban areas in the pattern of energy use for cooking. Approximately 83% households in rural and 21% households in urban areas rely on traditional cooking fuels such as firewood, coal, coke, and dung cakes.

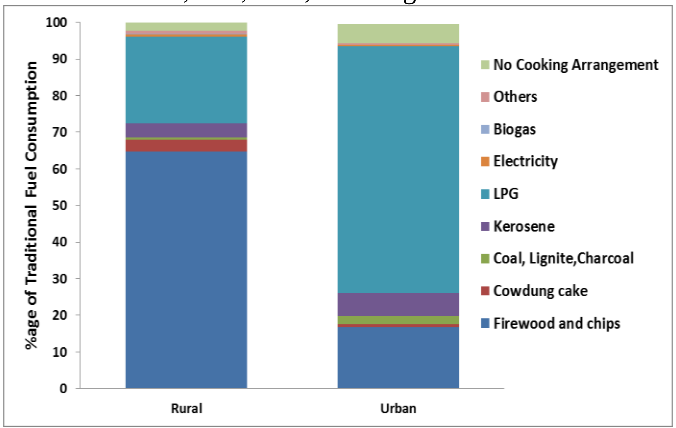

Figure 6. Percentage of Households by Primary Energy Source of Cooking.

3.1.1 Leading Causes of Biomass Fuel Use in Rural India

Due to population growth and economic development, India's energy consumption is increasing rapidly. Energy and energy technologies have a central role in social and economic development at all scales, from household and community to regional and national. Among its welfare effects, energy is closely linked with public health both positively and negatively, the latter through environmental pollution and degradation. The three main determinants in the transition from traditional to modern energy use are:

- Affordability
- Fuel availability, and
- Cultural preferences

3.3 Impact of Black Carbon

BC absorbs solar radiation and releases the energy as heat, which contributes to a strong regional and global atmospheric warming and accelerates the melting of ice and snow not only from atmospheric heating but also from the heat absorbed by black carbon soot. The direct effects of BC result in significant climate warming globally and regionally, provoking a broad swath of additional impacts as well [15].There is a growing consensus that black carbon emissions are of concern because of their impacts on climate, health, water and food resources, seasonal weather patterns, and livelihoods. A recent report UNEP identified reducing black carbon (as well as other short-lived pollutants) as a real opportunity to slow the rate of near-term climate change, improve public health, and reduce crop-yield losses, with near immediate results, especially in areas of the world such as South Asia [16]. A number of recent studies and assessments have pointed to the possibility that reducing BC could provide economic, environmental and social benefits within the next several decades. Some direct and indirect co-benefits of BC reduction are summarized below:

- Reduction of GHGs and other air pollutants (CO, SO_2, PM_{10} etc.)
- Reduction of other SLCPs (OC, O_3)
- Reduction in global and local temperature
- Reduction in Flood chances or hydrological drought
- Improvement in Monsoon fluctuation and crop production.
- Reduction in Health Problem (Women and Children), health expenses and mortality
- Increased water availability for domestic purposes,
- Employment Generation and improvement in economic condition of people.

3.4 Mitigation Measures of Black Carbon

Efforts to reduce black carbon emissions in South Asia (India) can therefore aid in reducing adverse impacts on population in this region, while also helping to reduce contributions to global climate change. The transportation and industrial sectors are also significant contributors. Approximately, 21% and 15% BC arises from transportation and industrial sectors which can be reduce through fuel switching, use of ultra-low sulphur diesel, use of clean fuel, use of ESP and process modification or change in kiln. And while 24% BC emissions form open biomass burning (Forest and Agriculture waste burning) which can also control through some technical initiatives such as social forestry, Joint Forest Management (JFM) and generation of awareness among the farmers.

In India, the residential sector represents the single largest source of black carbon emissions. Recognizing the acuteness and scale of the residential black carbon problem in India, the Govt. of India (GoI) embarked on an effort to identify and evaluate unique low-cost but high-impact opportunities to reduce black carbon emissions in South Asia. As part of this effort GoI has taken several initiatives like National Programme on Improved Chullah in 1983, National Biomass Cookstoves Initiatives in 2009 and Black Carbon research initiative under the National Carbonaceous Aerosols Programme (NCAP) in 2011 which is briefly described below:

3.4.1 National Programme on Improved Cookstoves (NPIC)

The Ministry of New Renewable Energy (MNRE), Govt. of India launched a National Programme on Improved Chulhas (NPIC) in 1985–1986. The programme objectives were identified to be (i) fuel wood conservation; (ii) removal/reduction of smoke from kitchens; (iii) reduction of deforestation and environmental degradation; (iv) reduction in the drudgery of tasks performed by women and girl-children and their consequent exposure to health hazards; and (v) employment generation in rural areas. In 2002 the NPIC was deemed a failure and funding was discontinued; responsibility for continued ICS dissemination was passed to the states. There were numerous barriers to introducing clean cookstoves. These include not only technical issues but also financial, social and institutional issues.

In view of the above, MNRE had explored the possibilities for launch of a new programme on Improved Biomass Cookstoves that aims to facilitate the development of the next generation of biomass stoves for household and community cooking and their widespread deployment with multiple benefits of health, mitigation of climate change and energy conservation. MNRE had incorporated some countermeasures into its new cook stove program and launched a new National Biomass Cookstoves Initiatives in 2009.

4.4.2 National Biomass Cookstoves Initiatives (NBCI)

As follow up to the aforesaid barriers, a National Biomass Cookstoves Initiative (NBCI) was launched by MNRE on 2nd December 2009 with the primary aim to enhance the availability of clean and efficient energy for the energy deficient and poorer sections of the country. It emphasizes on enhancement of technical capacity in the country by setting up state-of-the-art testing, certification and monitoring facilities and strengthening R&D programmes in key technical institutions. To reduce BC emission, some other points are highlighted below:

- Improving the Efficiency of Brick Making in the Industrial Sector.
- Replacing traditional brick kilns with vertical shaft kilns and with Hoffman kilns.
- Improving Public and Private Fleet Efficiency and Management in the Transportation Sector.
- Fuel switching in both Industrial and transportation sector.
- Improving the efficiency and adoption of Cookstoves in the residential sector.
- Use of renewable energy eg. Solar heater and biogas.
- Ban of open field burning of agricultural waste.
- Provide technical assistance and training to agricultural staff and people
- Encourage community level village development groups.
- Give demonstration on benefits of crop residue by the agriculture department eg. Fodder availability, soil quality, etc.
- Generation of awareness among the farmers.
- Promote Social Forestry system
- Organise regular community health camp.

4.4.3 Barriers to Implementing Clean Cookstoves

Much of the literature on cook stoves has highlighted these barriers—and much of that literature has focused on India e.g. “Cleaner Hearths, Better Homes: New Stoves for India and the Developing World”. There have been an equally diverse range of countermeasures to overcome these barriers—and many of these have been proposed for India which is highlighted in **Table 2**.

5.0 Results and Discussion

This section provides a descriptive assessment of varying levels of firewood and liquid petroleum gas (LPG) use in India through regression analysis to evaluate the relationship between socioeconomic variables and fuel use levels. It also looks at changes in this fuel use before and after a 2009 program was introduced to induce a shift to cleaner fuels in India’s states and union territories.

The data analyzed herein is based on annual survey of Indian households over the period 2005-2015 (currently data for the year 2007 is missing) as well primary survey on types of fuel consumption; the original data included firewood, cow dung cake, kerosene, LPG and coal. The fuel use data are measured in percentage terms from the Census of India and the National Sample Survey (NSS). In addition, per capita net state domestic product (NSDP) and Human Development Index (HDI) data were obtained from the Planning Commission of India. The survey involved about 900 households in 2015. The data covers 23 out of 25 states and UTs. Due to a lack of data, Goa and Uttrakhand states were not included in the analysis.

5.1 Variable Construction

This section is intended not only to demonstrate variation in the levels of firewood and LPG use. It is meant to determine whether and to what extent key independent variables such as NSDP and HDI can help explain this variation. The typical approach used to assess the magnitude and significance of different explanations is regression analysis. While the majority of regression analyses employ ordinary least squares (OLS), the data for this paper violates OLS assumptions. Namely, OLS assumes that estimated residuals—the difference between estimated and actual values of the dependent variables—are uncorrelated with each other as well as the independent variables. Because this is time series data, the residuals are closely correlated. Further, regular OLS regression does not consider heterogeneity across groups or time.

Rather than using an OLS model, this section relies on a pooled (cross sectional) time series models. One of the advantages of using a pool time series models is it increases the number of observations. This, in turn, increases the degrees of freedom needed to test a wider range of alternative explanations than would be possible in a model with, for instance, 30 units. In so doing, it also avoids the possibility of omitted variables that could bias the estimated values of coefficients.

The section uses three types of pooled time series models to discern what kinds of income and developmental variables are associated with these differing levels of fuel use. Altogether the section examines the effects of five independent variables in Box 1.

Box 1

- Per Capita Net State Domestic Product (NSDP) (Natural Log)
- A Squared Version of Per Capita NSDP (Natural Log)
- The Human Development Index (HDI)
- Dummy Variables for Data After the Year 2009
- Dummy Variables for Data for States and Union Territories for States and Union Territories

In using five variables for a pooled time series, it is important to discuss variable construction and hypotheses. A key independent variable is the measure of wealth or NSDP. The units for this variable have been transformed to their natural logarithms. This transformation was carried out because the original variables are not distributed normally; rather much of the distribution was concentrated at the lower levels of income with a few outliers at the upper end. To give the data a more normal distribution, taking natural logarithms increases the spread at the low end of distribution and brings in the higher valued units. All else being equal, I anticipate as states and UTs become wealthier they will use less firewood and more LPG. Similarly and once again holding other variables constant, I anticipate that wealthier states and UTs will use less firewood and more LPG.

The model also includes a squared version of the NSDP variable. This is done to see whether there are any non-linearities in the relationship between NSDP and fuel use. It is possible, for instance, that the use of fuels could rise at certain levels of development and then fall once surpassing certain thresholds. This is, in fact, the type of relationship that has been posited in the much-studied Environmental Kuznets Curve (EKC)—a curve that has suggested that pollution levels will initially rise at early stages of development before hitting an inflection point and then falling[**39**]. We anticipate that such an inverted U-shaped relationship will hold across differ states and time.

Table 2. Barriers to Implementing Clean Cookstoves Programme

Category	Barrier	Location and Study Cite	Countermeasures
Financial	High Initial Costs	• East Africa[17] • Gambia[18] • India[19] • Karnataka, Andhra Pradesh, West Bengal, India[20] • Bangladesh[21]	• Provide government/donor subsidies for poor families • Emphasize low-cost stove designs • Access clean development mechanism (CDM) carbon credits • Encourage private sector participation • Encourage and train local artisans • Use local material for cook stove manufacturing
	High Fuel Costs	• India[19, 22] • Africa[17] • China, Sri Lanka, Indonesia[23] • Bangladesh[21]	• Establish decentralized fuel supply network around target areas • Enhance research and development on locally appropriate fuels
	Fossil Fuel Subsidies	• India[19, 22] • Kenya[24] • Maharashtra, Haryana, Karnataka, Gujarat, Andhra Pradesh, West Bengal, India[20] • Nepal[25]	• Promote commercialisation of cook stoves • Introduce well-targeted subsidies and equitable pricing • Link financial assistance to performance of the technology/income of the user • Create a revolving fund to finance dissemination activities (awareness raising, etc). • Access CDM carbon credits
Social	Reluctance to Abandon Accepted Practices	• India[22] • Nepal[26] • Maharashtra, Haryana, Karnataka, West Bengal, India[20]	• Field test to ensure user acceptability • Established centers for field testing • Organize awareness raising and training activities
	Limited Awareness (Impacts, Alternatives, Government Programs)	• Maharashtra, India[19] • Haryana, Maharashtra, Karnataka, Gujarat, Andhra Pradesh, India[20] • India, Pakistan, Nepal, Bangladesh, Bhutan, Afghanistan, Sri Lanka, Maldives[27] • Nkweletsheni community in Kwa-Zulu Natal, South Africa[28] • Nepal[25]	• Organize multi-media awareness raising campaigns • Educate consumers about impacts (i.e. indoor air quality) • Develop and encourage women's and other community groups • Use marketing strategy to target key consumer groups • Encourage commercialization of programs and initiatives • Build stakeholder networks linking dealers, entrepreneurs and shop owners • Develop and encourage women's and other community groups • Organize community level training camps with technical, social and non-governmental organizations (NGOs)
	Limited Stakeholder Engagement	• India[29] • Nepal[30] • Maharashtra, Haryana, Karnataka, Gujarat, Andhra Pradesh, West Bengal, India[20]	• Empower NGOs and technical backups • Organize community level trainings with multiple stakeholders • Organize monthly review meeting with government officials
Technical	Poor Stove Design	• India[22] • East Africa[29] • Kenya[30,31] • Zambia[32] • Indonesia[33] • Ghana[19] • China[34, 35] • Maharashtra, Haryana, Karnataka, Gujarat, Andhra Pradesh, India[20]	• Modify existing design protocol • Design various sizes of stoves to ensure user acceptability • Field test to ensure user acceptability, especially for women • Emphasize low cost designs • Use appropriate materials and mixtures in cook stoves manufacturing • Build technical cell to evaluate stove designs and performance • Promote centralized production of stoves and parts
	Acceptability of Technologies	• Nepal[26] • Haryana,India[20]	• Use marketing strategy to target key consumer groups • Field test to ensure user acceptability, especially for women • Build stakeholder network linking dealers, entrepreneurs and shop owners

Category	Barrier	Location and Study Cite	Countermeasures
			• Organize multi-media awareness raising campaigns
	Lack of Repairs and Maintenance	• India[19] • Maharashtra, Haryana, Gujarat, Andhra Pradesh, West Bengal, India[21]	• Encourage and train local artisans, especially women • Organize multi-stakeholder community level training camp • Empower NGOs and technical backups
	Lack of Local Manufacturers	• India[22] • East Africa[29] • Zambia[32] • Andhra Pradesh, India[20]	• Encourage and train local workers • Empower small scale industrial units • Encourage centralized production of stoves and its parts • Encourage private sector participation • Promote commercialization of cook stoves
Institutional	Bureaucratic Fragmentation	• India[36] • Maharashtra, India[19] • Karnataka, Andhra Pradesh, West Bengal, India[20]	• Set up national program to be implemented by a single nodal agency • Reduce bureaucracy for effective implementation of national programs
	Lack of Capacity, Training and Monitoring	• Karnataka, Maharashtra, Haryana, Gujarat, Andhra Pradesh, West Bengal, India[20] • Nepal[25, 37] • Bangladesh[38]	• Empower NGOs and technical backups • Build stakeholder network linking dealers, entrepreneurs and shop owners • Empower existing technical resources • Establish multiple centers for technical assistance • Develop and encourage women's and other community groups • Develop private public partnerships (PPP) • Encourage and train local artisans • Certify facilities that can be run by independent organizations • Develop performance standards for certification • Organize community level training sessions • Establish field training and monitoring centers for potters and artisans
	Lack of Approved Suppliers, Entrepreneurs and Vendors	• Maharashtra, Haryana, Gujarat, India[20]	• Commission certification centers • Develop performance standards for approval • Build stakeholder network linking dealers, entrepreneurs and shop owners

A HDI variable is also included in the model. HDI originated in the early 1990s in an effort to develop a measure of prosperity that was more people-centered than simple income measures. It typically includes both income as well as measures of education and life expectancy. HDI was chosen because many of the behaviors that induce different types of fuel use are not perfectly correlated with levels of incomes. There is clearly some correlation with NSDP variables but not perfect one to one relationship. The scale of the HDI variables used in the model runs from 0.358 to 0.79. As with the wealth variables, I anticipate that both across states and time, higher levels of HDI will be associated with less use of firewood and greater use of LPG.

The other two variables are dummy variables for both the period and places where the India's clean cookstove programs were introduced and implemented. As discussed previously, the program was initially introduced in 2009 by the India's federal government. However, due to delays in program roll-out, eight states were chosen as target areas with the expectation that those states would be pilots before the program. For the first dummy variable-labeled program.dummy1-I have coded the 2010 and 2011 with a one and left the earlier years with a 0 to see whether the national program had significant impacts on fuel use. For the second dummy variable-labeled year. dummy. Program-I have coded the states and UTs that were the target of the special pilot programs. For both the dummy variables, I anticipate that the coefficient will be negative for firewood and positive for LPG.

Clearly there are other variables that could be included the model. For instance, natural resource endowments such as forested areas could have an important effect on firewood and is not controlled for in the current model. Similarly, climatic conditions could influence availability of firewood if certain years or locations receive an abundance of precipitation and this leads to greater firewood use. As for LPG, subsidy programs that are concentrated in certain regions or years could have a bearing on the dependent variables. Future iterations of this work will aim to include these variables (though to a certain extent the pooled time series will absorb specific to province or time effects). Another possible area for improvement is the dummy variables.

Box 2. Hypotheses.

Cause	Effect
Per Capita Net State Domestic Product (NSDP)	
H0: If NSDP(ln) increases **HA: If** NSDP (ln) increases	No impact on Fuel Consumption Use less firewood and more LPG
H0: If NSDP (R2) increases **HA: If** NSDP (R2) increases	No impact on Fuel Consumption Use less firewood and more LPG
Human Development Index (HDI)	
H0: If, HDI is increased **HA: If,** HDI is increased	No impact on health Use less firewood and more LPG
National Improved Cookstoves Program (NICP)	
H0: Implementation of NICP **HA:** Implementation of NICP	No impact on Fuel Consumption Whether the national program had significant impacts of fuel use

A dummy is admittedly a coarse proxy for a program that could be implemented with varying degrees of rigor across space and time. In the future, finer grained measures of implementation stringency will be sought such as resources spent on administration or personnel appointed to oversee the program.

In sum, we anticipate the relationships specified in the null and alternative hypotheses in box 2.

5.2 Hypothesis Tests and Results

This section uses the variables from above to test the hypotheses in Box 2. It will employ two types of pooled time series models: a fixed effect model and a random effects model. The fixed effect model assumes that there is heterogeneity over time within states and UTs that need to be controlled for in the model. The random effects model assumes that there is not only heterogeneity within but across different states that, once again, needs to be controlled for in the model. As will be discussed later, both models cannot only help to test the main hypotheses on the linkages between the independent and dependent variables. Rather a Hausman test can help determine what would be a better model given the current data (**Table 3**). The results to the fixed and random effects for fuelwood and LPG follow.

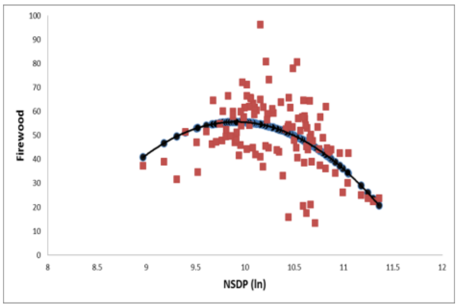

Figure 7a. Trends of Firewood Consumption.

The first noteworthy result involves the sign and

significance of the NSDP variable for firewood in both the fixed and random effects model. Contrary to expectations, the coefficient is positive and likely to be different from zero. This result, however, should not be interpreted independent of the squared NSDP coefficient. The squared NSDP variable is negative and statistically significant. The combination of a positive coefficient for the unsquared term and negative coefficient for the squared term suggests that there is a curvilinear relationship between firewood and income (**Figure 7a**).

That is, similar to the Environmental Kuznets Curve firewood use increases and then falls at a certain inflection point. The results for the LPG variable are also illuminating. Here again both the NSDP and its square are statistically significant; thus, use of LPG increases with income (**Figure 7b**)

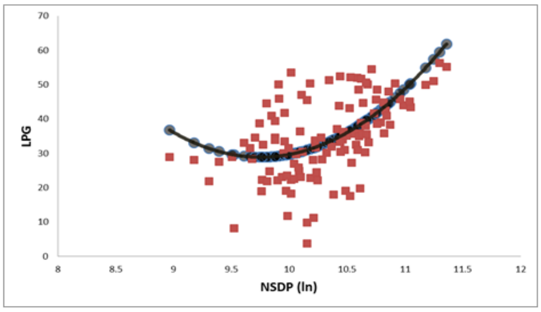

Figure 7b. Trends of LPG Consumption.

The results from the HDI variable are no less interesting. For firewood, both the fixed and random effects model suggests that we cannot be certain that this relationship is not equal to zero. For LPG, both the fixed and random effects suggest that increases in HDI lead to a statistically greater reliance on LPG. This result might be attributed to the inclusion of the NSDP variable (and it square) which, because of its close correlation with income, is soaking up some of the explanatory power of HDI. It could also be attributed to the difficulties of measuring HDI at the sub national level.

Another key set of variables are the dummy variables for the years after the India cookstove program was introduced; and the states where the program was initially targeted. For both these dummy variables for both fuelwood and LPG and in both the random and fixed models, there is insufficient statistical evidence to reject the null hypothesis.

That is, one cannot be certain that the new program is having a significant effect on fuelwood use or LPG use.

On a related note, however, one interesting finding examines whether a fixed or random effect model would be more suitable for analyzing this data. If the results of the Hausman test yield a p-statistic that is above the 0.05 threshold, then random effects is the proper model specification. If it is below 0.05, then fixed effects is the proper specification. Since the Hausman test produces an X, it is more appropriate to use a random effects model. This is important because it suggests that there is not only real heterogeneity over time but within groups.

This infers that there are many within state and within year effects that can help explain the variation in fuel use. Greater research needs to be done into these spatial and temporal effects.

5.3 Indoor air quality

The major finding of this study is that BC concentrations during cooking hours, both indoors and outdoors have anomalously large concentrations. The type of cooking fuel was also a major factor in concentrations of BC. Focusing on the quantitative values, **Figure 8** shows the indoor variation of BC concentrations in selected households. During morning cooking hours (06:00 to 09:00 AM) BC concentrations varied from 1.80 to 41.2 μgm^{-3} with an average value of 12.15 μgm^{-3}.

Table 3. Results Analysis.

Dependent Variables		Firewood		LPG	
Independent Variables		**Fixed effects Model**	**Random Effect Model**	**Fixed effects Model**	**Random Effect Model**
NSDP(ln)	Coefficient	230.4076	-407.426	328.74895	-249.253
	SE	126.1255	121.1242	520.3971	84.6852
	T-Test	1.8268	-3.3637	-3.023	-2.9433
	Prob.	0.07112	1.14E-03**	0.001586**	3.96E-03**
NSDP(square)	Coefficient	-12.3141	20.52702	-16.58946	12.781
	SE	6.1697	5.92505	4.94807	4.1272
	T-Test	-1.9959	3.4611	-3.3527	3.0967
	Prob.	0.04904	8.32E-04***	0.001098**	2.48E-03**
HDI				23.248	29.19749
				25.6514	17.96227
				0.9063	1.6255
				0.366772	0.106946
Program Year-2009	Coefficient	2.245	-0.98131	2.54354	-1.7018
	SE	3.2726	3.14278	3.15361	2.9321
	T-Test	0.686	-0.3122	0.8065	-0.5804
	Prob.	0.49451	0.755594	0.421667	0.562821
Year for Pilot-2014	Coefficient	2.669	-2.01083	0.73589	-1.5867
	SE	2.5052	2.4059	1.95627	1.8025
	T-Test	1.0654	-0.8358	0.3762	-0.8803
	Prob.	0.28962	0.405537	0.707516	0.380624

Similarly, during evening cooking hours (17:00 to 20:00 PM) BC concentration varied from 1.90 to 40.5 μgm^{-3} with an average value of 11.5 μgm^{-3}. The large variation in the BC concentrations observed during cooking hours could be attributed to the fact that not all households cook at the same time; some households start cooking early around 05:00 AM while other start a little later. Similar reasoning also explains occasionally sharp peaks in BC concentration (>30 μgm^{-3}) during the morning and evening cooking hours.

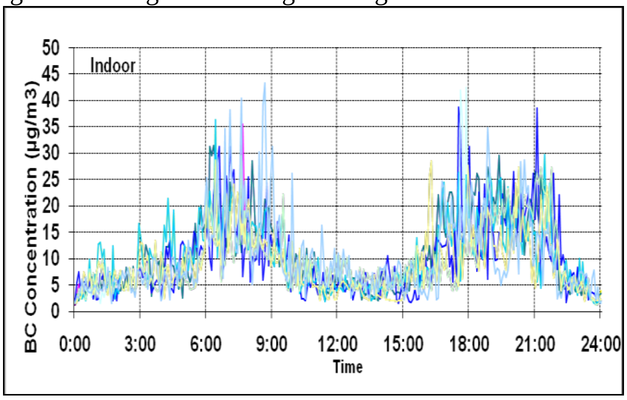

Figure 8: Black Carbon Emission in Households

5.4 Health Impact due to Biomass Fuel

The health effects of biomass smoke inhalation may not be restricted to the lungs because biomass smoke contains fine and ultra fine particles that readily cross the alveolar-capillary barrier and reach vital organs of the body through circulation. It is conceivable; therefore, that biomass smoke exposure could lead to systemic health impairment. However, little attention has been focused on the health impact of biomass fuel use in rural India. Cooking areas of many Indian households are poorly ventilated, and half of the households do not have separate kitchen. To a considerable extent life revolves around the cooking area, and women spend much of their time there, exposing themselves to high pollution levels. In India, 0.4 to 2 million premature deaths occur per year due to indoor air pollution with a majority of deaths occurring in children under five due to acute respiratory infections. The survey results indicate that 80-95% households in rural areas rely on traditional cooking fuels and also strong evidence of impact on women due to use of biomass (**Fig. 9**). During the survey, watering from eyes was found major problem in 26% households followed by eyes itching (25%), Asthma & respiratory (22%), cardiovascular disease (17%) and coughing in 10% households. Monthly per household expenditure on health was Rs. 258.34 on an average.

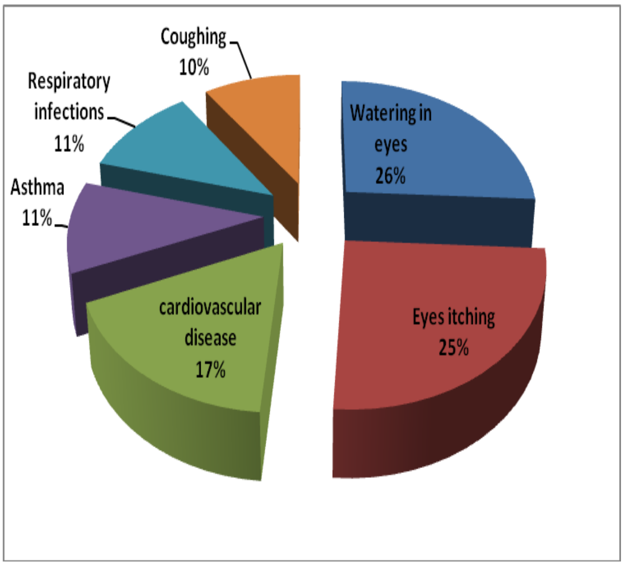

Figure 9. Health Impacts due to Biomass Fuel.

6.0 Conclusion

This article focused on one of the most frequently cited solutions to air pollution and near term climate changes: clean cookstoves. The potential benefits of clean cookstoves have long been understood. Initial waves of interest precede the current increased attention by at least forty decades. However, even with past and recent interest, often the projected benefits of clean cookstoves have gone unrealized. This is particularly true in India where cookstoves are an integral part of daily life. India's clean cookstove programs have often encountered a series of financial, institutional and social barriers. These include, for instance, community reluctance to adopt unproven technologies. They also include frequently high initial costs of these technologies.

Approximately 83% households in rural and 21% households in urban areas rely on traditional cooking fuels such as firewood, coal, coke, and dung cakes. To quantify BC concentrations, field measurements were conducted in 900 Households during April to June, 2015. Per household per month consumption of firewood in rural areas was 154.4 kg. Monthly per household consumption of LPG is 10.3 kg, and a household with access to LPG spends Rs. 218.54 per month on an average. LPG was the primary source of fuel for cooking in 65% of urban households. Firewood and kerosene are reported as primary sources of cooking fuel in 17% and 6% of the households, has been reported in urban households.

India has nonetheless recently stepped up efforts to improve on its earlier lackluster track record. A new cookstove program that was adopted in 2009 and rolled out in 2010-2011 aims to overcome many of the aforementioned barriers by disseminating and scaling up cleaner technologies. The article then gathered data and developed regression models to see whether and to what extent the program has succeeded with these goals. The models included a series of socioeconomic variables as well as dummy variables for the year when the program began and the states and UTs that were targeted for initial piloting. The results of the model suggest that there is both room optimism and pessimism. One perspective on the data results suggests that there is a good chance that India will grow its way out of the cookstove conundrum; that is there is reasonably good evidence to suggest that fuelwood use may initially increase but the fall at still low NSDP levels. Equally encouraging is that LPG use tends to increase over the developmental trajectory, albeit at a declining rate. Another less hopeful perspective would point to the apparent ineffectiveness of the newly initiated cookstove program. There is not sufficient evidence to assert that the program is currently having either an effect on fuelwood or LPG use.

There are many possible reasons for the set of results. Perhaps the most logical is that the recently started program is still in its infancy; it will take time before the program's effects are clearly visible. Another interpretation is that the barriers are so numerous and cumbersome that it will take more than a single program to alter fuel use patterns. Instead, broader developmental changes to both lifestyles and markets are more likely to yield demonstrable impacts. Policy can complement these changes, but will not be the driving force for these changes. A third interpretation involves the aforementioned use of dummy variables for the cookstove program; there is a greater need to understand where and to what extent the program was introduced with what kind of effort. Getting data for such a variable or qualitative case studies can help generate insights into the strength of program implementation. This—along with a fuller data set—will be pursued in future iterations of the project.

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