Replacing Conventional Fuels through Biogas for Mitigating the Threats related to Climate Change in India: A State-wise Assessment for Emission Reduction

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Introduction

Energy plays a crucial role in the socioeconomic development of the country as elsewhere in the world. The past five-year period from 2004–05 to 2008–09 witnessed the economy grow at an average rate of 8.5%, despite the worldwide financial crisis affecting the second half of the five-year period. For the expected economic growth trend (8-9%) to continue during the Twelfth Five Year Plan (2012-2017), the nation requires an annual growth of 6.5% per year in energy supply (GOI, 2011). In India, nearly half of the commercial, primary energy demand is met by coal, but the share of coal in India's total primary energy constitutes about 38%, while the contribution of non-commercial energy such as firewood, cattle dung and agricultural waste forms about 28% of the total primary energy consumed (GOI, 2006a, b).

It is evident that biomass is an important source of fuel for cooking purpose; it contributes 18% of the total primary energy use. Overall trends in total primary energy consumption show a decoupling of energy consumption with increasing GDP. Over the period 1990 to 2005, GDP multiplied by 2.3 times while energy consumption by 1.8 (Stephane et al., 2009). India is the fifth largest emitter of greenhouse gases (GHGs) in the world, accounting for approximately 4.7% of the total global emissions, while China is the largest emitter with 23% of total global GHG emissions (GOI, 2009). Various studies have reported that the use of wood for fuel is one of the major factors responsible for the degradation of forested landscapes, thereby reducing carbon sinks in the country (Osei, 1993; Nautiyal

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and Kaechele, 2008). Our study focuses on the replacement possibilities of polluting fuels with renewable energy sources and ensuring of emission abatement through manure management.[1]

Worldwide, about 2.4 billion people lack a ready access to safe and reliable energy while about 1.6 billion people do not have access to electricity. The problem of energy deficit is found to be acute in developing countries such as India, where about 89% of the rural and about 28% of urban households depend on polluting sources of energy such as firewood, chips and dung cakes for meeting their cooking needs (TERI, 2010). Further, in terms of expenditure per household, fuel for cooking and lighting purposes accounts for about 8% of the total expenses (NSSO, 2009-10).

In India, about 600 million people do not have access to electricity and about 700 million people are using biomass as their primary energy resource for cooking (PHD Chambers of Commerce, 2011). The integrated Energy Policy (Ministry of Renewable Energy) states that the total amount of LPG required for providing cooking energy to 1.5 billion persons amounts to around 55 million tonnes of oil equivalent (Mtoe). About 42% of people had access to clean LPG for cooking in 2005. With respect to the rural–urban divide, in 2005, it was only 9% of the rural households that had access to LPG, while 57% of urban households had access to LPG. About 28 kg of firewood and chips (13.03 kilograms of oil equivalent 'kgoe') and 1.82 kg of LPG (2.01 kgoe) are used by Indian households for cooking purpose on a per capita per month basis (NSSO, 2007). This order of the magnitude of energy requirement, if it were to be met by fuelwood *perse*, could raise CO_2 emissions from the current level of one billion tonne (Bt) to 5.9 Bt per year by 2031–2032 (Ravindranath and Balachandra, 2009). An average household dependent on fuel wood consumes 1800 kg of fuel in a year; 159 kg of kerosene per year per household; and 120 kg of LPG per year per household in the case of kerosene and LPG dependent households respectively. The annual fuelwood requirement of the country is estimated to be about 250 m tonnes (Mt), more than 80% of which is for domestic consumption. The availability of fuelwood from forests on a sustainable basis is said to be about 17 Mt (GOI, 2001).

Domestic energy sources like LPG and kerosene are subsidized by the government. Moreover, subsidy is extended to all domestic LPG users, irrespective of their economic status. Apart from contributing to GHG emissions the burning of inferior fuels has a tremendous impact on health, education and overall empowerment of girls and women who spend large part of their everyday life in collecting fuelwood.[2] It is estimated that the inhalation of indoor smoke is responsible for over 400,000 deaths annually, mostly among women and children (SEI, 2009).

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[1] The term "biogas" in this paper refers to biogas produced out of livestock manure with a generalized 60% of methane composition. GHG emission is taken to be CO_2 equivalent, manure management for methane. The term "states" includes all the 35 states and union territories of India.

[2] 85 million households spend 30 billion hours annually on fuelwood gathering (A study in North India as stated in the Integrated Energy Policy).

There has been an increasing loss of sequestered carbon in view of an unsustainable fuelwood harvesting over a period of time in the absence of an environment-friendly alternative. An earlier study had pointed out that by 2006, an estimated 139 m tonnes of fuelwood would be harvested above the sustainable supply from regulated sources (Bahuguna et al., 2004). An estimate by TERI puts India's fuelwood requirement at 228 m tonnes, out of which 128 m tonnes is met through a sustainable supply and the remaining 100 m tonnes through an unsustainable harvest (Aggarwal et al., 2009). The annual estimated harvest of wood from forests amounts to 1.23 m tonnes while the same from trees outside forested areas to 19.25 m tonnes. The total carbon stock of the country's forests estimated to be 6663 m tonnes (GOI, 2011), is getting affected because of unsustainable fuelwood collection. In the Indian context, statistics regarding the volume of fuelwood harvested (legally) are available but there is no estimate of areas coming under selective harvesting. Even the volume of timber harvested for timber and fuelwood is highly debated as the estimated consumption exceeds the recorded production (Haripriya, 2001). Thus the actual assessment of the loss of sequestered carbon seems very difficult.

Bio-energy as an Alternative Domestic Fuel; Climate Change Mitigation Dimension

Livestock population in India during 2007-08 stood at 530 million. With about 28% of the world's total cattle population, India ranks first in the world (Arora et al., 2010). The share of total dung, used as domestic fuel and farm yard manure, in the total value of livestock sector output amounts to 9% (GOI, 2011); the rest is dumped unused and releases methane into atmosphere. Methane which traps 21 times (IPCC, 2007) more heat than carbon dioxide accounts for 80% of global warming. Livestock contributes about 37% of anthropogenic methane, mostly through enteric fermentation and manure management. It is reported that livestock production accounts for 18% of the global GHG emissions including methane (CH_4) through enteric fermentation and manure management; nitrous oxide (N_2O) through animal manure; and carbon dioxide (CO_2) through land-use change caused by demand for food grains, grazing land and agricultural energy use. Livestock manure management is also a significant source of CH_4 emission (Swamy and Bhattacharya, 2006). India's livestock contributes 1.09 Tg (9%) methane through manure management (as of 2003). Dairy buffaloes and indigenous dairy cattle together constitute 60% of the total methane emission. The three high methane emitter states are Uttar Pradesh (14.9%), Rajasthan (9.1%) and Madhya Pradesh (8.5%) (Chabra et al., 2007).

The promotion of renewable energy generation through these unused resources in India has been supported by various legislations and policies such as Energy Conservation Act (2001), New and Renewable Energy Policy (2005) and Integrated Energy Policy (2009). National Biogas and Manure Management Programme

(NBMMP) a major initiative of the Government of India, was introduced in the early 80s to promote more than 12 million family type biogas plants. These biogas plants cost around Rs 16,000 each and is of two cubic metre (cum) size[3] fed by manure of 4-6 cattle and estimated to suffice cooking energy requirements of four member families. A family size biogas plant substitutes for 316 litres of kerosene, 5535 kgs of firewood and 4400 kgs of cattle dung cake used as fuels and reduces emissions of NO_x, SO_2, CO and volatile organic compounds into the atmosphere by 16.4, 11.3, 987.0 and 69.7 kg per year, respectively (Pathak et al., 2009). As of 2006, the total community-level biogas plants numbered 3902, a small number compared to India's 600,000 villages. Another approach towards supporting biogas plants – financing/subsidy mechanisms – under Clean Development Mechanisms of Renewable Energy projects as envisaged by the Kyoto Protocol, has become an important contributor in the last 4-5 years. Depending on the size of domestic digesters, their efficiency and productive period in a given year, each can save an annual combustion of 1.5-4.0 tonnes of fuelwood, equivalent to an emission reduction of 0.75-2.0 tonne C per digester (Pretty et al., 2002). It is estimated that 79 MT fuelwood can be saved by utilizing the available biogas potential in India. The corresponding carbon emissions avoided would amount to 15.8 MT annually, assuming that 40% of fuelwood requirements are from non-sustainable sources and 0.5 T C of dry wood (Ravindranath and Balachandra, 2009). Electricity is also produced by biogas plants installed under the Biogas Distributed/Grid Power Generation Programme (BGPG) launched by MNRE in 2006. Under this programme, projects are developed at the village level by community organizations, institutions, or private entrepreneurs, and the electricity produced is sold to individuals or communities or to the grid. The unit capacity ranges from 3 KW to 250 KW. MNRE reports 73 projects installed with total capacity of 461 kW (Arora et al., 2010). There are a few research studies (Sirohi and Michaelowa, 2004; Ravindranath et al., 2005) related to the estimation of biogas potential in India, which serve as a basis for the development of policies and schemes with a view to implementing bioenergy generation from livestock manure. The absence of a systematic research examining the actual emission reduction through manure management and conventional fuel replacement with state specific criteria has hampered planning for this energy alternative. In this backdrop, the aim of the paper is to estimate the potential of methane based bio-energy generation from livestock manure and to formulate strategies towards utilizing that potential in mitigating climate change related threats besides offering possible alternatives towards fulfilling the domestic energy needs.

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[3] Estimated for central parts of the country with material costs as of 2010-11.

Methodology

A comprehensive data regarding methane emission from various sources is not readily available so far. Through this present research study, authentic data was collected from different government departments' data banks and past research works. With respect to some of the data, details which vary across different sources have been crosschecked with standard sets of available data to arrive at the most reliable numbers. The data on livestock population and energy consumption for domestic purpose has been obtained from the data repository of websites of the Department of Animal Husbandry, Dairying and Fisheries (GOI, 2012), Ministry of Statistics and Programme Implementation (Govt. of India) and www.indiastat.com and synthesized following appropriate procedures. To understand, compare and contrast the relevance of the data and our observations across the sectors and states, a holistic approach in the context of a chosen objective was developed.

Biogas Yield Capacity

Methane emissions of different types of livestock through manure management are calculated on the basis of Livestock Census 2007, Department of Animal Husbandry, Dairying and Fisheries. The amount of excreta produced per day by different animals depends upon the breed, age and weight of animals and the total quantities of fodder fed to them. Large difference prevails in biogas generation potential and emissions between rural and urban areas. The proportion of rural livestock to the total livestock population works out to about 95% in India (Dholakia and Pandya, 2011). As for equivalence in size, animals belonging to the same family and comparable dung generation as stated in different data sources (Khendelwal and Mahdi, 1986; Ravindranath et al., 2000; Mang, 2005; Mahimairaja, 2008; Kalbande et al., 2011) are grouped into Cattle, Buffaloes, Sheep, Goats, Horses and Pigs. Largely, lower values of excreta generation per animal have been considered. The dung yield values per day per animal used in the calculations are 7.5, 10, 0.1, 10 and 2.5 for cattle, buffaloes, sheep and goats, horses and pigs respectively. The biogas yield capacity of one kg of animal excreta tending to 36 L for cattle, sheep, goats and horses and 30 L for buffaloes and 60 L for pigs, have been derived from other research findings where production rates are found as high as 66 L/kg for pig manure and as low as 20 L/kg for cattle manure depending on varied climatic regions. The procurable livestock excreta for different animals varies, viz. cattle 60%, buffaloes and pigs 80%, and others 30% of the total excreta generated per day.

Methane Emission Factors

There are several studies related to methane emission estimations based on IPCC Tier I and Tier II approaches; the factors adopted for this study are 2.75, 4.15, 0.21, 0.22, 2.18 and 6 per animal per annum for cattle, buffaloes, sheep, goats, horses and pigs respectively. As the methane emission factors for cattle vary from 2 to 3.5, the average is taken. The emission factors are chosen from literature survey and the selected factors derived across different climatic regions (cool: $<15°C$, temperate: 15-25°C and warm: $>25°C$) and methane-producing potential of manure (Swamy and Bhattacharyya, 2006). These factors have been developed following country-specific guidelines under IPCC Tier II approach for cattle and buffaloes, and Tier I approach for other livestock. This method is based on animal population of the States and Union Territories grouped into cool, temperate and warm regions according to meteorological data from 391 stations. These factors are considered as this is the recent updated research data available based on the IPCC guidelines. The total methane emissions per state are converted into CO_2 equivalents taking Global Warming Potential (GWP) of methane as 21 times that of CO_2 over a period of 100 years (IPCC, 2007).

Conventional Fuels and Energy Content

Data on fuelwood, kerosene and LPG consumption for each state with rural-urban divide for 2009 have been extracted from NSS reports (66th round survey). The emission factors in terms of CO_2 for per kg of fuelwood, per litre of kerosene and per kg of LPG amounts to 1.83 kg, 2.54 kg and 2.9 kg respectively (IPCC, 2006b). The energy content of different fuels referred to in this study has been sourced from O'Sullivan and Barnes (2006) (Table 1). The energy content of different fuels varies with fuel quality and combustion efficiency as explained in different studies. One of the widely cited LPG energy contents relates to 46.1 MJ/kg (Hargreaves, 2003). The extent to which households are able to extract useful energy from a particular fuel depends on the technology used.

Table 1 Energy content and efficiency of different fuels

Fuel type	*Energy content, MJ/Kg*	*Useful energy, MJ/kg*	*Approx. quantity of fuel required to provide 5 GJ of useful energy for cooking in kg*
LPG	45.5	27.3	180
Kerosene (pressure)	43	23.6	210
Kerosene (wick)	43	15.1	330
Firewood (Efficient stove)	16	4	1250
Firewood (Traditional stove)	16	2.4	2000
Biogas (60% methane)	22.8 MJ/cum	–	365 cum
Dung	14.5	1.7	2900

Adapted from O'Sullivan and Barnes, 2006.

Loss of Carbon Sequestration

The loss of carbon sequestration has been calculated by using two different approaches: volume of biomass used as fuel and forest cover lost on account of fuelwood harvesting. According to MoEF (2007), the total sustainable availability of wood from all sources, public and private amounts to about 127 million cum per year. Of the total estimated fuelwood consumption for the year 2009 (397 cum), the unsustainable collection accounted for 270 cum that can be considered as the primary cause for the degradation of forests. This 68% is considered for estimating the loss of carbon sequestration following the calculations mentioned below.

The Good Practice Guidance for LULUCF (IPCC, 2006a) explains the methods for the loss of carbon sequestration due to fuelwood gathering. The calculation for the same involves the following.

$$L_{\text{fuelwood}} = \text{FG} \times \text{D} \times \text{BEF2} \times \text{CF}$$

where L_{fuelwood} is annual carbon loss due to fuelwood gathering, tonnes C. yr^{-1}, FG = annual volume of fuelwood gathering, $\text{m}^3\ \text{yr}^{-1}$, D = basic wood density, tonnes d.m. M^{-3}, BEF2 = biomass expansion factor for converting volumes of extracted roundwood into the total aboveground, and CF = carbon fraction of dry matter (default = 0.5), tonnes C $(\text{tonne d.m.})^{-1}$.

The biomass expansion factor varies from 1.3 to 3.4 for different types of forests. Some estimation shows biomass expansion factors (total above ground biomass/volume-based biomass to 7 cm in diameter) of 1.50 for stands with volumes <90 m^3/ha and 1.35 for stands with volumes 290 m^3/ha for Indian forests (Iverson et al., 1994). The biomass expansion factors have also been calculated as Hardwood = 1, Spruce-fir = 1 and Pine = 0.81-0.95 (Sharma et al., 2011). The value of BEF-2 considered for this study is 1.35.

Another method (Chatterjee, 2004) for the estimation of carbon sequestration loss considers 1 cum of stemwood ~ 1 cum fuelwood ~ 2.3 cum of total biomass loss.[4,5]

$$\text{DM} = V_{\text{fuelwood}} \times 2.3 \times 0.43^{5}$$

$$\text{SC}_{\text{loss}} = \text{DM} \times 0.50$$

where DM is the dry matter content of the total biomass lost due to the exploitation of fuelwood unsustainably, V_{fuelwood} is the total volume of fuelwood acquired unsustainably and SC_{loss} is the loss of sequestered carbon.

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[4] The ratio of total biomass to usable stem biomass was assumed by the German Bundestag to be 1.6 for closed forest and 3 for open forest. One cum of stem wood is, therefore, taken to be equivalent to 2.3 m^3 of the total biomass.

[5] This value varies in relation to factors like plant species, geoclimatic conditions etc. Dry matter content with solid wood amounts to 0.45 tonnes per m^3 (IPCC, 2006).

Canada's Model Forest Programme (2000) is one of the highly discussed programmes in this respect besides being cited as one of the UNFCCC-REDD methods. Conversion factors from vegetation cover to carbon are:

1. Total wood volume = vegetation cover × 1.454 × 0.396 (in m^3)
2. Total dry matter biomass = wood volume × 0.43 (in tonnes)
3. Total carbon = dry matter biomass × 0.5 (in tonnes)

Estimation of Emission Reduction

The loss of methane during production across digesters varies. In the IPCC Guidelines for National Greenhouse Gases Inventories, it is given as 0-8 g of CH_4 lost during per kg of waste treated on wet basis (following Tier I approach). Emission reduction by utilizing potential livestock excreta for the production of biogas is a factor of methane emission through manure management, methane leakage in the production process, emission from inefficient combustion of biogas and mitigation of emission due to replacement of other polluting fuels with biogas. CH_4 lost to the atmosphere during the biogas production process is taken as 10% (UNFCCC, 2008) default leakage rate of 10% of the total production and the emission from inefficient burning as 5 kg of CH_4/TJ energy production (IPCC, 2006b).

Thus CH_4 emission due to leakage can be calculated as:

$$\mathrm{ME}_{\mathrm{leakage}} = \mathrm{BP} \times 0.1 \times 0.6$$

where $\mathrm{ME}_{\mathrm{leakage}}$ is methane emission due to leakage in the production process, BP is biogas potential, 0.1 is assumed fraction loss and 0.6 is assumed percentage of methane in the biogas produced.

$$\mathrm{ME}_{\mathrm{burning}} = \left(5 \times \mathrm{E}_{\mathrm{biogas}}\ \mathrm{in\ TJ}\right)\ \mathrm{kg}$$

where $\mathrm{ME}_{\mathrm{burning}}$ is the total methane emitted during inefficient burning and $\mathrm{E}_{\mathrm{biogas}}$ is the total energy generated from biogas.

Keeping the current situation in view, the total emission (in terms of CH_4) reduction can be calculated for four hypothetical scenarios for the country:

Scenario 1: Replacement of fraction of fuelwood with biogas
Scenario 2: Replacement of LPG and fraction of fuelwood
Scenario 3: Replacement of kerosene and fraction of fuelwood
Scenario 4: Replacement of LPG, kerosene and fraction of fuelwood

$$ER_m = ER_{mm} - \left[ME_{leakage} + ME_{burning}\right] + ER_{[fuel/fuels\ in\ scenario\ 1-4]}$$

where ER_m is methane emission reduction, ER_{mm} is emission reduction through manure management and $ER_{[fuel/fuels\ in\ scenario\ 1\text{-}4]}$ is reduction by replacing fuel/fuels under different scenarios.

Mapping of Distribution of Bio-energy Potential

The state-wise biogas potential is calculated under different scenarios such as firewood, kerosene and LPG, while their replacement percentage is calculated on the basis of livestock population across states; later average percentage of biogas potential of each state is calculated using these three values. Following of which, average percentage of biogas potential is created in the GIS database for analysing the data set in the spatial domain using ArcGIS 9.2 software. The whole range of high and low value percentage of replacement potential is reclassified into four classes and four classified values are categorized into four sensitivity zones according to their values i.e. very high, high, medium and low. The sensitivity zones are prepared by dividing the whole state potential replacement capacity with four group ranges as presented in Table 2, which is colour coded in the GIS domain.

The biogas potential density of rural India has been generated using ArcGIS 9.2 software by attaching the attribute data with the spatial data and converted to the raster by classifying the biogas potential in cum per capita per year and reclassified using the spatial analyst tool in the GIS software into five different classes of biogas density. The methane emission reduction potential of CO_2 through manure management is calculated and the data set created with spatial variability in the Geo database of the spatial domain using ArcGIS 9.2; further the data set is united with the GIS layer and converted into four different groups for analysis and these groups are weighted to four spatial zones.

Table 2 Classification of bio-energy potential (for replacing conventional fuels) for mapping

Classified % replacement capacity	*Sensitivity zone*
<16%	Low
16-32%	Medium
32-48%	High
48-64%	Very high

Results

According to the 58th round of the National Sample Survey Organisation (NSSO), more than 51% of the urban population has switched over to LPG as cooking fuel (PISCES, 2011). The energy supplied by three different sources varies largely across states. The contribution of fuelwood is as high as 95% in Nagaland and 94% in Arunachal Pradesh and as low as 4% in Delhi. It is evident from Table 3 that 80.8% of the household energy consumption flows from fuelwood and the rest from kerosene and LPG. The biogas potential in all the states and union territories can replace 29.52% of the total energy supplied by a combination of the three aforementioned fuels. Out of 206.8 million tonnes of fuelwood consumed annually, rural areas accounts for 91%. Nearly 38% of the rural fuel wood potential of biogas can be derived from (Dholakia and Pandya, 2011) 188.9 million tonnes of fuelwood used. The potential of biogas in rural areas is about 45,809 million cum annually, approximately 95% of India's total procurable biogas from livestock manure. Our calculation (data not presented here) based on various data source shows that rural India can generate about 61 cum per capita annually biogas for the rural population and reduction in methane emission up to 0.016 tonnes per capita annually.

The total quantity of livestock excreta generated across states is 4.98 million tonnes per day; 3.49 million tonnes of that is collectible. If that entire quantity is utilized, 151,057 MLD of biogas could be generated. Among all states, Uttar Pradesh has the highest biogas potential of 19,410 MLD. The states with more than 10,000 MLD biogas potentials are Andhra Pradesh, Madhya Pradesh, Maharashtra, Rajasthan and West Bengal. The states with a much higher production potential of biogas are Mizoram, Sikkim and Goa. Cattle and buffaloes together account for 57% of the total manure-based biogas generation in India, whereas pig population for 42% of the same.

With 95% of the livestock population in rural areas, the rural population has the potential to harness 48,220 million cum of biogas annually. Uttar Pradesh and Andhra Pradesh with a potential of producing 6462 million cum and 4821 million cum annually, rank top among states. In terms of biogas density, rural Uttar Pradesh

Table 3 Consumption of different fuels and their energy terms in India in the year 2009 and biogas potential as per livestock population 2007

Fuel type and energy	*Consumption*	*Energy consumed in terms of the given fuel in TJ*	*% contribution to the total* energy consumed*
Fuelwood	206.8 million tonnes	33,08,861	80.8
Kerosene	6867.76 million litres	295,314	7.2
LPG	10.83 million tonnes	492,869	12
Biogas potential	53,047.37 million cum	12,09,480	29.52**

* This total is for fuelwood, kerosene and LPG.

** Biogas has the potential to replace 29.52% consumption of other three fuels.

accounts for the highest density of 114,797 cum per square kilometre (sq km), followed by West Bengal and Bihar among 28 states. Most of the Union Territories show comparatively good biogas density, mainly because of their relatively low rural population and discrepancy in livestock population. Although Uttar Pradesh is bestowed with the highest biogas share in India, its per capita availability of biogas is quite low (47 cum/year), in view of its population-livestock ratio. Rajasthan (95 cum/year), Madhya Pradesh (89 cum/year) and Chhattishgarh (85 cum/year) accounts for the highest per capita biogas potential with respect to their respective rural population among the 28 states. Kerala has the lowest per capita availability of biogas potential per year with a value 13. With an optimum production and utilization of biogas in rural areas, rural populace can reduce methane emission by 0.74 kg per capita annually through manure management (equivalent to 15.54 kg CO_2e per capita annually). The biogas potential density of rural India shown in Fig. 1 helps predict the zones with a higher density of biogas potential. The map shows clearly that the central and western parts of India and two states in the northeastern region can harness a reasonably good quantity (>72 cum/capita/year) of biogas.

The contribution of GHGs constitutes 88%, 4% and 8% of fuelwood, kerosene and LPG respectively while their respective energy shares accounts for 81%, 7% and 12%. Besides, direct combustion emissions, there is a significant emission factor associated with LPG and kerosene through production and transportation. The production of LPG signifies higher energy consumption and release of more GHGs into the atmosphere. The production and transport emissions for LPG are 8.5 and 0.6 g-c in CO_2 equivalents per mj and 5.7 and 0.7 for kerosene respectively (Bailis et al., 2004). The total methane emission from manure of all the six categories of livestock studied across states are 3.9 million tonnes (Livestock Census, 2007). The emission of methane from the livestock categories are: Cattle 0.83 million tonnes, Buffaloes 0.5 million tonnes, Sheep 0.01 million tonnes, Goats 0.03 million tonnes, Horse 0.003 million tonnes and Pigs 2.5 million tonnes. Uttar Pradesh contributes 0.43 million tonnes of methane from livestock manure management and highest across states. The methane emission reduction potential in terms of CO_2 from manure management across states is grouped into four classes and converted according to their values (Fig. 2). As seen, Arunachal Pradesh and Andhra Pradesh have the highest emission reduction potential of CO_2 comparatively.

GHG emission abatement potential of biogas generation is a function of procurable manure, loss of methane during biogas production and emission from combustion of biogas as fuel. Total of 0.58 million tonnes of methane can be trapped from the entire cycle of manure management in India. Two states show negative reduction in methane emission levels as they belong to temperate zone where emission from manure is minimal and Andhra Pradesh has the highest methane emission reduction potential from biogas production amounting to 0.015 million tonnes. The yield of biogas varies with temperature in this study as the yield values are generalized for the country, also indicating Andhra Pradesh with

Fig. 1 Map of India showing density of potential biogas density across the states in cum/capita/year

the highest (0.15 million tonnes/year) emission reduction potential from manure management from biogas generation.

In Fig. 3, the states consuming more than 10 million tonnes fuelwood annually are shown with a fuelwood consumption replacement potential of biogas and a consequent reduction in emission in terms of CO_2e. The total emission in terms of CO_2 from fuelwood and kerosene amounts to 378 million tonnes and 17 million tonnes per year respectively; clean fuel LPG shows 32 million tonnes of emission in 2008-09. Figure 3 indicates Chhattisgarh in the highest sensitivity zone in biogas

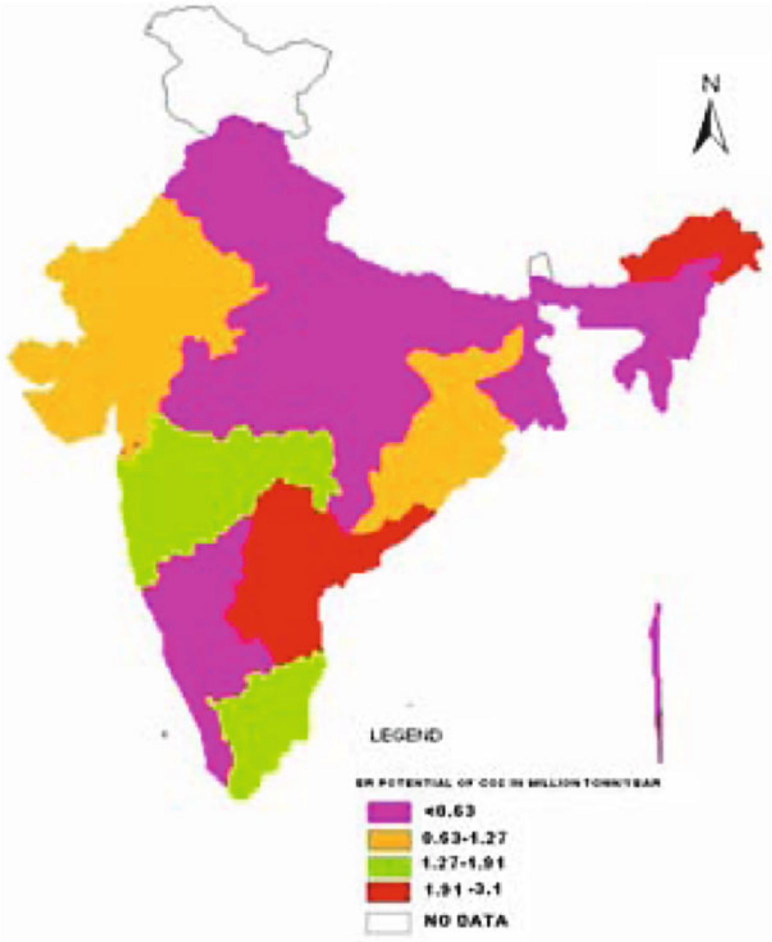

Fig. 2 Map of India showing the emission reduction potential across the country from manure management by utilizing the tappable manure for biogas generation

replacement potential as the livestocks' potential is relatively high due to consumption demand; similarly, the states of Kerala, Goa, Tripura, Mizoram and Delhi show a low potential zone for harnessing biogas because of low livestock population.

The replacement biogas potential (conventional fuel) of different states has been analyzed. Biogas has the potential to replace about 37% of fuelwood consumption in the country and about 30% of the total energy supplied by three conventional fuels viz. fuelwood, kerosene and LPG. The replacement of fuelwood can be achieved with varied percentage shares for different states i.e. as high as 82% for Delhi and as low as 4% for Kerala. The replacement of fuel wood with LPG is low in Chandigarh (6%) and Delhi (4%), where the consumption of domestic cooking energy is higher and livestock population is low.

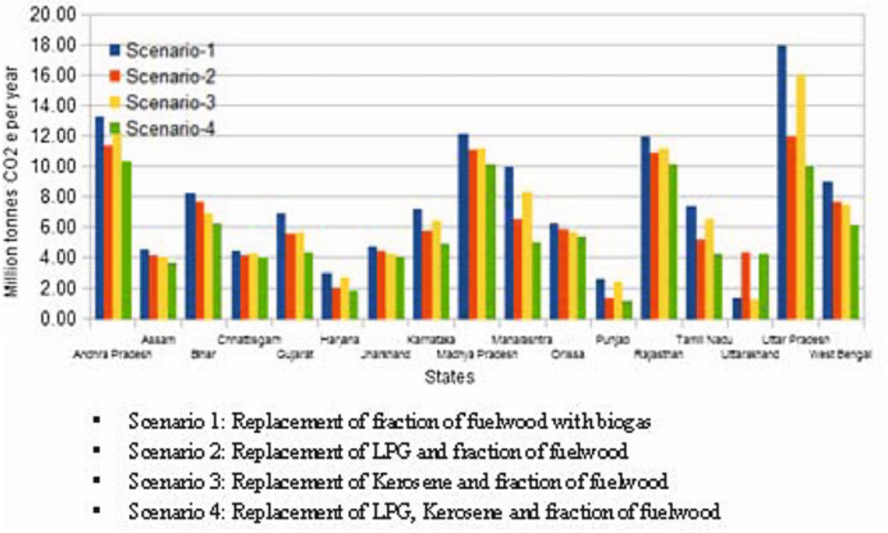

Fig. 3 Potential of biogas to replace fuelwood in states consuming fuelwood more than 10 million tonnes per year and the corresponding reduction in GHG emissions

An evaluation of the most efficient scenario for replacing conventional fuels with biogas to reduce GHG emissions is calculated (data not presented here) and if we consider biogas to replace only fuelwood, a total of 138.33 million tonnes GHGs per year can be reduced in fuelwood combustion. The same is achieved by LPG and fraction of fuelwood by 114.24 million tonnes annually. Given the higher potential of emission reduction, the replacement of fuelwood with biogas may be considered as the most appropriate scenario (Fig. 3), followed by replacement of fuelwood with kerosene and fraction of fuelwood (i.e. 122 million tonnes of GHG per year). The least efficient scenario is the replacement of fuelwood with all LPG and kerosene and fraction of fuelwood with emission reduction potential of 97.91 million tonnes of GHGs annually.

The loss of sequestered carbon is the result of an unsustainable exploitation of forest resources for fuelwood; it has been calculated using the IPCC recommended method as mentioned in the methodology. The unsustainable harvesting of fuelwood accounts for 68% of the total fuelwood consumption. The calculations based on biomass volume reveal a total loss of 82 million tonnes of sequestered carbon due to fuelwood use for the year 2008-09. The sequestered carbon lost in rural and urban areas amounts 75 million tonnes and 7 million tonnes respectively. The shares of rural and urban areas in the sequestrated carbon loss constitute 91% and 9% respectively, corresponding to the use of fuel wood. Uttar Pradesh, the largest consumer of fuelwood, has squandered 20.5 million tonnes and 0.80 million tonnes of carbon from its forests in rural and urban areas respectively. Karnataka and Rajasthan occupy 2nd and 3rd position in losing their sequestered carbon due to an unsustainable fuelwood gathering.

The computation of the total volume of carbon lost includes: (a) carbon transferred to forest products (in the form of biomass), (b) carbon released from forest biomass into the atmosphere due to clearing of forests or forest fires; and (c) carbon released to soil pools. The unsustainable harvesting of fuelwood implies a partial clearing of forests and the consequent degradation. When the forests are subjected to partial clearing, 85% of the stem biomass gets transferred to wood products, 10% remains on the stumps, and 5% is transferred to the soils (Haripriya et al., 2005).

Discussion

With a 13% of livestock population of the world, India contributes about 17% of GHG emission to the atmosphere from livestock sector (FAO, 2006). Although a major part of that emission is accounted for by enteric fermentation which cannot be managed. The manure, being an invaluable underused resource, possesses the potential to reduce the GHG contribution to global warming by replacing polluting fuels with renewable energy sources and to reduce emission through manure management.

Energy consumption patterns are extremely complex besides being one of the determinants of a nation's economy; household energy consumption for cooking and lighting is an issue associated with per capita energy sufficiency and overall development of a population. In 2005, India's total GHG emissions amounted to 1866 million tonnes CO_2e, while India's per capita GHG emissions to 1.7 metric tonnes of CO_2e. The results of five different independent studies show that in absolute terms India's annual GHG emissions in 2031 could reach between 4.0 billion tonnes of CO_2e and 7.3 billion tonnes under the BAU (Business-as-usual) scenarios (Climate Modeling Forum, 2009). An expert committee on integrated energy policy believes that it is possible to reduce India's energy intensity by upto 25% from the current level and GHG intensity of the economy by as much as one-third. This excludes mostly the non-commercial domestic fuels as energy intensity is based on commercial energy sources. Thus energy sources in this sector demand a special attention in the context of climate change uncertainties.

The energy potential of cow and buffalo dung comes to 562.2 PJ and 336 PJ respectively as estimated by Ravindranath and Balachandra (2009). This potential can be used by 17 million biogas plants and 150,000 community biogas plants for reducing GHG emissions by 5 TC/year and 10.8 TC/year respectively (Ravindranath et al. 2000). The climate change benefits in terms of carbon emission reductions are to the tune of 110 TC per year provided the available potential of bio-energy technologies are utilized (Ravindranath and Balachandra, 2009). The present study reveals that an optimum biogas production has the potential of reducing GHG emissions by 138.33 million tonnes of CO_2e by way of replacing fuelwood and 0.58 (only methane) million tonnes of CO_2e from manure management. Under CDM activity by the mid 2012 India has 2231 approved projects with a carbon credit of 730.8 million tonnes worth Rs 20,1730 million. The present price of carbon credit is worth Rs 276 per tonne while the entire spectrum of bio-energy envisages a reasonable earning through carbon credit if considered under CDM and would be helpful for self-sustenance. A further analysis of per capita biogas availability at the village level for actual project implementation would help develop a village-based model for biogas generation, distribution and utilization for ensuring self-sufficient domestic energy production under CDM initiatives.

Rural areas with more than 70% of the population and 95% of livestock population of the country consume 91% of the total fuelwood harvested. The replacement of fuelwood has been evaluated as the best suitable scenario for promoting and implementing biogas projects. Given these facts, it is apparent that the adoption of biogas as a major domestic energy source by fuelwood consuming households in the rural areas would be the most appropriate option, economically and environmentally. The total manure generated per day by all the six categories of studied animals works out to approximately 5 million tonnes, while about 3.5 million tonnes are collectible for generating 151,057 MLD biogas. In view of the states having varied ownership of livestock population, geo-climatic conditions, household energy needs and conventional fuel use patterns, it is difficult to generalize the statement regarding the biogas potential and the replacement prospect of fuelwood with kerosene and LPG. It requires a detailed plan at the state, district and much smaller regional levels. This paper has investigated the potential at the state level; a further assessment of demand and availability of resources (procurable animal excreta) is required in a decentralized manner for strategy development so as to implement biogas generation plants.

The regions with a reasonably high annual temperature and per capita biogas potential in rural areas can be considered as priority areas for implementing biogas plant projects for replacing conventional fuels and also for the consequent abatement of GHG emissions. The estimated potential of biogas plants was 1.23 crore family type plants; under NBMMP there was a cumulative achievement of 35% by the year 2011. This target had a global warming mitigation potential of 120 Mt CO_2 equiv. year^{-1} and US $1197 million as carbon credit under the CDM (Pathak et al., 2009). During the 11th Five Year Plan, there was an outlay of Rs. 562.00 crore for the promotion and implementation of biogas plants. On the other hand, the GOI is paying Rs 1973.6 crore as subsidy for the year 2010-11 for LPG cylinders for the entire country, which was to meet 12% of the energy consumed through fuelwood, kerosene and LPG, whereas biogas with a potential to supply about 30% of that total energy received comparatively little financial support. The expenditure on LPG is a recurring one besides being subject to a continuous inflation with the increasing cost of production, transportation and import. In the 12th Five Year Plan, the convergence of NBMMP with Indira Awas Yojna has been recommended. The cost of biogas plants varies with structural specifications of different models, for instance it is 30% and 50% more in hilly states and northeastern states respectively than in other parts of the country.

Although a good number of biogas plants have been installed, a significant slip-back has been noticed. Surveys conducted in various regions of India have found the proportion of functional plants to be from 40% to 81% (Dutta et al., 1997;

Bhat et al., 2001). To overcome this, an on-the-ground assessment based on conventional fuel availability and willingness to shift should be done along with a mass awareness agenda on climate change mitigation. Domestic biogas digesters have numerous challenges to overcome for a continued proliferation in the 21st century. Designs delivering lower cost, improved robustness, functionality, ease of construction, operation and maintenance would help market penetration of biogas plants (Bond and Templeton, 2011). However, in the absence of a proper technological up-gradation, operation and management, this valuable technology may become a source of environmental problems both at the local and global levels (Khoiyangbam, 2010). Therefore, it is necessary to rethink policies in evolving a flexible subsidy structure rather than the existing fixed subsidy structure. In view of the ineffective implementation of government-aided programmes, the recommendation for the convergence is not an effective way to promote; rather needs to be treated as a criterion for availing support under IAY. A detailed cost benefit analysis is of utmost importance for financial reshuffling under household energy sources considering both environmental internalities and externalities.

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