WORKING PAPER 58/2011

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K.S. Kavi Kumar and Brinda Viswanathan

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

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K.S. Kavi Kumar
Professor, Madras School of Economics,
kavi@mse.ac.in ; kavikumar@gmail.com

and

Brinda Viswanatha
Associate Professor, Madras School of Economics,
brinda@mse.ac.in

WORKING PAPER 58/2010

June 2011

Price : Rs. 35

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

Phone: 2230 0304/2230 0307/2235 2157
Fax : 2235 4847/2235 2155
Email : info@mse.ac.in
Website: www.mse.ac.in

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Abstract

Solid fuels are still a major source for cooking in many households in India causing significant disease and global warming burden. This study analyses the pollution-income relationship (for both local and global pollution), separately across rural and urban households in India based on unit record data on fuel consumption obtained through National Sample Survey data for 2004-05. Based on the estimated relationship, the study makes an attempt to project household level pollution for 2026. The study further analyzes the health burden and greenhouse gas emissions under various policy scenarios including deeper penetration of clean fuels and wider utilization of improved cook stoves.

Keywords: *Cooking Fuels, Air Pollution, Energy Policy, Health Burden*

JEL Codes: *Q25, Q40, R20 and D10*

Acknowledgements

An earlier version of this paper was presented at SANDEE @ 10: Environment and Development in South Asia, conference organized by the South Asian Network for Development and Environmental Economics at Kathmandu (December, 2010) and at MIDS-ICSSR National Seminar on 'Indian Economy in Transition: Prospects, Issues and Concerns', Chennai (February 2011). The authors gratefully acknowledge the valuable comments given by the conference participants.

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INTRODUCTION

The energy use at household level in a society is an important factor in determining the stage of development, status of local environment inside the house, and also the global emissions contributed by the region. A large number of Indian households, especially in the rural areas, still depend on solid fuels for cooking purpose. Barring a few exceptions in Eastern India firewood, dung and other bio fuels constitute bulk of the solid fuels used by the Indian households. It is now well documented that use of such fuels for cooking, particularly in kitchens without proper ventilation and using stoves with very low efficiency, results in significantly high emissions of various pollutants. The associated adverse health effects are also well documented. It is now becoming clear that incomplete combustion of these fuels leads to emission of black carbon, whose control is essential for climate change mitigation. Though income continues to be a significant determinant of solid fuel consumption, substantial scope exists for policy intervention. In this context, promotion of 'cleaner' fuels such as liquefied petroleum gas (LPG) and cleaner stoves assume greater importance. The penetration of LPG for cooking has seen significant surge in some states in India, whereas in other states its consumption is still relatively lower. Clean cookstoves programs launched earlier in India have not been very successful, but the recent new program launched by the Government of India aims to renew the efforts in this context and proposes to provide clean energy through next-generation of household cookstoves.

Given this background this paper attempts to analyse the trend and pattern of fuel use at household level in India using unit record data from the National Sample Survey for the year 2004-05. The paper estimates the relationship between income and pollution and uses the same to project local and global emissions from the Indian households under various policy scenarios, including the deeper penetration of clean fuels and wider utilization of improved cook stoves for the year 2026.

The paper is structured as follows: The next section provides a brief overview of the various strands of related literature. The third section describes the trend and pattern of fuel consumption across various regions of India. Profile of local and global emissions for the year 2004-05 is also provided along with its patterns across states and monthly per capita expenditure (MPCE) classes. The fourth section describes the econometric methodology and data used to estimate the income-pollution relationship and discusses the results obtained. The fifth section presents the estimates of future projections of local and global emissions from the Indian household sector under various policy scenarios. The last section provides concluding remarks.

HOUSEHOLD ENERGY AND POLLUTION

While the literature on household level energy use and resultant pollution is rich and vast, the review here focuses on three relevant strands for this study: (a) indoor air pollution and health burden; (b) access to clean energy, energy demand and pollution at the household level; and (c) modeling income-pollution relationship.

Health Burden due to Solid Fuels

Solid fuels burned in traditional stoves often result in inefficient combustion, with less than 80-90 percent conversion of fuel carbon into carbon dioxide (CO_2). The products of incomplete combustion – such as, carbon monoxide, formaldehyde, benzene and many other pollutants that have potential to cause health hazards – get emitted through small particles in many houses using the solid fuels.

Given that most houses have inadequate ventilation for kitchens, and living rooms are not separated from kitchen areas, the emissions from use of solid fuels are inhaled routinely by the members of the household. Particularly the women, children and elderly in the house get maximum exposure from these emissions.

Several studies have now conclusively established relationship between exposure to indoor pollution and some significant health risks. It must be noted that, since exact measurement of indoor pollution and the associated exposure is often difficult, most studies have linked use of solid fuels with the observed health burden. Despite the inaccuracies, the evidence on health burden appears to be robust (Ezzati, et. al., 2004). Smith *et al*. (2004) observe that most common health problems associated with exposure to indoor air pollution include (a) acute lower respiratory infections (pneumonia) in children, (b) chronic obstructive pulmonary disease, and (c) to a lesser extent, lung cancer. Health risks associated with indoor air pollution is now considered as one of the top ten risk factors in the world –countries like India and China are experiencing the maximum impact due to such risks. Balakrishnan et al (2004) in a study of indoor air pollution associated with use of solid fuels for cooking in Andhra Pradesh established that use of solid fuels for cooking exposes the members of the family on a daily basis to air pollution that is far higher than the standards prescribed for outdoor air pollution. Further the study established conclusively that even when cooking is done outside the house or in a separate kitchen, when solid fuels are used, the resultant levels of respirable suspended particulate matter (RSPM) and the household members' exposure to the same exceeds significantly the prescribed standards for ambient air. Some recent studies provide macro/micro estimates of health burden due to the use of solid fuels (Parikh *et al*., 2001, 2003; Smith and Mehta, 2000; and World Bank, 2001).

Another, relatively less discussed aspect of solid fuel usage is their contribution to global warming. The bio fuels, which constitute bulk of the solid fuels in India, are typically considered as 'carbon neutral' – i.e., the carbon released into the atmosphere through burning of these fuels is recaptured during the growth of the biomass. However, the incomplete combustion of biomass fuels releases what are known as 'black carbon' particles, which is a significantly stronger greenhouse gas pollutant than CO_2. Venkataraman *et al.* (2005) showed that use of wood and other biofuels in South Asia has resulted in release of black carbon to the tune of 172 gigagrams/year (Gg/year) in the year 1995 and almost similar amount (160 Gg/year) a decade earlier. This study also established that these emissions contributed significantly to atmospheric concentration of greenhouse gases from the region.

Enabling the household to shift from solid fuels to 'cleaner' fuels (such as LPG) for cooking results in not only reducing the health burden but also the global warming burden, and hence the climate change mitigation policies in this region should also include measures to reduce dependence of households on solid fuels for cooking. From this perspective, the National Biomass Cookstoves Initiative (NCI) launched in late 2009 by the Government of India could provide clean energy to the Indian households through next-generation of household cookstoves. These cookstoves are expected to result in particulate emissions that are similar to household using LPG. Venkataraman *et al.* (2010) estimated that about 570 thousand premature deaths and 3.2% of national disease burden would be avoided (due to reduction in particulate matter emissions) if such initiative were to be in place in 2005. Further they argue that about 4% of India's greenhouse gas emissions could be avoided through NCI. Similarly, Wilkinson *et al*. (2009) also showed significant health and greenhouse gas emission reduction benefits due to NCI. Thus, an initiative of this kind would have dual advantage of greenhouse gas emission reduction as well as health benefits. There could of course be several practical considerations in implementing such an initiative. NCI cookstoves would still be considered at the lower end of the energy ladder and also lacking in sophistication due to far lower ease of operation as a 'switch-off-switch-on' appliance like the LPG stove. At present, the NCI cookstoves have been lab-tested for certain forms of biomass, but their performance for *any* type of biomass is still unknown. On account of features that are less comfortable to operate, the acceptability of NCI cookstoves may be less widespread than envisaged.

If some of these apprehensions could be addressed, in the short run it could still prove beneficial to the poorer households allowing them to move out of energy poverty and lead healthier lives.

Household Energy Demand

In this context, an assessment of the current pattern of household energy consumption including its regional variation would be useful in estimating the current local and global emissions and the impacts of interventions like NCI cookstoves could have on these emissions. A large number of studies analyzed various issues related to household energy in India. Since a large majority depend on the so-called 'dirty' fuels (including firewood, dung, agricultural residue etc.), one of the primary areas of focus has been on access to 'clean' energy. ESMAP (2003) explored the role played by subsidies in enabling the poor to access 'clean' energy in India, while Antonette D'sa and Murthy (2004) analysed the factors determining the penetration of LPG across Indian households. These include issues concerning appropriate pricing and financing schemes, and dependable supply and delivery. Viswanathan and Kumar (2005) explored the regional differences in fuel use patterns in India. Observing that wide disparity exists between rural and urban households as well as across states, the study argues that pro-rich and pro-urban bias of kerosene supply through the public distribution system has influenced the observed variation in fuel consumption pattern. More recently, Patil (2010) provided a synthesis of the status of rural energy access in India. Arguing that the energy access levels were widely differing across the states, the study highlighted the significantly large disparity between the 'successful states' and 'failure states' in terms of the cooking energy access compared to electricity access (which could serve as a proxy for the overall development). The ratio was 5.3 and 3.4 for access to cooking energy and to electricity, respectively.

Filippini and Pachauri (2004) and Gundimeda and Kohlin (2006) used National Sample Survey data to estimate the demand elasticity for electricity and household fuels, respectively. The electricity demand is observed to be income and price inelastic, making it a necessary good while the expenditure elasticity for fuelwood was estimated to be high, indicating the likely use of this fuel for cooking purposes for a long time in India. More recent studies of similar nature have appeared in World Bank (2008) and Zigova *et al.* (2009) modeling household electricity and energy access, respectively. MestI and Eskeland (2009) used these expenditure elasticities to estimate future projections of emissions from household energy consumption. Their results showed that while deeper penetration of cleaner fuels would ensure improved health outcomes in future; however the greenhouse gas emissions would increase significantly from the household sector in India.

Environmental Kuznets Curve Hypothesis

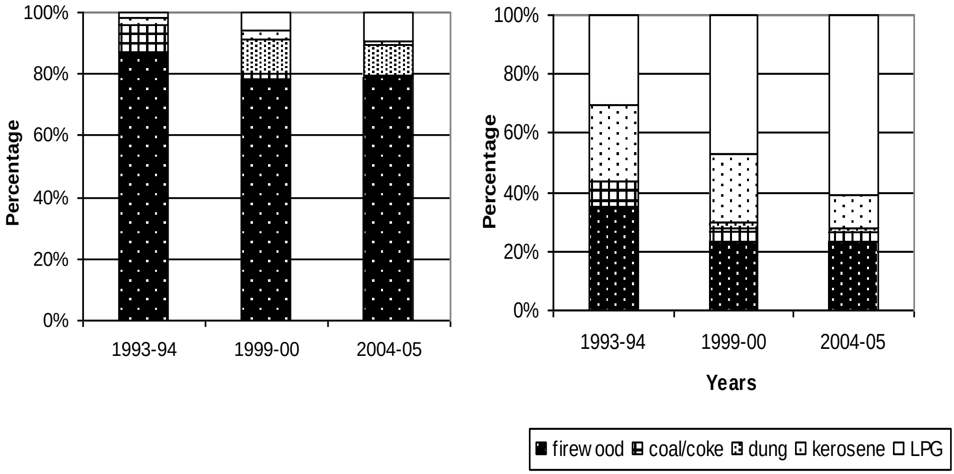
A combination of the type of energy and the efficiency of the appliances used determines the level of pollution at any given point in time for a specific region. An empirical regularity that has been observed in many instances is the inverted-U shaped relationship between pollution and income, referred as environmental Kuznets curve (EKC). This relationship has been assessed for both local and global pollutants either across a cross-section of households or countries at any given point in time or temporally for a given region and a given pollutant. While existing theoretical justifications for the EKC are largely based on macro-economic foundations, Andreoni and Levinson (2001) and Pfaff *et al*. (2004) have provided micro foundations for the EKC hypothesis. Chaudhuri and Pfaff (2002) have estimated the indoor air pollution and income relationship based on micro data for Pakistan. The study demonstrated that under plausible assumptions about the emissions implied by the fuel-use, inverted-U relationship exists between indoor air pollution and income. Kumar and Viswanathan (2007) using National Sample Survey data for the years 1983, 1993-94, and 1999-2000, showed that EKC exists for indoor air pollution among rural Indian households. Both these studies did not use directly measured indoor pollution data due to non-availability of the same. A more technically correct direct approach in measuring air pollution concentration was adopted by Zhang and Vanneman (2008) but no evidence for EKC among rural Indian households was found. However, the study results could be biased due to smaller sample and hence lesser variability in income.

Such an empirical assessment has been attracting wide-spread attention as it has enabled the understanding of the processes that have contributed to the turning point leading to a decline in pollution beyond a certain level of income. In several instances this observed decline in pollution levels after its initial rise has been attributed largely to the normal course of development. Exceptions to this, leading to either a lower peak that was achieved or a turning point earlier than the expected or both, are typically induced by technological changes and/or policy interventions. This is encouraging and beneficial to the developing countries as they need not trace the EKC and may have the option of 'tunneling through' to a lower level of pollution after a limited rise from its initial levels. The challenges to such an intervention are either institutional in terms of negotiating with the developed nations for facilitating technological transfer, or investing in indigenous research to arrive at locally suitable options.

TRENDS AND PATTERNS OF HOUSEHOLD ENERGY USE AND POLLUTION IN INDIA

Over the past one decade the composition of energy-mix showed very little variation in rural India. The evidence from NSS data shows that use of solid fuels (including, firewood, coal/coke, and dung cake) has slightly decreased from 1993-94 to 2004-05 with the percentage of households using such fuels as primary energy source for cooking declining from 95 to 85 percent. Urban India, on the other hand, registered significant change over the same period, with percentage of households using solid fuels declining from 40 in 1993-94 to 26 in 2004-05. One of the major differences between rural and urban Indian households is in terms of their use of kerosene as cooking fuel. Compared to almost negligible use of this fuel in rural India, kerosene played the crucial role as the transition fuel for urban India leading to an impressive LPG penetration. Figure 1 shows the changes in composition of various fuels used as primary cooking fuel by the rural and urban Indian households over the past decade. The rural-urban contrast firstly lies in the huge gap in the use of LPG with firewood as the most dominant primary source in rural areas. Secondly (and more significantly) the contrast is in terms of the absence of kerosene as a transition fuel in rural areas and realization of the unmet demand with other fuels like dung which are even lower than firewood in the energy ladder.

Figure 1: Primary Source of Energy for Cooking in India: 1993-94 to 2004-05



Rural **Urban**

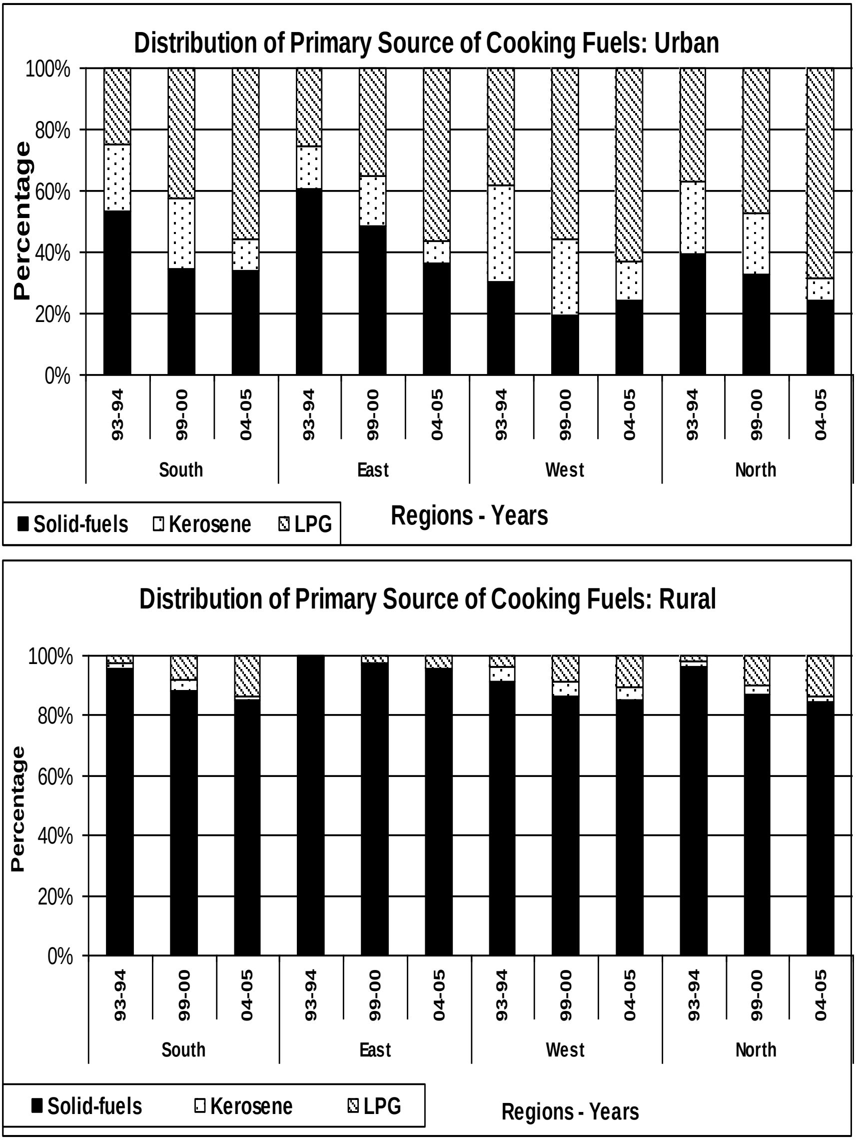
Consumption of Solid Fuels – Regional Differences

There are significant regional differences in India in terms of the consumption of solid fuels. Figure 2 shows the percentage of households using solid fuels (including firewood, coal/coke, dung cake etc.), kerosene and LPG as primary source for cooking in different regions for three time points in the past ten years for rural and urban India, respectively. In rural India, barring the Eastern Indian states, the rest of the states showed some penetration of LPG with about 10 to 12 percent of households reporting this fuel as primary source for cooking in the year 2004-05.[1] With the exception of Western Indian states, all states showed very little consumption of kerosene for cooking.

In urban India, penetration of LPG has been very impressive with all the regions having more than 50 percent of the households consuming LPG as primary cooking fuel in the year 2004-05. Further, in all the regions, kerosene served as transition fuel. In terms of the solid fuels, the Southern and the Eastern states have showed similar pattern of consumption over years, whereas the Western and the Northern states exhibited comparable consumption pattern of these fuels in the last decade.

[1] The states of India included in these regions are: 'South'- Andhra Pradesh, Karnatak, Kerala and Tamil Nadu; 'East'- Assam, Bihar, Chattisgarh, Jharkhand, Orissa and West Bengal; 'West'- Gujarat, Madhya Pradesh, Maharashtra and Rajasthan; and 'North' - Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Uttar Pradesh and Uttaranchal.

Figure 2: Distribution of Cooking Fuels across Regions and Years – Rural and Urban India



Profile of Household Emissions

The local and global emissions attributable to each household can be estimated using emission coefficients and the quantity data of each fuel consumed by the household. The National Sample Survey (NSS) data provides data on quantity of each fuel consumed for every household surveyed. In case of certain fuels like dung and agricultural residue, however the quantity data is not available. Not accounting for these fuels would lead to under-estimation of local emissions. In order to account for emissions from the fuels for which the quantity data is not available in the NSS data, the average household level energy consumption reported in other sources such as National Family Health Survey data is used. The quantity of energy attributable to dung and agricultural residue has been estimated by subtracting the energy consumed through the known sources from the average household level energy consumption.

The emission coefficients are sourced from Smith *et al*. (2000), Venkataraman *et al*. (2010), and MestI and Eskeland (2009). For the global emissions only three prominent GHGs are considered – namely, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In case of local pollution, while several pollutants like CO, NMVOC, PM, BC and OM are considered, the discussion is based only on particulate emissions. While calculating the GHG emissions from firewood it is the common practice to consider it as a carbon-neutral fuel. However, given the significant supply-demand gap reported for the firewood in various wood-balance studies, the present study assumes a non-renewability factor of 10% for firewood and hence treats it as a net emitter of CO_2. A similar approach is followed by other studies (e.g., Venkataraman *et al*., 2010).

Based on these assumptions Table 1 reports the emissions profile for rural and urban Indian households in 2004-05. The estimated aggregate local and global annual emissions are in line with other estimates reported in the literature (e.g., Venkataraman *et al*., 2010). The rural-urban differences are one of the most distinguishing features of the emissions profile reported below. While the per-capita emission of local pollution is higher among rural households, the per-capita global emissions are higher among urban households – reflecting the respective fuel use pattern.

Table 1: Household Emissions Profile – 2004-05

	Rural	Urban	All-India
Total Emissions			
PM (000 tons/yr)	806.4	103.0	908.4
CO_2 (million tons/yr)	50.2	24.6	74.8
CO_2-hh (million tons/yr)	102.0	81.4	183.6
CO_2e (million tons/yr)	138.0	85.6	224.4
Per-capita Emissions			
PM (kg/yr)	1.12	0.44	0.95
CO_2 (tons/yr)	0.07	0.11	0.078
CO_2-hh (tons/yr)	0.14	0.35	0.19
CO_2e (tons/yr)	0.19	0.37	0.24

Source: Own calculations based on NSS unit record data. Emission coefficients are from Smith *et al.* (2000), Venkataraman *et al.* (2010), and Mestl and Eskeland (2009).

Note: PM – particulate matter; CO_2 – carbon dioxide from cooking fuels; CO_2-hh – carbon dioxide from cooking fuels plus electricity consumption; CO_2e – greenhouse gas emissions from cooking fuels and electricity consumption, expressed in carbon dioxide equivalent terms.

Figure 3 shows the state-wise local and global per-capita emissions for the year 2004-05, along with national average in rural and urban households. As could be seen from the figure, the particulate matter emissions are lower among the urban households on an average across all states. However, in eastern states with access to solid fuels like coal higher particulate matter emissions are observed even among urban households. In fact the per-capita particulate matter emissions among urban households are higher than that in rural households in Jharkhand. The per-capital global emissions are uniformly higher among urban households compared to rural households across all states. The observed differences in per-capita emissions are largely a reflection of the fuel consumption pattern shown in figure 4.

Figure 3: Per-capita Local and Global Emissions: 2004-05

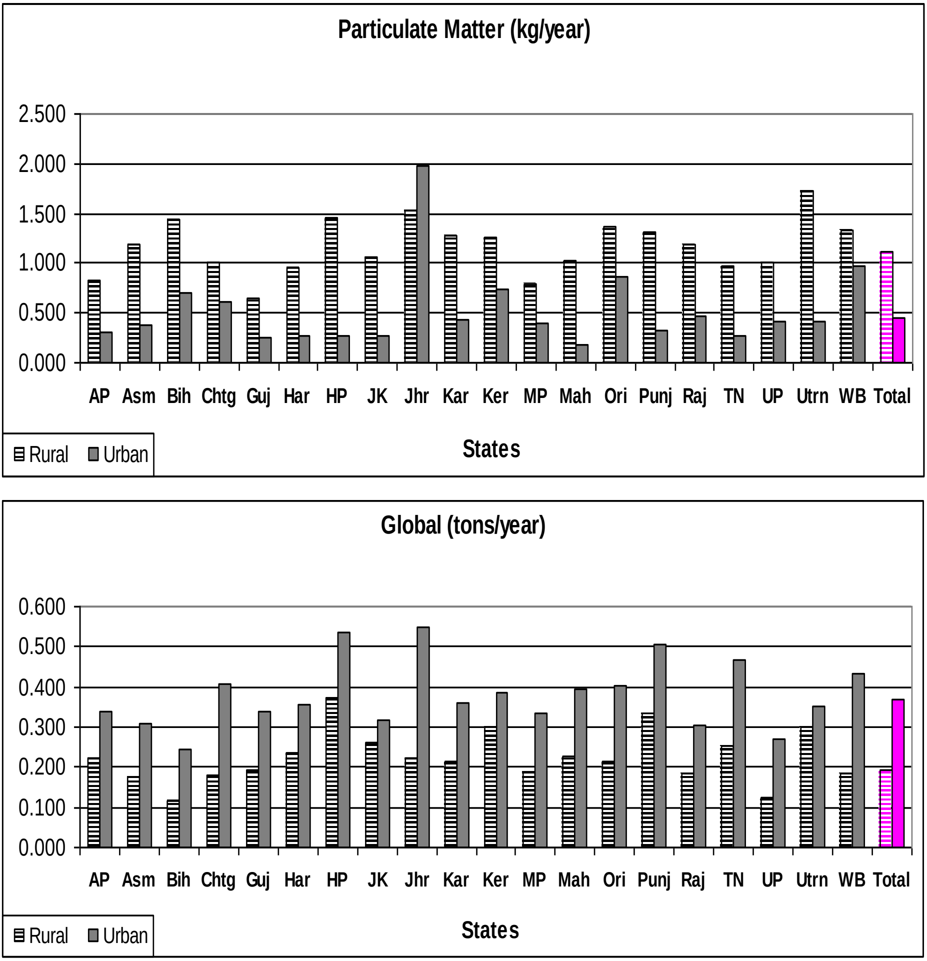
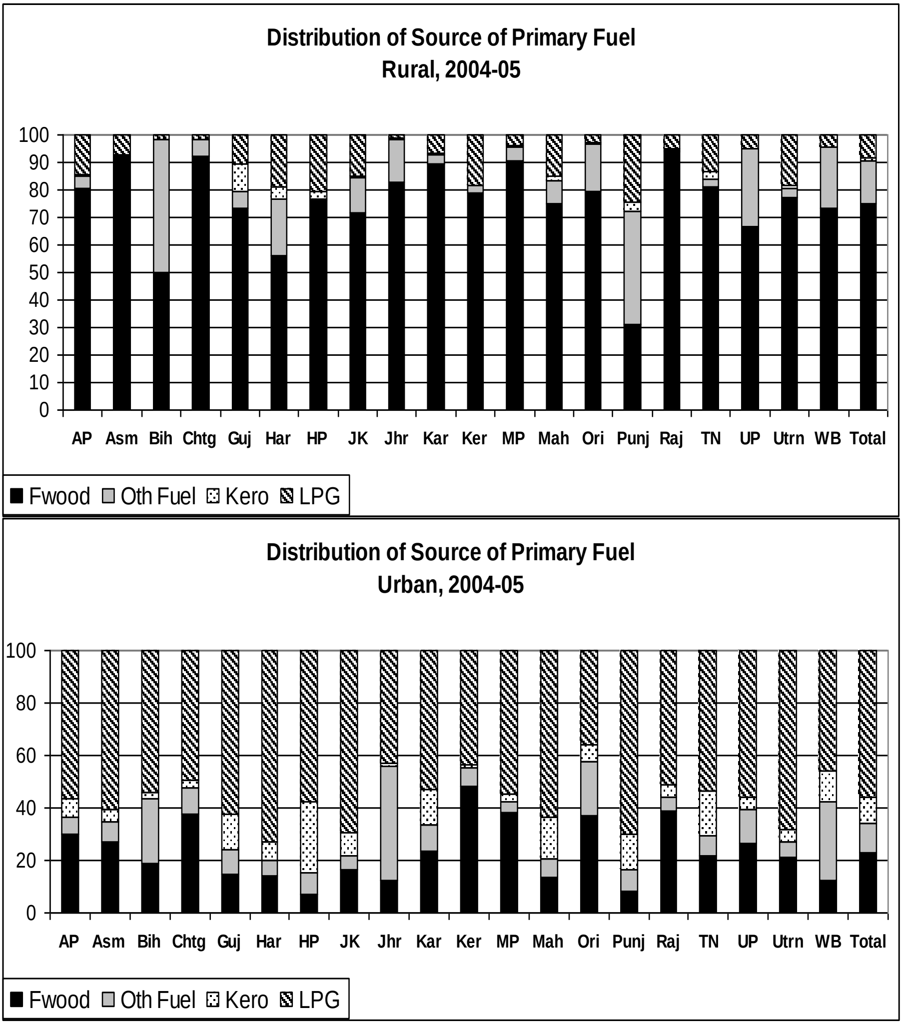


Figure 4: Household Cooking Fuel Consumption across States: 2004-05

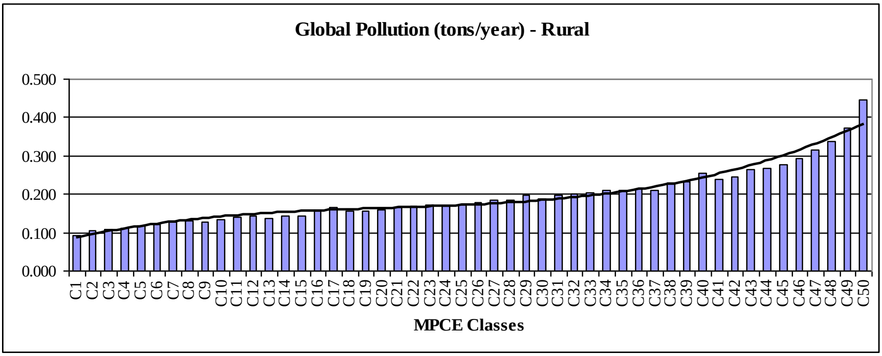


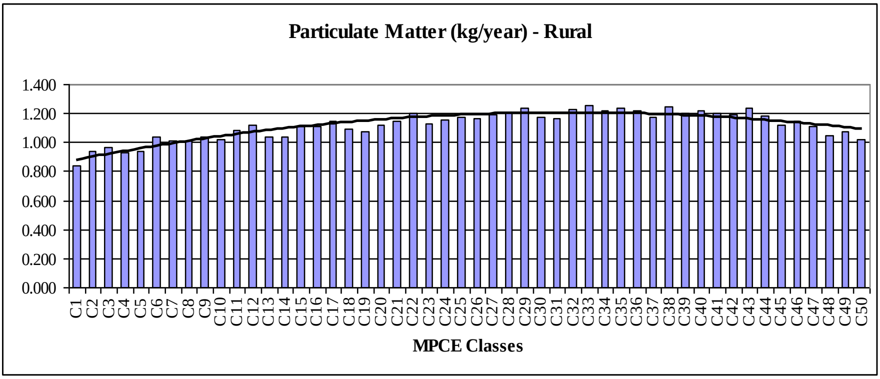
The rural households on an average depend largely on firewood for cooking purpose, however some states show an exception to this trend due to access to other fuels including agricultural waste (e.g., Haryana, Punjab) and coal (e.g., the eastern states). This is true even among the urban households – for example, Jharkhand and West Bengal report large dependence on coal and Kerala reports dependence on firewood (possibly the coconut waste). Besides access, household income plays an important role in determining the household level pollution.

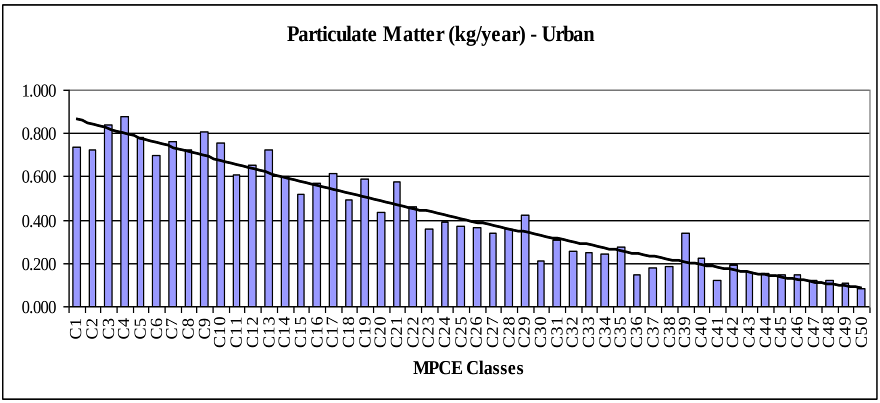
The aggregate picture reported above masks the differences across MPCE classes though regional differences are captured. Figure 5 shows the local and global per-capita emissions across monthly per capita expenditure classes[2] in India for the year 2004-05. As could be seen in case of local pollution there is a clear inverted-U shape relationship between pollution and household expenditure in rural India, while among urban households local pollution declines with income as expected. As far as global pollution is concerned there appears to be a non-linear relationship of order higher than two, perhaps a cubic relationship. Overall the global pollution is likely to increase with household expenditure. The following section econometrically estimates the pollution-income relationship using household level data.

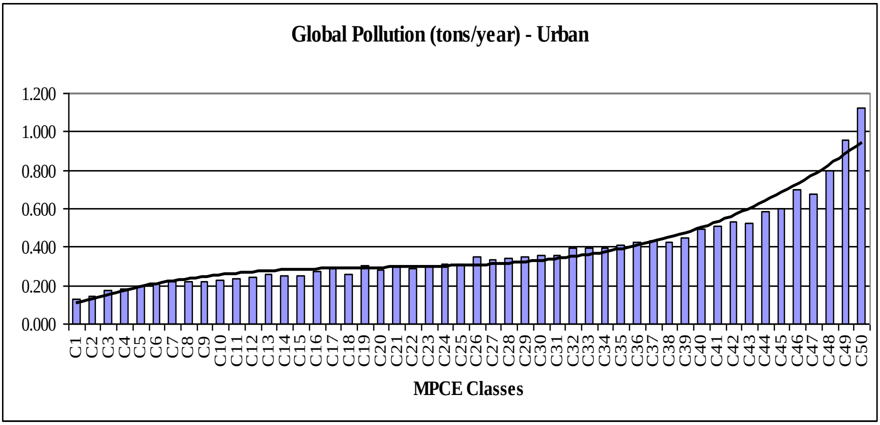
[2] For greater clarity of the pollution distribution, the households are divided into fifty equal expenditure classes.

Figure 5. Per-capita Local and Global Emissions across MPCE Classes: 2004-05









POLLUTION-INCOME RELATIONSHIP – ESTIMATION APPROACH AND RESULTS

As outlined in section 2, a number of studies have explored the relationship between pollution and income in an attempt to test existence of the environmental Kuznets' curve hypothesis. While analyses involving outdoor pollution are common, a few studies have also attempted to find relationship between indoor pollution and income (see Kumar and Viswanathan, 2007 for an analysis involving Indian data). The analysis reported here follows this strand of literature with some important new features included. Since there is no data on pollution directly available at the household level, the same is estimated in the present analysis using the household level consumption of various fuels and electricity. The household level information on fuel use, income and other characteristics is obtained from the unit record data of the 61st round of the NSS corresponding to the year 2004-05. Based on the insights obtained in the previous section, the econometric specification for the estimation of pollution-income relationship is based on the following equations:

$$PM_h = a_1 + a_2 y_h + a_3 y_h^2 + \sum b_j C_{hj} + e_h \qquad (1)$$

$$CO_2 e_h = a_1 + a_2 y_h + a_3 y_h^2 + a_4 y_h^3 + \sum b_j C_{hj} + e_h \qquad (2)$$

where, PM_h are emissions of particulate matter per month from household 'h'; CO_2e_h are the CO_2 equivalent emissions per month[3] from household 'h'; y_h is the per-capita monthly expenditure of household 'h' used as proxy for household income; C_{hj} are control variables including household size, proportion of children, choice of primary fuels expressed as ratio of expenditure on a specific fuel to the total fuel expenditure of the household, including dummy variables that capture differences between households in terms of caste, religion, occupational groups, and regions/states. Equation (1) is estimated separately for local (particulate matter- PM_h) and global (carbon dioxide equivalent- CO_2e_h) emissions. The estimations are also carried out separately for rural and urban households using all-India sample comprising of about 67000 and 38000 observations, respectively. The equations are estimated using the sampling weights so that they are representative of the population. Equation (1) has also been estimated for each of the states separately and the discussion here is largely confined to the all-India level estimations.

Pollution-Income Relationship – Local Pollution

Table 2 reports the estimated pollution-income relationship for local pollution for the rural and urban households. The estimated pollution-income relationships have several expected features with the adjusted R^2 values of about 37 percent for the rural sample and above 50 percent for the urban sample. The control variables are statistically significant and have expected impact in all regressions, including the state-level regressions. The household size coefficient is negative in all regressions due to economies of scale reflecting that - keeping MPCE, household compositions and other variables constant - households with larger size tend to consume less cooking fuel and hence could have less indoor

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[3] Three important greenhouse gases, namely, carbon dioxide, methane, and nitrous oxide are included in the calculations of carbon dioxide equivalent emissions. Also, 10 percent non-renewability factor is assumed in case of biomass based fuels and hence accounts for net positive carbon dioxide emissions from such fuels.

pollution. The coefficient for proportion of children capturing household composition is also negative indicating that households with larger proportion of children (keeping everything else as the same) report lower per capita fuel usage. The coefficients of proportions of primary fuel expenditure in the overall fuel expenditure have significant role in the estimated pollution-income relationship. In particular the coefficients of *pry-fwd* and *pry-othfl* are positive and have large magnitudes indicating that the households depending on firewood and other fuels such as agricultural residue and dung will have proportionately higher pollution levels. Based on state level estimations (results not reported here) it is observed that the coefficients of these variables have larger magnitudes (compared to the all-India average) in states that depend largely on firewood and/or other fuels, especially in rural areas. For instance in states like West Bengal, Jharkhand, and Orissa due to their greater dependence on coal and firewood; in Haryana and Punjab due to their easier access to agricultural residue and dung; and in Kerala and Uttaranchal due to their dependence on firewood.

Table 2: Pollution Income Relationship – Local Pollution

	Rural	**Urban**
Income	0.081 (0.00)	-0.005 (0.00)
$Income^2$	$-3.9x10^{-5}$ (0.00)	$2.8x10^{-7}$ (0.14)
Household Size	-6.8 (0.00)	-2.2 (0.00)
Proportion of Children	-23.4 (0.00)	-4.5 (0.04)
Pry Fuel - firewood	54.2 (0.00)	57.3 (0.00)
Pry Fuel – LPG	-10.1 (0.001)	1.3 (0.115)
Pry Fuel – other fuel	148.3 (0.00)	158.8 (0.00)
Observations	67100	37802
R^2	0.37	0.52

Note: The dependent variable is per capita PM emissions. The figures in brackets indicate the *p* values.

The estimated pollution-income relationship indicates that there is evidence for EKC hypothesis among rural households (at all-India as well as state level), whereas the pollution-income relationship is monotonic among the urban households with income having negative influence on particulate matter emissions. These results are in line with the earlier studies in this field for India (Kumar and Viswanathan, 2007) and other developing countries like Pakistan (Chaudhuri and Pfaff, 2002).

Pollution-Income Relationship – Global Pollution

In case of global pollution, as mentioned above the emissions of three main greenhouse gases (CO_2, CH_4 and N_2O are considered together) due to cooking fuels and electricity consumption by the households. The greenhouse gases are aggregated using the 100-year global warming potential of each gas and expressed in CO_2-equivalent terms. Table 3 shows the estimated pollution-income relationship for rural and urban households for global pollution. The estimated pollution-income relationships exhibit healthy goodness-of-fit with the adjusted R^2 values of about 45 percent for the rural sample and above 48 percent for the urban sample. Most of the estimated coefficients are significant.

As in case of the local pollution, the influence of household size and proportion of children is negative (keeping everything else as the same) on global pollution. Among other control variables, dependence on firewood is likely to bring down the global pollution in both rural and urban households. On the other hand the coefficient of proportion of expenditure on electricity in household’s total energy expenditure is positive and significantly large reflecting strong linkage between electricity consumption and global pollution.

The estimation results show that income, income square and income cube terms have positive, negative and positive impacts, respectively on global pollution for rural households. In the urban areas on the other hand the squared income term is not significant. Thus the dataset does not provide evidence for EKC in case of global pollution. Though the overall nature of the estimated pollution-income relationship is similar in both rural and urban areas, the income coefficient is more than two times higher for urban households compared to their rural counterparts, indicating relatively large contribution to global pollution from the urban households. On the whole the estimated pollution-income relationship for the global pollution is in line with the available evidence in the literature, which suggests that lack of alternative low carbon fuels and carbon intensive lifestyles have restricted the pollution-income relationship so far to the upward sloping segment of the EKC.

Table 3: Pollution Income Relationship – Global Pollution

	Rural	**Urban**
Income	6.732 (0.000)	14.553 (0.000)
$Income^2$	-0.00027 (0.000)	0.00074 (0.276)
$Income^3$	2.48×10^{-9} (0.000)	-2.12×10^{-7} (0.000)
Household Size	-1037.8 (0.000)	-1025.6 (0.000)
Proportion of Children	-3827.6 (0.000)	-4841.5 (0.000)
Pry Fuel – firewood	-2701.4 (0.000)	-5661.2 (0.000)
Pry Fuel – LPG	1135.1 (0.000)	-2434.6 (0.000)
Pry Lighting – Electricity	7582.5 (0.000)	7612.9 (0.000)
Observations	68409	37748
R^2	0.46	0.48

Note: The dependent variable is per capita CO_2-equivalent emissions. The figures in brackets indicate the *p* values.

Household Level Pollution – Future Projections

Based on the estimated pollution-income relationship discussed in the previous section an attempt is made here to project future levels of local and global pollution from rural and urban households in India. The discussions in this section are based on projections made for the year 2026. The choice of 2026 is made keeping in view the availability of population projections for that year, and also allowing the results from this study comparable with other similar studies in the literature (e.g., Mestl and Eskeland, 2009).

For the purpose of projections the population is assumed to reach 1.4 billion by the year 2026 in line with the Government of India projections. About 67 percent of the projected population is assumed to reside in rural areas. The rural and urban incomes are assumed to grow at 2 percent and 5 percent per annum, respectively. The pollution projections are made for the following scenarios:

(a) Business-as-usual (BAU) – With population and income projected to grow as per the assumptions mentioned, the estimated pollution-income relationship discussed in section 4 is used to assess the future pollution levels.

(b) Fuel Change – Similar to BAU, but with the proportion of expenditure on primary cooking fuels and lighting altered in such a way that there is a shift towards LGP for cooking and towards electricity for lighting.

(c) Clean Stoves – While the population and income projections are similar to those assumed in the previous two scenarios, this scenario attempts to capture the impact of National Biomass Cookstoves Initiative on local and global pollution from the households. Expecting complete transition to the clean cookstoves, the local and global emissions from households using firewood and other biomass based fuels are estimated using the emission coefficients of LPG. The income-pollution relationship (for both local and global pollution) is re-estimated for rural and urban households using this relatively 'clean' per-capita pollution as dependent variable in equation 1.

(d) The re-estimated pollution-income relationship for local pollution still exhibits inverted-U shape for the rural households, but with a much diminished magnitude for the slope coefficient (results not reported here). The re-estimated relationship for urban households is similar to the earlier one, again with relatively smaller slope coefficient. The influence of clean stoves on the relationship between global pollution and income is much weaker as is expected.

Figure 6 shows the local and global pollution for the above three scenarios for the year 2026 in rural and urban India. For comparison purpose the 2004 emissions are also shown in the figure. From the projections the following can be inferred:

(a) The 'BAU' scenario projects the local emissions to go up by close to 60 percent in both rural and urban households.

(b) While both the 'fuel change' and 'clean stoves' scenarios result in lower local pollution compared to the 'BAU' scenario in both rural and urban households, the effects are significantly high in case of rural households and under the 'clean stoves' scenario. In case of 'clean stoves' scenario the reduction in local emissions compared to the 'BAU' is close to 86 percent in the rural India and is about 70 percent in the urban India. Given the large base value, particularly in the rural India, these reductions in particulate matter emissions would most certainly lead to significant benefits in reducing health burden. The 'fuel change' scenario has relatively higher contribution in reducing pollution in urban India, especially because of greater penetration of LPG in the peri-urban areas.

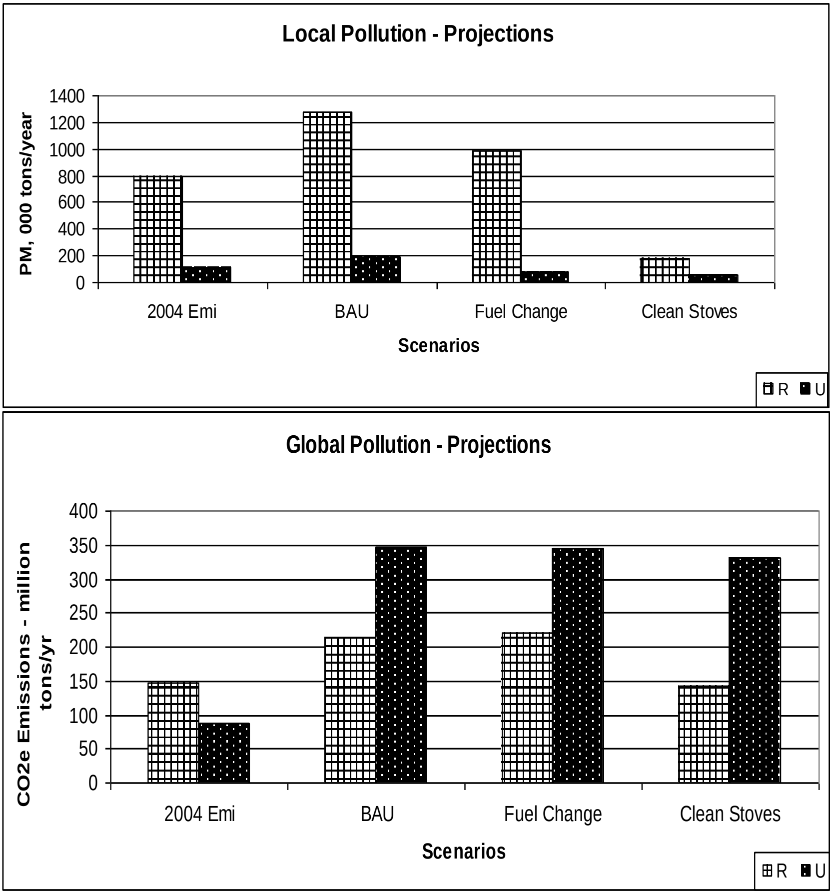
(c) In case of global emissions, the 'BAU' scenario projects about 45 percent increase in rural India and close to four fold increase in urban India.

(d) The 'fuel change' scenario has relatively less influence on global emissions in rural and urban India, compared to the 'clean stoves' scenario. However, both the scenarios have far lesser effect on global pollution compared to the local pollution. Further, the effects are relatively more pronounced among rural Indian households compared to the urban households (especially the 'clean stoves' scenario).

In case of 'fuel change' scenario the thrust is on shifting towards fuels that result in lower local pollution. But such shift may lead to higher global pollution as shift from firewood to LPG will result in higher CO_2 emissions while leading to lower PM emissions. In case of 'clean stoves' scenario the thrust is on ensuring clean combustion so that the households using firewood, for example can continue to use that fuel for cooking but safeguard themselves from particulate emissions and related health risks. In other words, the 'clean stoves' scenario could in principle result in lower local emissions without necessarily increasing the global emissions. The emission projections presented here should be seen from this perspective. While India's earlier attempt to introduce clean cookstoves has not been very impressive[4], the new initiative with its focus on efficient combustion has the potential to put India on sustainable development path.

[4] Despite considerable investment by the Government of India, the earlier cookstoves program could penetrate only about 15 percent of Indian homes between 1980 and 1992 (Parikh *et al*., 1999).

Figure 6. Local and Global Pollution Projections: 2026



CONCLUSIONS

This study based on unit record data of the 61st round of the NSS corresponding to the year 2004-05 assessed the local and global pollution profile in rural and urban India and corresponding estimated the pollution-income relationship. The results provide evidence for EKC in rural India for local pollution corroborating the earlier findings (Kumar and Viswanathan, 2007). Highlighting the significant difference between rural and urban India in terms of access to clean energy, the results also indicate monotonically decreasing pollution-income relationship among urban households for local pollution. The global pollution, on the other hand, is monotonically increasing among both rural and urban households reflecting carbon intensive energy use. The study also projected emissions under various scenarios including clean cookstoves. The results indicate that penetration of clean cookstoves has significantly large potential to reduce both local and global pollution from the household sector in India.

The importance of NCI and its ready implementation in India can be further understood through a quick glance at the ever increasing pattern of firewood usage across India. In rural India, the per-capita firewood consumption in 2004-05, for instance, has increased in as many as 15 states compared to 1999-2000, and in 11 states compared to 1993-94. In urban India firewood usage is less pronounced but still significant. The per-capita firewood consumption in 2004-05 has increased in as many as 11 states compared to 1999-2000, and in five states compared to 1993-94. The LPG usage correspondingly has not shown significant increase over time and in some states like Gujarat (rural and urban) and Himachal Pradesh (urban) the usage has even declined over time This can be seen as a reflection of growing energy demand and unmet energy needs, viz. energy poverty.

While NCI has the potential to put India on sustainable development path, an obvious issue that needs further attention is the scope and feasibility of penetration of the 'clean stoves' in India. A few issues in this context are worth mentioning and can also be seen as pointers for further research:

- Are 'LPG-like' emissions from 'clean stoves' possible? – There is not much evidence on the performance of 'clean stoves' in the non-laboratory conditions. The evidence on emissions is further weak when multiple fuels like dung and crop-residue are also used along with firewood.
- Acceptability – while the global evidence on acceptability of advanced biomass stoves appears encouraging, more studies on Indian households are needed to assess the factors affecting the penetration.
- Urbanization – increasing rate of urbanization along with its fast changing lifestyle would necessitate the use of cooking facility that has the switch-on/switch-off features. Hence this could lead to shift towards LPG and could in principle undermine the climate co-benefits from NCI.
- Fiscal burden – while no estimates have so far been made on the likely fiscal burden due to full-blown implementation of NCI, given the scale of such implementation it is quite likely that the fiscal needs would be significant. If the advanced cook stoves have the potential to reduce about 4 percent of India's total annual GHG emissions, then this would be worth around $1.4 billion in the international carbon market. Hence it could be useful to explore the carbon financing option for NCI implementation.

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