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Valuation of fuelwood from agroforestry systems: a methodological perspective

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Abstract This article presents a methodology for the valuation of agroforestry with respect to fuelwood supply for cooking and its opportunity cost. The share of fuelwood consumption declined gradually from 78 to 67% and 30 to 14% for cooking in rural and urban India, during 1993–94 to 2011–12, respectively. However, the total consumption of fuelwood increased significantly from 106 to 130 million tonnes (Mt) in the corresponding period due to population growth. Fuelwood and chips are in the process of substitution with Liquefied Petroleum Gas (LPG) gradually and many LPG-adopter households continued to use fuelwood as well. The results verified that the maximum quantity of fuelwood for cooking was obtained from agroforestry systems (64%), followed by forests (24%), and from common property resources (12%) during 2011–12. The annual total calorific energy generated from agroforestry through fuelwood, was estimated at 1297.4 PJ, valued at US$ 4053 million. Around 103 Mt of dry dung cake needs to be burnt to generate the same amount of energy. It is estimated that by replacing dung cake by fuelwood derived from agroforestry systems, could save US$ 1116.6 million annually, sparing the dung cake for use as farmyard manure. In another scenario, if entire energy derived from fuelwood obtained from the agroforestry system is to be replaced by LPG, it would require over 196.4 million additional domestic LPG connections that would incur an expenditure of about US$ 36,487.5 million at the country level for the year 2011–12.

Keywords Cooking fuel · Dung cakes · Improved biomass cookstove · Liquefied petroleum gas · Opportunity cost

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Introduction

Globally, the use of wood energy is gaining importance in the context of climate change and energy security. Wood energy is treated as a climate-neutral and socio-economically viable source of renewable energy (FAO 2015). Wood energy offers cost-effective and sustainable opportunities for reduction of greenhouse gas emissions. The mitigation potential of woodfuel is based on two main factors: the biomass that replaces fossil fuels and the sequestration of carbon in standing biomass (FAO 2010a). If woodfuel substitutes fossil fuels, the land used for sustainable

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biomass and bioenergy production can continue to provide emission reductions indefinitely (FAO 2010b). Wood biomass is a renewable and CO_2-neutral source of energy, which, if used sustainably and efficiently can contribute to a cleaner environment (FAO 2015). The use of renewable wood resources for energy presents a mitigation opportunity, as they can replace the use of fossil fuels and potentially reduce net greenhouse gases (GHGs) emissions. Significant mitigation can also be achieved through increased efficiency in the production and use of woodfuel (FAO 2016a). The adverse climate impacts arise in the process of fuelwood burning from two pollutant flows: CO_2 is emitted because a fraction of the woodfuel is harvested unsustainably, while methane (CH_4), nitrous oxide (N_2O), black carbon and other short-lived climate factors are emitted because of incomplete combustion. Therefore, if the annual harvesting of fuelwood exceeds incremental growth, then it is unsustainable and non-renewable (Matthews and Robertson 2005).

Currently, over one-third of households worldwide depend on fuelwood energy for cooking and heating, particularly in developing countries. It is also increasingly used in developed countries to reduce dependence on fossil fuels. According to a World Health Organization (WHO) survey of 128 low and medium-income countries, over 75% of rural households and around 20% of urban households depend primarily on woodfuel for cooking (WHO 2016, 2018). The consumption of woodfuel increased globally from 2012 to 2016 (1854 to 1860 million cubic meter). In the United States of America (USA) and the United Kingdom (UK), woodfuel consumption increased by Annual Compound Growth Rate (ACGR) of 9.81 and 14.19%, respectively, while in India it decreased by ACGR of 0.21% between 2012 and 2016 (FAO 2012, 2014, 2016b, 2018). About 11% of households used wood as an energy source, mainly for space heating, in 2015 in the USA (IEA 2017). Wood and wood products accounted for almost half (45%) of the European Union's (EU) gross inland energy consumption of renewables in 2016 (Eurostat 2019). Although woodfuel is less frequently-used for cooking in Europe (3% of energy use) and the USA (less than 1%), in India it is estimated that fuelwood demand by 2051 will reach 339 million tonnes (Sharma 2017). The projected fuelwood energy consumption by households in India would increase from 88 in 2010 to 102 million tonnes of oil equivalent (Mt) by 2030 at an annual growth rate of 8% gross domestic product (Parikh 2012). In India, the number of people without access to clean cooking facilities is projected to decline from 834 million in 2015 to 580 million by 2030; however, firewood will remain the cooking fuel for one-third of the population by 2030 (IEA 2015, 2017, 2018). The preference for Liquefied Petroleum Gas (LPG) for cooking has been restricted to urban areas, with rural areas still dependent on traditional fuels, owing to affordability and accessibility. The high initial cost has emerged as a barrier among 86% of households, irrespective of monthly income level (GoI 2016a, b, c, d, e). Fuelwood offers several advantages over fossil fuels such as LPG and Piped Natural Gas (PNG) for cooking. Biomass cannot be overlooked and efficient biomass cookstoves have to be included in the basket of solutions for addressing the problem of improved energy for cooking. Rural consumers will also 'stack' cooking fuels – combining a range of fuels at different times or for different types of cooking-, which suggests the need for an array of cooking fuels in national cooking fuel strategies. These strategies will also have positive ripple effects on public health, gender, livelihoods, and environmental aspects of the country (GIZ 2015; NITI Aayog 2017).

The substitution of fuelwood with LPG can create more environmental risk based on Life Cycle Assessment (LCA). Morelli and Rodgers (2017) calculated LCA from changes in fuels and stove usage in India, China, Kenya, and Ghana. They identified 10 impact indicators to measure the environmental impact of different fuels: global climate change potential (GCCP), cumulative energy demand (CED), fossil depletion potential (FDP), water depletion potential (WDP), particulate matter formation potential (PMFP), photochemical oxidants formation potential (POFP), freshwater eutrophication potential (FEP), terrestrial acidification potential (TAP), ozone depletion potential (ODP), black carbon and short-lived climate pollutants (BC), along with sensitivity analyses that test the effect of stove thermal efficiency, stove technology use, electrical grid mix, forest renewability factor and allocation approach on environmental impacts of cookstoves use. They show that the promotion of the highest possible thermal efficiency for improved cookstoves can yield appreciable reductions in environmental impact. The study quantitatively demonstrates that both cooking fuel mix substitutions and stove technology upgrades provide promising avenues for reducing particulate matter and black carbon emissions. However, reducing GCCP impact in the future will be a challenge for India as the country moves to adopt modern fossil-based fuels, such as LPG for cooking. Based on the findings of this study (Morelli and Rodgers 2017), it is estimated that GHGs emissions from a household consuming 11 MJ/day energy for cooking, the GCCP value of LPG (630.36) was higher than firewood (594.22) by 36.14 kg CO_2eq /household/year for cooking. The values of FDP and WDP were also higher for LPG used for cooking (235.66 kg oil eq and 0.77 m^3/year/household, respectively) compared with firewood. The value of GCCP, FDP, and WDP are inversely related to the fuelwood renewability factor used in the estimation of these parameters, which are related to the depletion of non-renewable natural resources.

The range of fuelwood renewability varies from 24% (Singh and Gundimeda 2014) to 90% (Venkataraman et al. 2010) in their respective studies. Prominent nitrogen-fixing tree species are: *Leucaena leucocephala* (300–548 kg N ha^{-1} yr^{-1}), *Acacia nilotica* (40–100 kg N ha^{-1} yr^{-1}), *Prosopis juliflora* (30–80 kg N ha^{-1} yr^{-1}), *Albizia lebbeck* (94 kg N ha^{-1} yr^{-1}) *Casuarina equisetifolia* (50–80 kg N ha^{-1} yr^{-1}), with an overall average fix of about 60–600 kg N ha^{-1} yr^{-1}. These multipurpose tree species are commonly used for fuelwood in India (Sharma and Kapoor 2005). However, the value of PMFP for the use of firewood was higher than LPG by 9.49 kg PM10 eq/household/year, which can be reduced by further improvement in cookstoves.

Singh and Gundimeda (2014) assessed the life cycle environmental footprint of all cooking fuels used in India. They assumed a figure of 76% for non-renewability of fuelwood for cooking. However, they reported that if all the firewood was supplied from renewable sources, the global warming potential (GWP) would sharply reduce to 71 kg CO_2 eq/GJ. They concluded that a steep increase in the cost of crude oil and natural gas prices in the international markets would further raise the economic barriers impacting fuel transition in rural and low-income urban households. Given the prevailing situation in India, it is important to shift the focus from fossil to biomass energy. They suggested that sustainable use of firewood could be a potential source of bioenergy for cooking in rural areas and LPG for urban areas. Venkataraman et al. (2010) conducted a study on the potential of improved fuelwood cookstoves for affordable and reliable cleaner cooking options for the 160 million households using traditional cookstoves in India. They recognized that there is a need for ensuring the availability of stove technologies that can deliver superior performance, both in terms of thermal efficiency and emission reduction as well as through effective delivery mechanisms. They estimated 10% non-renewability for woodfuel in India and reported that the total potential benefit of a fully implemented National Biomass Cookstoves Initiative (NCI) scheme in 2005 would have resulted in reductions of 61.9, 1.5 and 0.042 Mt annually of CO_2, CH_4, and N_2O. Bhattacharya and Salam (2002) analysed the selected options available for seven Asian countries including India in the context of reducing total greenhouse gas emission per unit of useful energy for cooking. They assumed that biomass as an energy source is CO_2 neutral. However, other GHGs emitted from biomass combustion cause a net greenhouse effect; accordingly, in this study only the non-CO_2 greenhouse gases i.e. CH_4 and N_2O were considered in estimating GHGs emission for different biomass-based cooking options. They reported that the total GHGs emission from traditional wood-fired stoves was estimated to be about 110 g of CO_2 equivalent per megajoule of useful energy (g CO_2^{-e} MJ^{-1} useful) delivered to the cooking pot; this can be compared with 42 and 196 g CO_2^{-e} MJ^{-1} useful energy for improved wood and LPG-fired stoves, respectively. GHGs emissions amounting to about 18.1 million tonnes of CO_2 equivalent and firewood of 69.5 million tonnes can be reduced annually in India by substituting traditional stoves with improved cookstoves. They also estimated that GHGs emissions will increase by 24.5 and 34.4 million tonnes of CO_2 equivalent per year if all traditional stoves are replaced by natural gas and LPG stoves, respectively. Improved biomass-based cooking stoves can potentially play an important role in mitigating GHGs emissions from domestic cooking by providing an alternative to LPG. Panwar et al. (2009) examined greenhouse gas reduction and fuel-saving through the use of improved biomass cookstove in actual use and estimated that a single improved biomass cookstove can save about 700 kg of fuelwood per year and at the same time reduce CO_2

emission by 161 kg per year. Improvements in households' biomass burning stoves therefore potentially result in reduced fuel demand that has social benefits—economic and time-saving benefits to the household and reduced human exposure to health-damaging air pollutants- and also environmental benefits- increased sustainability of the natural resource base, and reduced emission of greenhouse gases.

Burning fuelwood causes indoor air pollution (IAP) due to emission of harmful substances such as carbon dioxide (CO_2), nitrous oxide (N_2O), sulphur dioxide (SO_2), carbon monoxide (CO), benzene (C_6H_6), formaldehyde (HCHO) and particulate matter at higher levels than the recommended limits set by World Health Organization (WHO). Inhalation of toxic fumes emitted by traditional cookstoves causes acute lower respiratory infections (ALRI), chronic obstructive pulmonary diseases (COPD), lung cancer, cataracts, and other illnesses. The majority of rural Indian kitchens are poorly ventilated thus, increasing the risk of inhaling harmful smoke, gases, and particulates. In households without separate indoor kitchen facilities, cooking is usually done in the corner of a room, sometimes separated by a half wall, leading to smoke filling the entire house and impacting other members of the family. In rural areas, 39.4 and 32.2% of houses in India had one room and two rooms, respectively and 83.3% households cooked inside their houses, of which 37.9% households did not have a separate kitchen facility (Census of India 2011). Incorporating the agenda of universal clean fuel access or cleaner technology within the broader framework of rural development will be challenging but will go a long way towards reducing respiratory disease burden (Sehgal et al. 2014).

Gould and Urpelainen (2018) reported that fuel stacking is a norm in India as most households will continue using firewood even after adopting LPG. In future, more people will switch to LPG, due to its accessibility and improvements in their economic status. But the availability of LPG will not be infinite, as reserves are limited. It cannot therefore, meet the requirements of all the people of the country on a sustainable basis. Data from the Petroleum, Planning & Analysis Cell (PPAC 2019) shows that 96.5% of households had access to LPG and there were 253.6 million active connections, of which 80.33 million were under the Pradhan Mantri Ujjwala Yojana (PMUY) scheme as on October 1, 2019. The total subsidy expenditure on LPG was US$ 5.2 billion, of which US$ 4.4 billion was under the Direct Benefit Transfer for LPG (DBTL) scheme and US$ 0.8 billion under the PMUY scheme during 2018–19. The total subsidy expenditure on LPG accounts for 12% of the total subsidy expenditure of India during 2018–19. The import bill for petroleum products was US$ 111.9 billion, which was 60.8% of the negative trade balance and 27.2% of the foreign exchange reserve of India for 2018–19. The import dependency of petroleum products and natural gas was estimated at 83.8 and 47.3%, respectively. About 79% of LPG was produced from crude oil and 21% from natural gas in India. The reserve/production ratio of crude oil was estimated at 14 years for India and 50 years for the overall world average. The Comptroller and Auditor General (CAG 2019) of India observed that among the 31.8 million PMUY consumers, who had completed one year of subscription or more as of December 31, 2018, 17.61% consumers never came back for the second refill and 33.02% consumers used 1 to 3.0 refills only in a year in comparison to 6.7 refills by non-PMUY consumers in India.

There is a myth about wood energy that, "the major source of fuelwood for cooking comes from forest and its use is responsible for degrading the natural forests", and "fuelwood demand overtake supply". This "Fuelwood gap theory" implies that consumption of fuelwood for cooking is unsustainable. However, this theory has been discarded by various empirical studies (Arnold et al. 2003; Ndayambaje and Mohren 2011) and fuelwood use is no longer considered to be a major cause of global deforestation, although, in certain areas and locations, fuelwood use is responsible for deforestation (FAO 1997). An NCAER (1985) study revealed that during 1978–80 only 26% woodfuel directly came from forests, 17% from roadside trees, 27% from the market (which could be from forests, privately-owned trees, or other sources), 26% from privately-owned sources and the remaining 4% from other unknown sources. Treating this estimate as a base, the production of fuelwood from forests has been estimated to be 52 million m^3 (FSI 2009), with the remaining 209 million m^3 coming from farmland, community land, homesteads, roadside, canal side, and other wastelands. The UK's Department of International Development (DFID) and the M.S. Swaminathan Research Foundation (2010), reported that due to the implementation of social forestry and large scale afforestation programmes in India, the area of fuelwood production has gradually shifted from forests to non-forests area. For example, the forest-deficient Haryana state of India has surplus fuelwood produced from outside forests. Similarly, in the forest-rich state of Kerala, most of the fuelwood requirements of the rural population are met from trees grown in homesteads. The Forest Survey of India (FSI 2011) estimated that the 853.9 million people used fuelwood as a source of energy for cooking, of which 199.6 million (23.4%) used fuelwood collected from forests in India. The total quantity of fuelwood used every year in the country was estimated to be 216.42 million tonnes, of which 58.75 million tonnes were collected from forests. India has a well-articulated forest policy, and steps taken to conserve biodiversity and existing forest resources have increased restricted areas, where removal of fuelwood is not permitted. As a result the area under fuelwood production increased in non-forest areas viz homesteads, agroforestry, wastelands, roadside, and canals. Gradually, common property resources started declining substantially due to deterioration in community management over the years (NSSO 1999).

As common property resources are in the process of diminishing, farmers need to focus on the production of trees on their land. In recent times, the process of adding trees to farming systems has been accelerated in most areas by the commercialization of timber, fuelwood, and other tree products. Agroforestry systems provide multifunctional ecosystem goods and services such as food, fodder, fuelwood, timber, raw materials for paper and plywood industries, etc. along with several intangible benefits. Fuelwood is an important provisioning ecosystem product, which is predominantly used for cooking purposes, especially in rural India. Valuing ecosystem services like fuelwood serves several purposes for stakeholders, such as providing evidence for prioritizing funding for research and development along with economically feasible subsidies for agroforestry adoption. The sustainable management of both forests and agriculture and their integration in land use plans is essential for achieving sustainable development goals, ensuring food security, and tackling climate change (FAO 2016c). There are various empirical studies available on household consumption and estimation of source-wise supply of fuelwood for cooking in India (NCAER 1985; Leach and Gowen 1987; Gregersen et al. 1989; Saxena 1993; Natarajan 1996; Kursten 2000; Pandey 2002; Joon et al. 2009; Sood and Mitchell 2011). However, there is a dearth of pertinent studies on fuelwood supply from agroforestry and its valuation, resulting in fuelwood from agroforestry being an undervalued good (IFPRI 1992).

Nearly half of households collect fuelwood from their farm, 33% collect from roadside trees and bushes, and only 17% from the forests (Natarajan 1996). Pandey (2002) reviewed and critically analysed the studies related to fuelwood consumption in households during the last two decades in India and reported that urbanization, the distance of forest resources, and income are the main determinants for fuelwood consumption. More than 75% of India's wood energy comes from trees outside forests, i.e. homesteads, farmland, alongside roads, canals, and railways, and other common lands. Fuelwood is considered a free-good, especially in rural India, where 86% of agricultural households are marginal and small (below 0.02 km^2 landholding) and operate their farm on a subsistence level; for them time is considered as free and plentiful. However, gradual transformation of subsistence to commercial agriculture and scarcity of labour and enhancement of the wage rate in rural India is gaining importance over time. The wage rates of agricultural labour (male) have been increased in all the states ranging between 44 to 87% in nominal terms and 3 to 50% in real terms during the period of the agricultural year 2008–09 to 2011–12 at all India level (Singh 2013).

The Greenhouse gases (GHGs) emissions and health hazards of fuelwood used for cooking are important negative externalities. These adverse effects are influenced by combustion performance, fuelwood properties, and ventilation. Cleanness and efficiency are affected by the combined performance of fuel and stove. Woodfuel can be burned cleanly and effectively if matched with well-designed fuel-saving stoves. In the International Workshop Agreement, stoves that meet efficiency ($\geq$ 25%) are considered efficient and those meet air emissions ($\leq$ 9 g CO and $\leq$ 168 mg $PM_{2.5}$ per MJ delivered to the pot) considered clean (FAO 2018). It is recognized that in the process of transition of cooking fuel that meets World Health Organization Air Quality Guidelines (WHO AQG) value for PM $_{2.5}$, will take time, hence, intermediate steps may be inevitable and appropriate to promote this transition process. The Ministry of New and Renewable Energy (MNRE), Government of India has taken up several initiatives to address these pertinent issues and issued guidelines for approval of the models of improved cookstoves (ICS). ICS for cooking is cost-effective in terms of fuel-saving of 30 to 60% and a reduction in GHGs emissions up to 90% relative to the traditional stoves. Venkataraman et al. (2010) reported that the dissemination of 160 million advanced ICS in India may result in the mitigation of 80 Mt CO_2 eq/yr (IPCC 2012).

The Government of India is focusing on enhancing the efficiency of fuelwood cookstoves through various schemes under the Ministry of New and Renewable Energy (MNRE) and implemented a National Programme on Improved *Chulhas* (NPIC) during the period 1983–84 to 2002–03, under which about 35.0 million improved *chulhas* were installed before the scheme was transferred to state governments in 2003–04. Subsequently, the MNRE launched the National Biomass Cookstoves Initiative (NBCI) on 2[nd] December 2009 to enhance the availability of clean and efficient energy and improved technical capacity in this sector in the country. The *Unnat Chulha Abhiyan* (UCA) programme launched in June 2014 aims at promotion of improved biomass cookstoves in the country for providing a clean cooking energy solution and reduce consumption of fuelwood with higher efficiency and low emissions. So far 36,940 family type and 849 community type improved cookstoves have been distributed, which is only 1.5% of the target. There is a dearth of information about sources of supply and the value of fuelwood used for cooking at the macro-level in India. To develop policies, plans, and strategies related to reliable and affordable energy for cooking needs a source-wise value of energy, particularly for fuelwood, which contributes the lion's share of cooking energy in rural India is required. Knowledge about the value of fuelwood at market price and opportunity costs with a possible substitute will help policymakers in the preparation of suitable policies for sustainable supply of fuelwood and management of the system.

In view of these considerations, the current study aims to address a number of pertinent questions: (i) what proportion of households use different energy sources for cooking,, what is the consumption by occupation, and the Monthly Per Capita Consumption Expenditure (MPCE) of people, and what are the trends?; (ii) what quantity and value of fuelwood is consumed in major Indian states?; (iii) what are the relationships between fuelwood consumption and forest cover, per capita forest cover availability, per capita net state domestic product, and poverty exist in major states?; (iv) what quantity and value of fuelwood is supplied from the forest, from agroforestry, and from other sources?; (v) what is the opportunity cost of fuelwood in relation to dung cake and LPG in rural areas in India as a whole?; and (vi) what policy research areas and policy prescriptions are needed to strengthen agroforestry research and development in India? The research objective of this study was to estimate fuelwood value supplied from agroforestry systems and suggest policy research areas and measures to ensure access to affordable, reliable, sustainable energy for cooking in India.

Materials and methods

Data and methodologies

This study is based on secondary data, which were compiled from published sources of various departments of the Government of India.

To estimate the value of monthly consumption of fuelwood in rural and urban areas by the Indian states, the following equation was used:

$$FC_i = P_i * S_i * Q_i * V_i * 10^{-8}$$

where i = 1, 2, 3…n. (1 to 17). n is the number of states.

Where,

FC is the value of fuelwood consumption by rural/urban population in a particular state ($US million $month^{-1}$);

P is the total number of rural/urban population in a state;

S is the percentage share of the rural/urban population consuming fuelwood (%);

Q is the quantity of fuelwood consumed per capita/month (kg $person^{-1}$ $month^{-1}$) by rural/urban population; and.

V is the price of fuelwood ($ US kg^{-1}) for the rural/urban population.

Data related to the consumption of fuelwood and their prices in various states were taken from various publications of Central Statistics Office (CSO), Ministry of Statistics and Programme Implementation (MoSPI), Government of India. (CSO 2014, 2015; NSSO 1997, 2007, 2012,2013a, b,2015). The data related to national income and the poverty line was taken from publications of the Reserve Bank of India (RBI 2015). The net heating value (MJ/kg) was taken as15.5 and 12.0 for fuelwood (with 20% moisture and 13–18% conversion efficiency range) and dry dung cake (with 12% moisture and 12% conversion efficiency), respectively, in the present study. It was assumed that about 50% nutrients of FYM are lost between production and application in the field (ICAR 2009). The conversion factors such as fresh dung to dry dung cake (20% of weight), FYM (24% of weight) were used in the present study. The availability of nitrogen 0.5%, phosphorus 0.3%, potash 0.4% and sulphur 0.02% in FYM was assumed in this study. The annual average value of conversion between US$ and Rupee were of 47.9 was used in the study.

Results and discussion

Growth and distribution of primary sources of energy used for cooking

The growth and distribution of primary sources of energy used for cooking at the national level during 1993–94 to 2011–12 are illustrated in Table 1. The data revealed that woodfuel (firewood and chips) were used by more than two-thirds (67%) of rural households, followed by LPG (15%), dung cake (10%), coke and coal (1%) for cooking during 2011–12. It was observed that the share of firewood and chips consumer households reduced by 12% and LPG consumers increased by 13%, which might be substituted by LPG over the past two decades in rural India. Dung cake was a major fuel for cooking (10%) of rural households and its share declined only by 2% during the study period.

In urban India, over two-thirds (68%) of households used LPG as a primary source of energy for cooking, followed by firewood & chips (14%) and kerosene (6%) during 2011–12. The consumption of LPG increased more than two-fold (from 30 to 68%), while the share of firewood and chips declined by 50%. The consumption of kerosene declined markedly from 23 to 6% during the same period. It indicates that firewood & chips along with kerosene were replaced by LPG due to easy availability and the next progression in energy use for cooking.

Firewood and chips along with LPG were used by over 82% of households in both rural and urban areas in a reciprocal relationship. Firewood and chips were in the process of substitution with LPG, however substitution between these two major sources of energy was slow and households which had adopted

Table 1 Growth and distribution of primary source of energy used for cooking in India, 1993–94 to 2011–12

Sources of energy for cooking	Percentage of households with primary source of energy used for cooking				Compound annual growth rate (CAGR) during 1993–94 to 2011–12 (%)	
	Rural		Urban		Rural	Urban
	1993–94	2011–12	1993–94	2011–12		
Wood fuels(Firewood and chips	78.2	67.3	29.9	14.0	− 0.8	− 3.9
Dung cake	11.5	9.6	2.4	1.3	− 0.9	− 3.2
Kerosene	2.0	0.9	23.2	5.7	− 4.1	− 7.1
Liquefied Petroleum Gas (LPG)	1.9	15.0	30	68	11.5	4.5
Coke/coal	1.4	1.1	5.7	2.1	− 1.3	− 5.1
Other sources (Gobar gas, Charcoal, Electricity, etc.)	4.1	4.9	3.0	1.5	0.9	− 3.6
No cooking arrangement	0.7	1.3	6.3	6.9	3.3	0.5

Source: Authors' estimate. with data from 50th (1993–94) and 68th (2011–12) round of the 'Energy Sources of Indian Households', National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India

LPG retained the use of firewood and chips. The share of fuelwood consumption especially in rural areas declined (78 to 67%), but the total consumption increased substantially (106 to 130 Mt) due to the increase in population during the study period.

The population with irregular income (casual labour in agriculture and casual labour in non-agriculture used relatively more firewood and chips and less LPG than other groups in rural households (Table 2). The casual labour in agriculture group used the highest proportion of fuelwood (80.4%), followed by Casual labour in non-agriculture (72.9%), then Self-employed in agriculture (70.6%). By contrast, the Regular wage/salary earning group ranked first in the use of LPG (44.5% of their fuel use), followed by Self-employed in non-agriculture (24.5%).

The consumption of fuelwood and LPG by MPCE class in rural and urban households is shown in Figs. 1,2. It indicates that the lowest seven percentile classes of rural households were using more than 70% fuelwood for their cooking energy. By contrast, the percentage of rural households using LPG for cooking increased with the increase in the MPCE level. In the case of urban households consumption of LPG also increased with the increase in MPCE level, while fuelwood consumption for cooking decreased. Results revealed that the highest MPCE class (90–100) continued to use about an equal share of fuelwood (40% of households) and LPG (45% of households) for their cooking in rural India. It implies that despite an increase in income, people will retain fuelwood as a substantial share of their cooking fuel in the future in rural areas of the country.

Quantity and value of monthly consumption of fuelwood and chips in major states

The quantity and value of monthly consumption of fuelwood and chips in major Indian states are presented in Table 3. More than 56% of rural households consumed woodfuel (firewood and chips) for cooking in all major states except Haryana (41.70%) and Punjab (30.50%). Highest percentage use in rural India was in the state of Chhattisgarh (93.20%), followed by Rajasthan (89.30%) and Odisha (87.00%). In urban areas Odisha ranked first (36.50%), followed by Kerala (36.30%) and Chhattisgarh (34.70%). This indicates that households in the states of Chhattisgarh and Odisha depend heavily on fuelwood and chips for cooking in both rural and urban areas. The highest quantity of per capita monthly fuelwood consumption in rural areas was in the state of Kerala (32.40 kg), followed by Odisha (30.00 kg) and Assam (29.90 kg). The same pattern of consumption occurred in urban areas, with the state of Kerala ranked first (20.60 kg), followed by Odisha (15.70 kg) and Chhattisgarh (7.60 kg).

Table 2 Distribution of rural households by occupation and primary source of energy used for cooking in India, 2011–12.

Household type/Occupation	Sources of energy for cooking (Percentage)						
	Wood fuels(Firewood and chips)	Liquefied Petroleum Gas (LPG)	Dung cake	Kerosene	Coke/ Coal	Other sources (Gobar gas, Charcoal, Electricity, etc.)	No cooking arrangement
Casual labour in agriculture	80.4	4.6	5.8	0.7	1.0	7.9	0.1
Casual labour in non -agriculture	72.9	8.5	11.8	1.2	1.6	3.3	0.5
Self-employed in agriculture	70.6	10.8	12.8	0.3	0.8	4.7	0.0
Self-employed in non-agriculture	58.6	24.5	8.7	1.2	2.3	4.3	0.3
Others	48.9	22.0	8.3	1.3	1.0	4.1	14.1
Regular wage/ salary earning	41.4	44.5	5.9	2.0	1.1	2.1	3.0
All	67.3	15.0	9.6	0.9	1.1	4.9	1.3

Source: Authors' estimate with data from 68th (2011–12) round, report No. 567 on 'Energy Sources of Indian Households', National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India

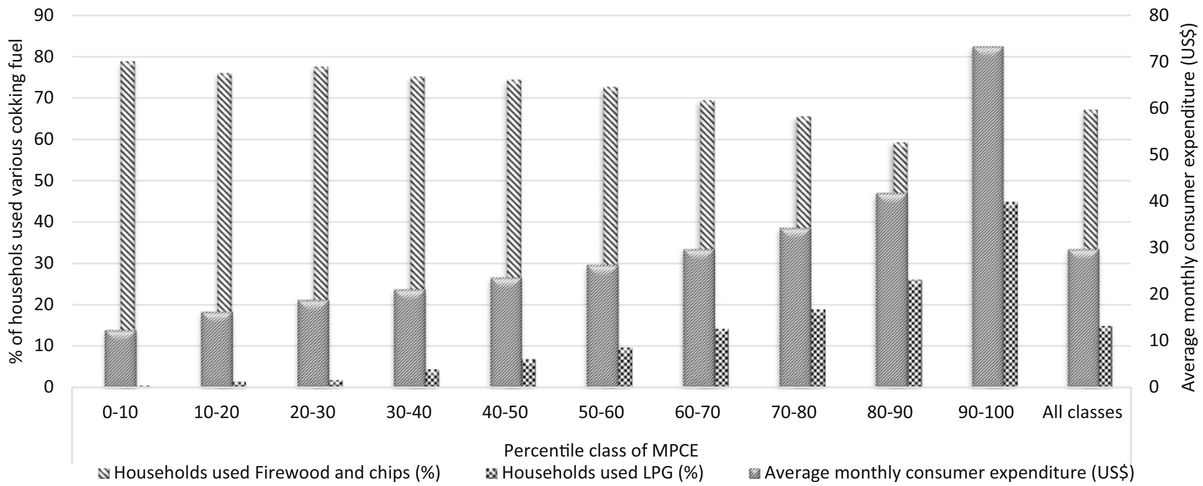

Fig. 1 Consumption of cooking-fuel by fractile class of per capita monthly expenditure, Rural-India, 2011-12

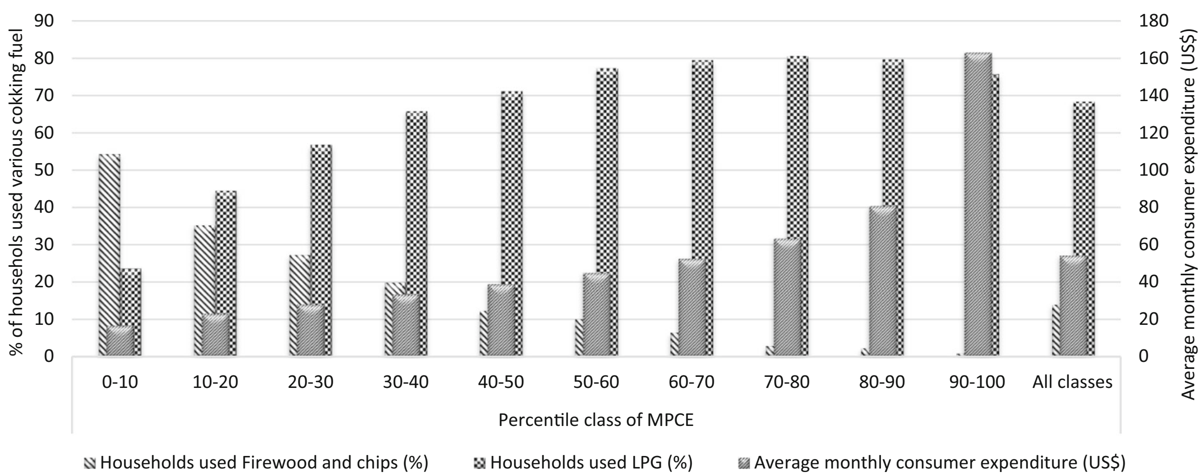

Fig. 2 Consumption of cooking-fuel by fractile class of per capita monthly expenditure, Urban-India, 2011-12

Correlation between forest cover, price of fuelwood, per capita NSDP and poverty in major states

Results revealed that in both rural (− 0.84) and urban (− 0.62) areas, per capita consumption of fuelwood was negatively correlated (Table 4). The percentage share of households using fuelwood with per capita Net State Domestic Product (NSDP) at current prices also showed negative correlation in rural (− 0.39) and urban (− 0.40) areas. This implies that the price of fuelwood and per capita income are inversely related to fuelwood consumption in both rural and urban areas. However, the price of fuelwood and per capita income showed strong and weak negative correlation with the consumption of fuelwood, respectively. This finding is shown clearly in the case of Kerala, where fuelwood price was second lowest (US$ 0.03/kg in rural areas) and NSDP was second highest (US$ 1726.9/capita). Therefore, it can be inferred that despite higher income, people would retain the use of fuelwood in the future. This finding is consistent with the findings of Mishra (2008).

The results of the simple correlation depicted that the percentage share of rural households using fuelwood with per cent of the geographical area under forest cover (0.52), per capita forest cover (0.68), and per cent of people under below poverty line (0.58)

Table 3 Quantity and value of monthly consumption for fuelwood and chips in major states, India, 2011–12

State	Population used wood fuels (firewood & chips (%)		Quantity of fuelwood and chips consumption (kg person^{-1} month^{-1})		Price of fuelwood and chips ($ US Kg^{-1})		Total quantity of fuelwood & chips consumption per month '000 tonnes'		Total value of fuelwood & chips per month (US$ million)	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Andhra Pradesh	67.5	10.1	18.9	2.9	0.04	0.05	718.0	8.3	31.5	0.4
Assam	81.0	16.8	29.9	5.5	0.04	0.06	648.5	4.1	25.0	0.2
Bihar	56.4	24.9	9.9	4.2	0.08	0.09	515.5	12.4	43.3	1.2
Chhattisgarh	93.2	34.7	24.1	7.6	0.05	0.08	440.7	15.6	22.7	1.2
Gujarat	79.7	15.9	20.7	3.4	0.06	0.08	572.2	14.0	33.7	1.1
Haryana	41.7	6.0	11.6	1.7	0.07	0.08	79.7	0.9	5.3	0.1
Jharkhand	77.7	5.6	20.5	2.5	0.05	0.05	398.7	1.1	18.9	0.1
Karnataka	80.5	14.8	28.1	6.4	0.04	0.06	847.1	22.5	36.1	1.4
Kerala	66.3	36.3	32.4	20.6	0.03	0.04	375.4	119.1	11.2	4.3
Madhya Pradesh	80.8	25.7	16.1	5.5	0.06	0.08	683.2	28.1	44.3	2.1
Maharashtra	62.1	5.7	17.0	1.7	0.06	0.08	648.8	5.0	36.9	0.4
Odisha	87.0	36.5	30.0	15.7	0.04	0.05	911.6	40.1	39.2	1.9
Punjab	30.5	6.7	12.3	1.9	0.05	0.09	65.2	1.3	3.5	0.1
Rajasthan	89.3	18.7	28.6	5.3	0.02	0.08	1313.2	16.8	27.4	1.3
Tamil Nadu	58.3	11.2	19.3	3.7	0.05	0.06	418.3	14.4	19.1	0.8
Uttar Pradesh	56.1	21.0	11.8	4.3	0.07	0.09	1032.3	39.9	72.1	3.4
West Bengal	62.9	10.7	18.0	3.4	0.05	0.06	704.8	10.6	37.0	0.7
All India	67.3	14.0	19.0	4.3	0.05	0.06	10,373.0	354.2	507.2	20.5

Source: Authors' estimate with data from 68th (2011–12) round of the 'Energy Sources of Indian Households' and 'Household Consumption of Various Goods and Services in India', National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India

were moderately positively correlated. At the same time the percent share of urban households using fuelwood with urban poverty was weak, but positively correlated. This finding indicates that despite a higher percentage of people below the poverty line in the urban area, the consumption of fuelwood is substituted with other progressive fuel because of easy availability at the doorstep and higher opportunity cost of time spent for collecting fuelwood.

Annual quantity and value of fuelwood and chips and its supply for cooking from various sources

The total annual quantity and value of fuelwood consumption were estimated from monthly estimates of the national level. The share of supply of fuelwood from the forest was estimated to be 23.80% of total fuelwood supply, based on India State of Forest Report-2011 (FSI 2011). It was reported that 45% of rural households collected their fuelwood from Common Property Resources (CPRs) and the share of fuelwood collected from CPRs was estimated to be 55% in their total fuelwood consumption in the year 1998. The estimated area under CPRs was 15% of the total geographical area, with a shrinking rate of 0.38% per annum (NSSO 1999). This means that the contribution of CPRs was 25% of the total supply of fuelwood in rural India in 1998. The area under CPRs was estimated to be 12.03% of the total geographical area, which includes land under permanent pastures (3.37%), miscellaneous tree crops and groves (1.04%), culturable wasteland (4.13%) and fallow lands other than current fallows (3.49%). Therefore, in the present study it was presumed that CPR contributed 12.03% of the total demand for fuelwood.

Table 4 Correlation between forest cover, price of fuelwood, per capita NSDP and poverty in major states, India, 2011–12

State	Price of fuelwood in rural area (US$/kg)	Price of fuelwood in urban area (US$/kg)	% Forest cover of geographical area	Per capita forest cover (ha)	Rural poverty (%)	Urban poverty (%)	Per capita Net State Domestic Product (NSDP) at current prices (US$)
Andhra Pradesh	0.04	0.05	15.3	0.05	11.0	5.8	1351.7
Assam	0.04	0.06	35.2	0.09	33.9	20.5	757.9
Bihar	0.09	0.09	7.7	0.01	34.1	31.2	471.3
Chhattisgarh	0.05	0.08	41.1	0.22	44.6	24.8	1009.3
Gujarat	0.06	0.08	7.5	0.02	21.5	10.1	1794.2
Haryana	0.07	0.08	3.6	0.01	11.6	10.3	2218.6
Jharkhand	0.05	0.05	29.5	0.07	40.8	24.8	762.8
Karnataka	0.04	0.06	19.0	0.06	24.5	15.3	1420.1
Kerala	0.03	0.04	49.5	0.05	9.1	5.0	1726.9
Madhya Pradesh	0.07	0.08	25.1	0.11	35.7	21.0	775.9
Maharashtra	0.06	0.08	16.5	0.05	24.2	9.1	1946.6
Odisha	0.04	0.05	32.3	0.12	35.7	17.3	907.0
Punjab	0.06	0.10	3.5	0.01	7.7	9.2	1604.6
Rajasthan	0.02	0.08	4.7	0.02	16.1	10.7	1140.1
Tamil Nadu	0.05	0.06	20.3	0.03	15.8	6.5	1858.3
Uttar Pradesh	0.07	0.09	6.0	0.01	30.4	26.1	626.5
West Bengal	0.05	0.06	19.0	0.01	22.5	14.7	1113.9
All India	0.05	0.07	21.3	0.06	25.7	13.7	1290.8

Source: Authors' estimate with data from 68th (2011–12) Round of the 'Household Consumption of various Goods and Services in India', National Sample Survey Office, Ministry of Statistics and Programme Implementation; India State of Forest Report, 2011 and 2015, Forest Survey of India, Ministry of Environment, Forests and Climate change, National Institution for Transforming (NITI, Ayog) India

The contribution of agroforestry to fuelwood supply was estimated as total consumption minus supply from forests and CPRs at the national level. The highest share of fuelwood supply was from agroforestry systems (64%), followed by forests (23.8%) and CPRs (12%) during 2011–12. The finding of the study corroborates estimates of the Ministry of Statistics and Programme Implementation (MOSPI), Government of India (CSO 2014). The value of total fuelwood estimated at US$ 6333.1 million, is lower than the US$ 10,011.7 million estimated by MOSPI for the year 2011–12. The reasons for this lower value may be attributed to the fact that only 17 major states were taken into consideration for calculating consumption of fuelwood for cooking purposes in the present study, while all the states and Union territories with 1.0764 factor for adjustment to the contribution of fuelwood for industrial and religious purposes was considered by MOSPI in their estimates.

The annual opportunity cost of fuelwood used for cooking switching to dry dung cake in the rural area of major states

The opportunity cost of maintaining a particular area as a forest would be the value of agricultural production that would be otherwise obtained from conversion (Table 5). In a scenario, where total consumption of fuelwood used for cooking was substituted by dry dung cake in rural areas of major states in India, about 160.8 Mt of dry dung cake would be required to provide energy of 1929.4 PJ for switching from fuelwood to dry dung cake. This would require approximately 803.9 Mt of wet dung. To fulfill the requirement of wet dung, approximately 97 million additional bovines would need to be added to the present number of 300 million bovines in India. The rearing of these additional bovines would be a herculean task in the country, where the carrying capacity of the land to support livestock is already exceedingly high. The area under permanent pasture and other grazing land and fodder crops is 10 and 7.7 million ha, respectively to support a total of 512 million livestock. Another challenge would be to increase their numbers, which showed a declining trend by 1.59% during 2007–2012. Moreover, it is reported that the livestock sector contributes a significant share to anthropogenic GHGs emissions, hence under these circumstances switching to dry dung would be a costly affair in India. Villagers use dung cake as cooking fuel only when fuelwood is not available or not easily accessible, except for thickening milk, which requires a slow-burning fuel. This particular cooking practice is prevalent in many rural parts of India and cow dung cake is mostly used as an alternative to fuelwood.

The use of dung cake as a fuel results in the loss of nutrients. Wet dung is a major source for farmyard manure (FYM), which helps in improving soil health by providing soil organic matter, various primary, secondary nutrients, and micronutrients as well as improvement in the water holding capacity of the soil. The opportunity cost of switching to dung cake in terms of plant nutrients illustrates that a substantial amount of money would be required to purchase available nutrients as estimated in FYM such as

Table 5 Estimated annual opportunity cost of fuelwood used for cooking switching to dry dung cake in rural area of major states during 2011–12 in India

State	Calorific value of fuelwood. Petajoule (PJ)	Estimated quantity of dry dung cakes (million tonnes)	Estimated quantity of fresh dung (million tonnes)	Estimated quantity of farm yard manure (FYM) (million tonnes)	Estimated value of nutrients from FYM (US $ million)				
					N	P	K	S	Total
Andhra Pradesh	133.6	11.1	55.6	13.4	26.8	24.7	24.5	1.3	77.3
Assam	120.6	10.1	50.3	12.1	24.2	22.3	22.1	1.2	69.8
Bihar	95.9	8.0	40.0	9.6	19.3	17.7	17.6	0.9	55.5
Chhattisgarh	82.0	6.8	34.2	8.2	16.5	15.1	15.0	0.8	47.4
Gujarat	106.4	8.9	44.3	10.6	21.4	19.7	19.5	1.0	61.6
Haryana	14.8	1.2	6.2	1.5	3.0	2.7	2.7	0.1	8.6
Jharkhand	74.2	6.2	30.9	7.4	14.9	13.7	13.6	0.7	42.9
Karnataka	157.6	13.1	65.6	15.8	31.7	29.1	28.9	1.5	91.2
Kerala	69.8	5.8	29.1	7.0	14.0	12.9	12.8	0.7	40.4
Madhya Pradesh	127.1	10.6	53.0	12.7	25.5	23.5	23.3	1.2	73.6
Maharashtra	120.7	10.1	50.3	12.1	24.3	22.3	22.1	1.2	69.8
Odisha	169.6	14.1	70.6	17.0	34.1	31.3	31.1	1.6	98.1
Punjab	12.1	1.0	5.1	1.2	2.4	2.2	2.2	0.1	7.0
Rajasthan	244.3	20.4	101.8	24.4	49.1	45.1	44.8	2.3	141.4
Tamil Nadu	77.8	6.5	32.4	7.8	15.6	14.4	14.3	0.7	45.0
Uttar Pradesh	192.0	16.0	80.0	19.2	38.6	35.5	35.2	1.8	111.1
West Bengal	131.1	10.9	54.6	13.1	26.4	24.2	24.1	1.3	75.9
All India	1929.4	160.8	803.9	192.9	387.9	356.3	354.0	18.5	1116.6

Source: Authors' estimate with data from 68th round of the 'Energy Sources of Indian Households' National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India nitrogen (US$ 776.9 million), phosphorus (US$ 713.5 million), potassium (US$ 709.0 million) and sulphur (US$ 37.1 million) annually. The important issue is that about 50% of the demand for nitrogenous and phosphatic fertilizers and total potash in India is met by import, which incurs valuable foreign exchange.

The estimated opportunity cost of fuelwood in India in terms of dung cake was US$ 1116.6 million, which is less than the value of fuelwood (US$ 6333.1 million), however only four out of 16 plant nutrients available in FYM were calculated in the present study. The conversion factor between fresh wet dung to dry dung cake and FYM was taken as 0.20 and 0.24, respectively. The conversion factor for fuelwood to dry dung cake was taken as 1.29 based on calorific value, in comparison to 3.53 used in a study conducted by Dikshit and Brithal (2010). In another study, the economic value of fuelwood by comparison with the opportunity cost of soil fertility and maize production was estimated, when dung was used as a fuel and assumed that it will enhance 15% yield when used @ 8 tonnes of FYM per hectare in Nepal (Gregersen et al. 1989). Moreover, the estimated value of required dung cake coincided with the value of US$ 2435.4 and US$ 4399.6 for dung fuel and dung manure, respectively by CSO, Government of India for the year 2011–12, which included all livestock in the country. The most common uses of cow dung are preparation of FYM for plant nutrients and dung cake for fuelwood. Diversion of dung for fuel use hampered crop production.

Generally, as income increases, energy consumption increases, and many households switch to a fuel higher up the so-called energy ladder due to either greater convenience or desired status. Substitution between different fuel sources depends on two factors: scarcity and income. When any fuel becomes scarce, more quantities of alternative fuels are consumed due to cross-price elasticity. These alternatives may be traditional or commercial in nature depending upon the nature of the household involved. Joon et al. (2009) reported that income was an important factor in determining the choice of fuel for cooking, but some socio-cultural factors were equally important in making fuel preference at the household level. In lowest income groups, relatively little energy substitution may take place due to an increase in the consumption of food and less priority given to energy consumption.

The energy ladder hypothesis (Leach 1992) proposed that the promotion and infrastructure for expanding modern energy access will decrease per capita use of fuelwood for cooking with rising income and urbanization. Generally, an increase in household income and adoption of the upper ladder of the source of energy has a positive correlation in any society. If all the households, which use fuelwood switch to LPG for cooking, the country may require 2980 million domestic LPG cylinders to meet the energy requirement. This in turn incurs a total cost of US$ 46,129.2 million for India. It implies that 248 million additional connections (with the assumption that each family consumes one cylinder each month) will be required to achieve complete transition in the entire country.

The Government of India initiated the scheme for providing free LPG connections through Oil Marketing Companies to women belonging to the below poverty line (BPL) in rural households under PMUY since 2016–17. The scheme has achieved the target to cover 80 million BPL households by 2020. The scheme provides financial support of US$ 26.2 for each LPG connection to the BPL households and US$ 1308.5 million for three years. The objective of the scheme is to provide clean cooking fuel to rural poor households. Now questions arise- is India capable of providing 116.4 million additional domestic LPG connections under the scheme? Especially, when the present total domestic LPG connections are about 191 million and production of natural gas is decreasing from 52.22 in 2010–11 to 33.66 billion cubic meters (BCM) during the year 2014–15. This is to be seen in light of the fact that India imported 14.09 MMT (2015–16) of Liquefied natural gas (LNG), valued US$ 9385.7 million (GOI 2016b).

Moreover, the share of the rural population under the poverty line was estimated to be 25.7% by Tendulkar Methodology and 30.9% as per the recommendation of 'Report of the expert group to review the methodology for measurement of poverty' during 2011–12 (NITI Ayog 2014). The lowest seven percentile classes of rural households were using firewood & chips for more than 70% of their cooking energy (Table 2). It is evident that high investment costs for cooking gas and cylinder deposits are major constraints to the adoption of LPG as a fuel source for poor households. At present US$ 73.6 is required for non-BPL households (with two cylinders) and US$ 40.2 after deduction of US$ 33.4 subsidy under the scheme for BPL women in rural households. There are five major challenges in the switching of fuelwood to

LPG: firstly, a declining trend in the production of petroleum products; secondly, the increasing trend in the import of petroleum products; thirdly, LPG is non-renewable and may not be a sustainable source of energy in future; fourthly, higher installation costs and finally, self-reliance, accessibility, and affordability for the continuous use of LPG by poor people, especially the lowest three percentile of people, for whom MPCE was less than US$ 20.9 and the cost of an LPG cylinder was US$ 8.3 in rural India during 2011–12. In addition to these factors, the estimated per-unit cost (US$ MJ^{-1}) of fuelwood is found to be less than half the LPG cost in rural India.

The opportunity cost of fuelwood supply from agroforestry concerning dung cake and LPG for cooking in the rural area at all India level

Cost, benefits, and scarcity are the important factors to consider when comparing various fuel sources (Table 6). To meet the total calorific energy (1297.4 PJ) provided by fuelwood from agroforestry, would require 103 Mt of dry dung cake. It is estimated that US$ 1116.6 million was saved through the use of fuelwood from agroforestry in terms of supply of N, P, K, and S through FYM. Saved money through the use of fuelwood in place of dung cake was a partially accounted contribution, excluding the improvement of soil health and saved scarce foreign exchange. The contribution of ruminants such as cattle, buffaloes, and small ruminants through enteric methane in the emission of GHGs is also a pertinent issue in estimation of the opportunity cost of fuelwood concerning dung cake in India, where about 60% of the contribution of enteric fermentation in total GHGs is attributed to agriculture sector.

In another scenario, where the entire energy used for cooking through fuelwood from agroforestry is switched to LPG, we would require 196.4 million domestic LPG connections and that would have incurred a cost of US$ 36,487.5 million during 2011–12 at the all India level. The projected LPG connections are over three times the target of PMUY and approximately US$ 522 million would be required for connections under the scheme.

Conclusions and policy suggestions

This study has shown that woodfuel (firewood and chips) were used for cooking by more than 67% of rural and 14% of urban households during 2011–12. Firewood and chips consumers reduced by 12% (78 to 67%) in rural areas, but the total consumption increased substantially (106 to 130 Mt) due to the increase in population during the past two decades in India. The lowest seven percentile classes of rural households were using firewood and chips for more than 70% of their cooking energy. The highest MPCE class (90–100) continued to use about an equal share of firewood and chips (40% of households) and LPG (45% of households) for their cooking in rural India. It implies that despite an increase in income, people will retain a substantial share of firewood and chips for cooking in the future. Most households in Chhattisgarh and Odisha states depend on fuelwood and chips for cooking in both rural and urban areas. The price of fuelwood and per capita income are inversely related to fuelwood consumption in both rural and urban areas. However, the price of fuelwood was strongly negatively correlated, and per capita income was weakly negatively correlated, with consumption of fuelwood. Therefore, it can be inferred that, despite higher income, people would retain the use of fuelwood in the future. However, for people below the poverty line in urban areas, the consumption of fuelwood is substituted with modern fuels because of easy availability at the doorstep. The highest share of fuelwood quantity supply was from the agroforestry system (64%), followed by forests (24%) and CPRs (12%) during 2011–12. To meet the total calorific energy (1297.4 PJ) provided by fuelwood from the agroforestry system, would require 103 Mt of dry dung cake, which has implications for soil improvement and greenhouse gas emissions. It is estimated that US$ 1116.6 million could be saved through the use of fuelwood from agroforestry in terms of supply of N, P, K, and S through FYM.

The government of India is implementing PMUY and UCA programmes for efficient cooking and reducing drudgery among rural women. These two programmes are complementary to each other, however there is a wide gap in terms of expenditure and adoption of these two schemes. The total subsidy expenditure incurred on LPG was US$ 5.2 billion, which accounts for 12% of the total subsidy

Table 6 Estimated annual opportunity cost of fuelwood switching to Liquefied Petroleum Gas (LPG) in rural area of major states, India, 2011–12

State	Estimated quantity of LPG (million tonnes)	Estimated number of domestic LPG cylinders (million)	Estimated cost of domestic LPG cylinders (US$ million)
Andhra Pradesh	2.3	163.2	2525.7
Assam	2.1	147.3	2281.0
Bihar	1.7	117.1	1813.3
Chhattisgarh	1.4	100.1	1550.1
Gujarat	1.8	130.0	2012.6
Haryana	0.3	18.1	280.3
Jharkhand	1.3	90.6	1402.4
Karnataka	2.7	192.5	2979.7
Kerala	1.2	85.3	1320.3
Madhya Pradesh	2.2	155.2	2403.3
Maharashtra	2.1	147.4	2282.2
Odisha	2.9	207.1	3206.5
Punjab	0.2	14.8	229.3
Rajasthan	4.2	298.4	4619.4
Tamil Nadu	1.3	95.0	1471.3
Uttar Pradesh	3.3	234.6	3631.0
West Bengal	2.3	160.1	2479.1
All India	33.5	2357.0	36,487.5

Authors' estimate with data from 68th (2011–12) round of the 'Energy Sources of Indian Households' and 'Household Consumption of Various Goods and Services in India', National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India; 'India State of Forest Report, 2011', Forest Survey of India, Ministry of Environment and Forests, Government of India; 'Agricultural Statistics at a Glance-2014', Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture and Framers Welfare, Government of India

expenditure of India during 2018–19. At the same time the import dependency of petroleum products and natural gas is estimated at 83.8 and 47.3%, respectively. The reserve/production ratio of crude oil has been estimated as 14 years for India and 50 years for the overall world average.

Given the prevailing situation in India, the national strategy on clean cooking energy should focus on multidimensional aspects of availability, affordability, convenience, and self-reliance on fuel supply. Researchers and practitioners should apply a holistic approach on the circumscribed basis and focus on continuous upgrading of firewood cookstoves in terms of both thermal efficiency and GHGs reduction along with effective delivery mechanisms. Cookstove improvement would also benefit health of households by reducing exposure to pollution from unimproved cookstoves. There are several policy implications of the study: including rationalization of LPG subsidy, resource allocation for UCA programme and prioritization of investment in cooking energy development that could achieve cost-effective GHGs reduction at the regional level. There are important researchable issues such as: why is the adoption of improved cookstoves (1.5%) negligible in comparison to LPG (96.5%) for cooking in India? Also, what are the fuelwood renewability factors at the district and state level in India? These pertinent issues should be addressed by policy research. This study concluded that the importance of agroforestry in terms of sustainable supply of fuelwood for cooking is crucial in the context of self-reliance, saving of scarce foreign exchange, renewable and nearly carbon–neutral fuel, and energy security for the poor population in India.

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