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RESEARCH PAPER

Cooking with Modern Energy in Rural Households of India: A Cost–Benefit Analysis

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Abstract: Between 2016 and 2019, there has been an improvement in the percentage of rural households using clean cooking energy, partly owing to government interventions. However, unclean solid fuels are still the primary source of energy for cooking purposes for about 60% of rural households. One of the foremost reasons for this is the cost of acquiring and using clean energy sources. This paper estimates the cost incurred by a household when switching from solid fuels to liquefied petroleum gas (LPG) or electricity for cooking, followed by a social cost–benefit analysis of two interventions: universal provision of LPG to all rural households and universal provision of electricity to all rural households. The findings suggest that electricity is a cheaper alternative to LPG at the household level; however, investing in the universal provision of LPG is socially beneficial for the government. Universal provision of electricity for cooking can only become socially beneficial if the proportion of renewable electricity increases, reducing the environmental costs of carbon emissions from coal-based power plants.
Keywords: LPG, Electricity, Rural, India, Cost–benefit analysis
JEL codes: Q410, Q480

1. INTRODUCTION

Globally, the transition to cooking with clean fuels has been slow: from 2010 to 2019, there has been an increase of only 1% in the population that has access to clean fuels and technologies. This is partially an outcome of interventions promoting clean cooking in developing countries in the last decade. Nevertheless, 52% of the global rural population is still dependent on solid, polluting sources of energy to meet their primary cooking needs. The combustion of solid fuels is associated with indoor air pollution through the emission of hazardous gases such as carbon monoxide, nitrogen dioxide, and polycyclic aromatic hydrocarbons in addition to inhalable particulate

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matter that adversely affects the health of women and children exposed to it (Gould and Urpelainen 2018; Masera, Saatkamp, and Kammen 2000). Indoor air pollution has a significant disease burden, causing about 3.2 million deaths per year in 2020, which includes 237,000 children below the age of five (WHO 2022).

LPG and electricity are both products of fossil fuels, but they have a higher energy content compared to solid fuels and cause minimal smoke emission on combustion. As a result, the transition to LPG or electricity for cooking can not only help reduce indoor air pollution but also help save time spent on cooking. By virtue of being clean, modern fuels occupying the top level of the energy ladder, LPG and electricity are both expensive fuels. Cost is one of the prominent barriers when it comes to making a transition to these fuels (World Bank 2003; Reddy 2003; Gupta and Ravindranath 1997; Farsi *et al.* 2006; Jeuland and Pattanayak 2012; Jain *et al.* 2015). While some studies find that the upfront or fixed costs of acquiring clean cooking energy or stoves are obstacles to the adoption of clean fuels such as LPG (Farsi, Filippini, and Pachauri 2007), other studies have shown that the recurring cost of refilling LPG cylinders, rather than the capital cost, can lead to low adoption of LPG, especially among poor households (Jeuland and Pattanayak 2012; Isihak, Akpan, and Adeleye 2012; Bruce *et al.* 2017).

The adoption of clean fuels as the primary energy source for cooking has been low in India, especially among rural households. Between 2016 and 2019, the percentage of rural households using LPG almost doubled from 20% to 39.7%. On the other hand, the percentage of rural households using electricity for cooking remained less than 2% (IIPS 2022). This period coincides with the launch and implementation of both the Pratyaksh Hanstantrit Labh Scheme (PAHAL Scheme, also known as the Direct Benefit Transfer of LPG Scheme)—for more efficient LPG subsidy deployment—as well as the Pradhan Mantri Ujjwala Yojana (PM Ujjwala)—for increasing LPG accessibility to poor households. This period also marks the growth of rural electrification access from 56.6% to 99% in 2020 (IIPS 2022; IIPS 2017). However, despite the increasing access to LPG and electricity, the disease burden attributable to indoor air pollution in 2019 was still 0.6 million deaths and more than 20 million disability-adjusted life years (DALYs), primarily from ischaemic heart disease, chronic obstructive pulmonary diseases, lower-respiratory-tract infections, and stroke (Pandey *et al.* 2020). These figures show that it is imperative to transition to clean cooking to reduce indoor air pollution and the associated disease burden, and government intervention is crucial to achieve this transition.

Cost–benefit analyses were used extensively in the 1950s, primarily for the appraisal of water-related projects (Eckstein 1958; Krutilla and Eckstein

1958), where the fundamental idea was to "compare the gains and losses associated with an investment project or policy" (Pearce 1998, 84). Over the next three decades, cost–benefit analyses became more institutionalized and widespread (Maass 1966; Marglin 1967; Musgrave 1969; Little and Mirrlees 1968, 1974; Dasgupta 1972), incorporating the framework of welfare economics, with benefits being expressed as a utility function. In the 1990s, social cost–benefit analyses increasingly included environmental factors in projects (Pearce 1998; Vanclay and Bronstein 1995; Quah and Tan 1999; Wattage *et al.* 2000; Crookes and de Wit 2002).

In 2006, the World Health Organization (WHO) formulated guidelines for conducting cost–benefit analyses of household energy and health interventions (Hutton, Rehfuess, and WHO 2006). They specify what should be counted as costs and benefits to provide a holistic idea about the gains or losses from a policy intervention, and health is an important aspect of their framework. This framework has been used by Hutton, Rehfuess, and Tediosi (2007) and Malla *et al.* (2011) to perform cost–benefit analyses at the regional and multi-country levels, respectively, by Jeuland and Pattanayak (2012) and Irfan, Cameron, and Hassan (2021) for clean cooking interventions in India and Pakistan, respectively, and by Haselip and Rivoal (2017) and Larsen, Dalaba, and Wong (2020) to analyse LPG interventions in Tanzania and three different LPG and cookstove interventions in Ghana, respectively. In all these countries, LPG interventions were found to be more beneficial compared to stove interventions, albeit under different discount rates (Malla *et al.* 2011; Isihak, Akpan, and Adeleye 2012; Rivoal and Haselip 2017; Larsen, Dalaba, and Wong 2020; Irfan, Cameron, and Hassan 2021).

2. RESEARCH GAPS

One of the primary barriers to the adoption of clean, modern energy sources—such as LPG and electricity—is the cost. Cost has typically been calculated using levelized cost-of-energy or life cycle analysis in the literature (Jain *et al.* 2015; Gould and Urpelainen 2018; Singh and Gundimeda 2014; Leach *et al.* 2021), which gives an idea about the cost-effectiveness of energy sources. However, this method does not provide an estimate of the expenditure that a household incurs. Moreover, a levelized cost-of-energy or life cycle analysis requires information on stove characteristics, including stove efficiency and lifetime, and which differ with stove types and are not relevant for this analysis. This analysis tries to emphasize the importance of current fuel prices, which constitute the variable cost for a household. These shortcomings need to be addressed. Hence, the cost to the household is calculated as a simple addition of the fixed cost and a variable cost based on current prices rather than using levelized cost.

Most of the recent literature on fuel use or the energy transition in India focuses either on the factors affecting fuel use and the transition to clean fuels in specific regions of the country, using national-level consumer or household surveys (Farsi, Filippini, and Pachauri 2007; Pandey and Chaubal 2011; Gould and Urpelainen 2018), or on the evaluation of the policies implemented by the government to facilitate such a clean energy transition (Dabadge *et al.* 2018; Harish and Smith 2019). However, there is a dearth of cost–benefit analysis studies that evaluate whether an intervention promoting LPG use is socially beneficial. Moreover, despite the tremendous progress in electricity access among rural households during 2016–2019, a cost–benefit analysis of switching to electricity as a cooking fuel has not been conducted yet for rural households in India. Since interventions are essential for rural households in a developing country such as India to make the transition to clean cooking, performing a cost–benefit analysis is relevant to determine the policy approach that will aid in the transition to clean cooking.

Many studies have shown LPG interventions to be socially beneficial in developing countries like Nigeria, Tanzania, Ghana and Pakistan (Isihak, Akpan, and Adeleye 2012; Rivoal and Haselip 2017; Larsen, Dalaba, and Wong 2020) and LPG to be comparatively more beneficial than electric cooking (Jeuland and Pattanayak 2012; Irfan, Cameron, and Hassan 2021). However, these findings are specific to the country, the intervention, and the assumptions about cost and benefit made by the authors. In the last decade, there were two cost–benefit analysis studies on clean cooking energy in India conducted by Jeuland and Pattanayak (2012) and by Patel *et al.* (2016). The frameworks used in these studies were different, with the former using the WHO framework and the latter using the analytical hierarchical process to incorporate the preferences of rural households in estimating the costs and benefits of cooking with different fuel and stove options. While Jeuland and Pattanayak (2012) focussed on improved cookstoves and their net private and net social value, Patel *et al.* (2016) assigned weights to all factors constituting a cost or benefit to the user and used the benefit–cost ratio to rank fuel alternatives. The common aspect in both these studies is that the household is the unit of analysis. However, both of these studies do not give importance to costs accruing to the government when investing in interventions to make these clean energy sources available to households.

3. OBJECTIVES

There is not only very limited literature on cost–benefit analyses of clean cooking energy interventions in India, but no recent study has examined the costs incurred by a household when switching from solid fuels to LPG or electricity for cooking. This paper aims to address these two research gaps by estimating the costs to a household when LPG or electricity is used for cooking through a cost–benefit analysis of interventions involving the universal provision of LPG or electricity for cooking in rural households. This paper has two objectives. Firstly, it tries to understand the cost to a household in switching from solid fuels to LPG or electricity for cooking and highlights the importance of supply in household cooking energy-use patterns. Secondly, this paper performs a social cost–benefit analysis using costs to the government, environmental costs, and social benefits accruing from two government interventions—the universal provision of LPG for all rural households and universal provision of electricity for cooking in all rural households.

4. COST TO A HOUSEHOLD OR PRIVATE COST

The rationale for calculating the private cost to a household in the transition to cooking with LPG or electricity is to find which energy source is financially cheaper for a rural household. The World Bank standard as per O'Sullivan and Barnes (2006) is used to calculate the amount of LPG or electricity required when they are used as exclusive cooking fuels in the household. According to the World Bank study of household energy use in developing countries, an average household of five members requires 5 GJ of cooking energy a year, with a per capita consumption of 1 GJ a year (O'Sullivan and Barnes 2006). The average household size for rural households in India in 2019–2021 was 4.5 (IIPS 2022). Using the World Bank standard for annual consumption of useful energy for cooking per capita, the household cooking energy consumption per year is 4.5 GJ and—given that the energy content in an LPG cylinder is 46 MJ per kg and the conversion efficiency is 60%—this translates to 11.5 LPG cylinders a year. Therefore, an average household of five members should have access to 12 LPG cylinders per year for a complete transition to cooking with LPG. Similarly—given that each kilowatt (kW) is equivalent to 3.6 MJ of energy and 85% of this energy is transferred to the cooking vessel—the amount of electricity required for cooking exclusively with electricity is 1,471 units a year. The assumptions for conversion efficiencies have been taken from the World Bank study (O'Sullivan and Barnes 2006) and Sweeney *et al.* (2014).

The cost to a household in the transition to LPG or electricity is the total cost borne by a household in making this transition—that is, the sum of the fixed cost and the variable cost in this transition. The costs of procuring a connection and stove for LPG use are taken as the fixed cost to switch to

LPG. This amounts to ₹4,800 for the connection, hose pipe, pressure regulator, security deposit for the cylinder, and a double burner stove (Jain *et al.* 2015). Sharma and Dash (2022) use the cost of the LPG connection and the cost of refilling cylinders as the energy dimension based on which households make decisions on cooking fuel. In contrast, an electricity connection is primarily taken for lighting. If electricity is to be used for cooking as well, the connection load must be higher, which means that the base charges will be higher. These base charges for the connection load are added to constitute the variable cost of electricity along with the tariff. The fixed cost of using electricity for cooking includes the cost of procuring an induction cooktop of 1,500 W rating and flat-bottomed utensils used specifically for induction cooking, the prices for both of which are obtained from online marketplaces such as Amazon and Flipkart. The variable cost of LPG is the price paid for the cylinder refills that a household purchases. The price of an LPG cylinder is taken as the price of one cylinder in Delhi, which was ₹744 in April 2020 (GoI 2020). The average domestic tariff rate is taken as ₹5 per unit, and the average base charge for each kW of connection load is taken as ₹50 (obtained from tariff schedules of all states for 2019–2020 from their respective electricity regulatory authorities). All costs are calculated based on 2020 prices (pre-COVID) and the domestic tariff rates for 2019–2020, expressed in rupees. Costs are calculated on an annual basis for three categories of rural households: (i) those that have only purchased the connection and stove (fixed cost) or simply made the switch to LPG or electricity, (ii) those that are using LPG or electricity in their first year (fixed cost and variable cost), and (iii) those that have already been using LPG or electricity for more than one year (variable cost). The costs to a household for both LPG and electricity are given in Table 1.

The cost incurred by a household in switching from solid fuels to LPG or electricity for cooking—the fixed cost—is almost similar for both. If a household opts for a cheaper stove and utensils for electric cooking, then electricity can be the cheaper option for the household. As the household becomes a primary user of LPG or electricity, in the first year—when both fixed and variable costs must be incurred—and subsequent years—when only variable costs must be incurred—the annual costs the household has to bear will be lower in the case of electricity. These results are similar to those of the findings of Hakam *et al.* (2022) and Anggono *et al.* (2022) in Indonesia, who have found that the energy costs of using electricity for cooking (including both fixed costs and variable costs) will be lower than the cost of cooking with LPG. The question, therefore, is why has there been a greater increase in switching to LPG compared to electric cooking among rural households?

Table 1: Annual Cost to the Household When Cooking with LPG and Electricity (2020, ₹)

Cost to the Household	LPG	Electricity
Fixed cost in switching (connection + stove)	4,800 (connection + stove)	2,000 to 3,000 (stove) + 1,500 to 2,000 (utensils) = 3,500 to 5,000*
Cost to household in the first year of switching	Fixed cost + variable cost on refills = [4,800 + (12 × 744)]	Fixed cost + variable cost on units consumed (including monthly base charges) = [5,000 + (50 × 12) + (5 × 1,471)]
	13,734	11,455 to 12,955
Cost to the household in subsequent years of using the fuel	Variable cost on refills = (12 × 744)	= [(50 × 12) + (5 × 1,471)]
	8,934	7,955

*__Note__: The fixed cost of electricity does not include connection charges, as the electricity connection is taken as part of lighting energy expenses in the household.
Source: Jain *et al.* (2015); GOI (2020a), tariff schedules of state electricity regulatory authority for all states (Jain 2022).

There are two possible answers to this. First, electricity supply is not adequate or reliable in rural areas. Second, there have been no government interventions to promote electric cooking in the country. Although almost 100% of rural households have access to an electricity connection, they have a basic connection load of 0.5 kW, which is inadequate to operate an induction cooktop, and the supply is uncertain because of frequent power failures and blackouts (Jain *et al.* 2015; Banerjee *et al.* 2016). Moreover, in the last decade, clean cooking has been synonymous with access to LPG, as it is a clean and convenient fuel option that most households are already familiar with. Electricity is a popular lighting energy alternative to kerosene lamps, and access to the basis 30–50 units of electricity have been a result of rural electrification schemes (Jain et al. 2015). The need for government intervention arises because modern energy sources require a strong supply and distribution infrastructure as well as financial incentives for greater adoption since they are expensive. Banerjee *et al.* (2016) report that when rural households in Himachal Pradesh were given subsidized induction cooktops, it replaced the secondary fuel in a majority of households; traditional biomass was replaced by LPG for primary use. This was also observed in Cameroon where the availability of and familiarity with LPG for cooking deterred the use of electric cooking, which was seen as a secondary option (Rubenstein *et al.* 2022). Gould *et al.* (2020) have found that in

Ecuador, where simultaneous subsidy programmes for the adoption of LPG and induction stoves are operational, more rural households adopt LPG than electric cooking. Hence, in a country where LPG is popular as a clean cooking fuel and there are efforts to scale up its adoption, electricity needs aggressive policy support and a stable and dependable distribution network to compete with LPG. Nonetheless, despite the cost advantages of electric cooking at the household level, the question remains as to whether the universal provision of electricity as a cooking fuel for all rural households is socially beneficial or not.

5. SOCIAL COST–BENEFIT ANALYSIS

Social cost–benefit analysis is a method of evaluating policy interventions through comparisons of the costs and benefits accruing from these interventions. Here, this analysis has been conducted using the WHO framework to understand what can count as costs and benefits and how the benefit–cost ratio and net present value (NPV) should be calculated for both interventions—namely, the universal provision of LPG to all rural households and the universal provision of electricity for cooking to all rural households. The time for the interventions has been taken as 10 years (up to 2030). A social discount rate of 3% has been used.

6. COSTS OF THE INTERVENTIONS

6.1. Cost to the Government

The cost to the government includes the cost that the government must bear to provide LPG or electricity universally to all rural households. For universal provision of LPG, 60% of the rural households that do not use LPG as a primary cooking fuel are to be provided with an LPG connection or gas stove, and the other 40% are to be given 12 LPG cylinders a year. In the scenario of universal provision, it is assumed that the government bears the entire cost of importing and subsidizing LPG at the rate at which the subsidy was given in 2019–2020 to PM Ujjwala beneficiaries, that is, 30% of the market price (GOI 2020). Hence, the cost to the government in the LPG intervention is the sum of the cost of importing 60% of the LPG and subsidizing LPG for 60% of rural households that still depend on solid fuels as the primary source of energy for cooking.

The cost to the government for the universal provision of electricity as a cooking fuel to all rural households is the sum of the cost of providing induction cooktops to all rural households, the cost of extending the load to 2 kW for supporting the operation of induction cooktops, and the cost of supplying electricity (base charges in terms of load and tariff for the units consumed) to all rural households. Since less than 2% of rural households use electricity as cooking fuel, the assumption here is that none of the rural households possess an induction cooktop or utensils. Consequently, the fixed cost of providing the stove and utensils for all rural households—along with the cost of supplying electricity (variable cost)—has to be borne by the government in the scenario of universal provision.

6.2. Environmental Costs

The environmental costs of LPG are not very significant because it is a by-product of the process of crude oil refining. However, if the environmental impact of LPG has to be extrapolated from the environmental impact of crude oil refining, then a proportion of the carbon intensity of crude oil production can be attributed to LPG production. According to Jing *et al.* (2020), India's oil refining carbon intensity is 50.4 kg CO_2 equivalent per barrel, but the proportion of LPG production was just 5% of the total crude oil production in 2019–2020. Using that threshold, the carbon and greenhouse gas emissions from LPG production are calculated to be 21,773.5 tonnes of CO_2. Due to the lack of social cost measures for greenhouse gases other than carbon-based gases, the estimate of the social cost of carbon given by Ricke *et al.* (2018) is used to arrive at a monetary value of the cost of carbon arising from the increased production of LPG to support universal rural provision.

In the case of electricity, about 70% of the electricity generated in the country is from coal-based power plants, which emit CO_2 and other greenhouse gases during production. There is no universally accepted method of calculating the environmental impact of these emissions. Nonetheless, a study by Mittal, Sharma, and Singh (2012), which estimates the greenhouse gas and particulate matter emissions from coal-based power plants, concludes that for every kW of power generated, there is an emission of 0.8 to 1 kg of CO_2. Therefore, the environmental costs of the CO_2 emissions from coal-based electricity generation for the universal provision scenario are calculated using the 1 kg CO_2/kW threshold.

7. BENEFITS OF THE INTERVENTION

According to the WHO guidelines for cost–benefit analyses of energy interventions, the impacts of the interventions essentially include health benefits, time savings, productivity gains, fuel savings, and local and global environmental benefits. The transition to both LPG and electricity is assumed to happen from solid fuels, which have a detrimental impact on health; lead to time loss because fuel collection and cooking are time-intensive; cause a loss in output, and harm the environment in the form of carbon emissions and deforestation. Hence, in a way, the benefits of switching to LPG or electricity also include the averted costs of using solid fuels. As a result, these benefits are assumed to be the same for both LPG and electricity. Any qualitative differences (status, convenience, familiarity, etc.) for either fuel LPG or electricity, which could contribute to specific benefits from either, have not been acknowledged as a significant part of the economic or social benefits.

7.1. Health Benefits

To evaluate the health benefits, two metrics are considered: DALYs and deaths averted due to a reduction in indoor air pollution. DALYs and deaths due to household air pollution in 2019 in India were 21 million and 0.61 million, respectively (Pandey *et al.* 2020). For this analysis, we assume the cost of averted DALYs for every rural household switching to LPG to be one-third of the gross domestic product (GDP) per capita, based on Woods *et al.* (2012) and Ochalek, Lomas, and Claxton (2018), and the cost of averted death to be equal to the GDP per capita. This paper focuses on rural households, but rural GDP estimates are not available from official data sources, which is why GDP per capita[1] for India has been used. However, we assume that 90% of these DALYs and deaths from household air pollution are in rural households, as only 10% of urban households were using solid fuels as the primary energy for cooking in 2019–2021 according to NFHS-5 (IIPS 2022).

7.2. Averted Healthcare Expenditure

The average expenditure per rural person for non-hospitalized treatment of the diseases caused by indoor air pollution for 15 days is ₹649. This implies that the monthly expenditure on non-hospitalized treatment for a rural person will come to ₹1,300. Therefore, the annual averted health care expenditure or annual health care savings due to a transition to clean cooking fuels will be ₹15,600 per person. For this analysis, we assume that there is one person in each rural household using solid fuels as the primary cooking fuel, who has to bear this expenditure in a year. However, to arrive at a more realistic estimation of the averted healthcare expenditure, we have assumed treatment-seeking behaviour to be prevalent only among 50% of rural households using solid fuels.

7.3. Output Loss Averted

[1] Linear forecast values for GDP per capita have been used since health benefits are assumed to accrue at the end of the intervention period.

The productivity gains have been calculated by Hutton, Rehfuess, and Tediosi (2007) using the human capital approach, wherein the number of days of illness averted is multiplied by the average gross national income per capita of that region. Isihak, Akpan, and Adeleye (2012) follow a similar approach. This paper uses a slightly different approach by considering the loss in output averted rather than productivity gain from not missing work. According to the *Lancet* study on the *Global Burden of Diseases 2019* (Pandey *et al.* 2020), the economic loss due to output lost from premature deaths and morbidity attributable to household air pollution as a percentage of GDP in India was 0.49% in 2019. A major part of these premature deaths and morbidity were in the rural sector, as they have a higher number of solid fuel users. We have assumed that 90% of this economic loss will be averted if rural households switch to using clean cooking fuels.

7.4. Time Savings

Time savings are an essential benefit accruing from the use of clean cooking fuels, because with LPG and electricity, no time is lost in fuel collection and a significant amount of time is saved while cooking because of the higher efficiency of LPG and electric stoves. The *Time Use Survey 2019* conducted by the NSS finds that in India, the time saved in the collection of fuel is 74 minutes (GOI 2020b). Since it is women who are generally involved in fuel collection and cooking, we have considered the daily wage for a rural woman involved in agricultural activities such as sowing, transplanting, weeding, or harvesting, which was ₹265 in 2019. We assume that 50% of the time saved is used for income generation, similar to Larsen, Dalaba, and Wong (2020).

7.5. Fuel Savings

Fuel savings are assumed to be negligible in this analysis, because the alternatives to clean, modern energy sources like LPG and electricity in rural India are firewood, dung, crop waste, grass, charcoal, and so on—all of which are available free of cost or are extremely cheap compared to LPG or electricity. As a result, the transition to LPG or electricity is from a solid fuel that does not have a market price, so the fuel savings are assumed to be zero.

7.6. Environmental Benefits

Environmental benefits have been a part of cost–benefit analyses of energy interventions in studies by Hutton, Rehfuess, and WHO (2006), Jeuland and Pattanayak (2012), and Isihak, Akpan, and Adeleye (2012). However, each of these studies uses a different method to evaluate the value of deforestation or the cost of carbon and greenhouse gas emissions that may result from solid fuel use. The environmental effects of switching to LPG or electricity from firewood include averted deforestation and lower carbon emissions since firewood is the most commonly used solid fuel for cooking in rural households. For this analysis, the environmental effect of averting deforestation is used as the measure of environmental benefits. The economic value of forests is taken from the report on the revision of rates of the NPV applicable for different classes/categories of forests (CAG 2014). Specifically, the maximum total economic value of forests—after adjusting for double counting—and the amount of averted deforestation is obtained from the World LPG Association report on substituting LPG for wood, where the averted deforestation from a household switching to LPG has been calculated (WLPGA 2018). Since substituting wood with electric cooking will also bring down deforestation by the same amount as a transition to LPG will, we assume that the averted deforestation for both fuels is the same.

8. SOCIAL RATE OF DISCOUNT

In the cost–benefit analysis, future benefits and costs are discounted relative to present benefits and costs to obtain their present values. The need to discount arises because there is an opportunity cost to the resources used—they could earn a positive return elsewhere and most people prefer to consume in the present rather than the future. The social discount rate is one of the most important inputs in cost–benefit analyses due to its major influence on present-value calculations, thereby playing an influential role in determining whether a project passes or fails a cost–benefit test. Typically, a social discount rate between 3% and 6% is used for calculating the present values of costs and benefits for clean cooking interventions (Hutton, Rehfuess, and Tediosi 2007; Jeuland and Pattanayak 2012). This paper uses a discount rate of 3% to find the benefit–cost ratio and NPV of both interventions.

The present value of social benefits and social costs have been calculated to arrive at the benefit–cost ratio and the NPV of the interventions based on the formulae given in Box 1. Costs and benefits are expressed in crores of rupees, and the prices and tariffs for the year 2021 (post-COVID) have been used to calculate the variable costs. Hence, the first year of intervention is assumed to be 2021, and the forecasted period of nine years ends in 2030. There may be a possible effect of the COVID-19 pandemic and economic lockdown on prices, tariffs, and even energy-use patterns. Nonetheless, rather than making assumptions, this paper performs an uncertainty analysis to determine how the benefit–cost ratio and the NPV might change with changes in the values of the variables used in the calculation.

Box 1: Formulae for Calculating Social Cost, Social Benefit, Benefit–Cost Ratio, and Net Present Value

Social cost (SC) = Cost to the government (fixed cost + variable cost) + environmental costs (if any) Social benefits (SB) = Health-related income effects + averted healthcare expenditure + output loss averted + time savings + fuel savings + environmental effects
Benefit–Cost ratio (BCR) = Present value of total social benefits (PV_{TSB})/present value of total costs (PV_{TC}) BCR = $\{TSB/(1 + r)^n\}/\{TC/(1 + r)^n\}$, where *r* denotes the social discount rate and *n* denotes the number of years for the intervention Net present value (NPV) of intervention = Present value of total social benefits – present value of total social costs NPV = $TSB/(1 + r)^n – TSC/(1 + r)^n$, where *r* denotes the social discount rate and *n* denotes the number of years for the intervention

Source: Hutton, Rehfuess, and WHO (2006).

9. FINDINGS

Table 2: Social Cost for LPG and Electricity Interventions by 2030 (₹)

Social Cost	LPG	Electricity
Cost to the government	Cost of importing and subsidizing LPG for all rural households	Cost of induction cooktop and load extension to all rural households + cost of supplying additional electricity
	= 166,212 crore	= 98,410.5 crore
Environmental costs	Part of the carbon emissions from crude oil drilling and refining	Cost of carbon emissions from coal-based power plants
	= 14,044 crore	= 114,500 crore
Total social cost	Cost to the government + environmental costs	Cost to the government + environmental costs
	= 180,256 crore	= 212,910.5 crore

Note: The total number of rural households is 17.24 crore and 60% still use solid fuels.

Source: Calculated by the author from Table 1 and based on assumptions made by the author.

9.1. Social Costs

The cost to the government and environmental costs together make up the total social costs of both these interventions. Table 2 shows that the cost to the government is lower for the universal provision of electricity for rural households for cooking, owing to the high price of LPG cylinder refills, which leads to increased recurrent costs. However, the difference is not significant. Environmental costs measured using carbon emissions and the social cost of carbon are eight times higher for electricity. This is because 70% of the electricity generated in the country is from coal, and according to the United States Environmental Protection Agency (EPA), coal has the highest carbon intensity and produces the most emissions from combustion compared to other fossil fuels such as natural gas, petroleum, or even LPG (EPA 2023). Hence, the environmental costs of the universal provision of electricity for cooking in rural households are higher. As a result, the social costs of the universal provision of LPG for rural households are significantly lower than the corresponding costs for the universal provision of electricity.

9.2. Social Benefits

Although the health benefits are qualitative, the cost of averted DALYs and the cost of averted deaths have been used as estimates of the health effects of the interventions, as in Malla *et al.* (2011) and Larsen, Dalaba, and Wong (2020). This study uses a threshold of one-third of the GDP per capita as the cost of averted DALYs, which is much lower than the threshold used in in Ghana in Larsen, Dalaba, and Wong (2020), which is 1.3 to 1.6 times the GDP per capita for LPG interventions, as well as the threshold given by the WHO, which uses one to three times the GDP per capita (WHO CMH and WHO 2001) (see Table 3 below).

Hutton, Rehfuess, and Tediosi (2007), Isihak, Akpan, and Adeleye (2012), and Irfan, Cameron, and Hassan (2021) include reduced health expenditure as a part of the social benefits obtained from the transition to cleaner cooking fuels. This study also estimates healthcare expenditure averted using the amount spent on treatment and assuming the proportion of rural households seeking treatment. Treatment-seeking behaviour has not been addressed in other studies, but it is important in this calculation, as the focus here is on rural households, whose members generally avoid seeking treatment for most diseases unless it is economically viable. However, despite these conservative assumptions, the averted healthcare expenditure is the largest part of the total social benefits at ₹80,683 crore.

Upon switching to clean cooking fuels, time is saved in cooking as well as fuel collection—a crucial aspect of their benefits. Hutton, Rehfuess, and Tediosi (2007), Malla *et al.* (2011), Jeuland and Pattanayak (2012), Isihak, Akpan, and Adeleye (2012), Larsen, Dalaba, and Wong (2020), and Irfan, Cameron, and Hassan (2021) all include time savings in their analyses by either using wage rates or gross national income per capita to express it in monetary terms. This paper uses rural wages of women involved in agricultural occupations to take into account the gender bias involved in cooking and the collection of fuel. Other than that, the proportion of time saved that is used for income generation is higher than that assumed by García-Frapolli *et al.* (2010) for rural Mexican households—where 25% of the time saved was used for income generation—and the same as that used in Larsen, Dalaba, and Wong (2020) for households in Ghana—50% of saved time is used for income generation—as one of the interventions studied here is the universal provision of LPG, along the same lines as the LPG intervention in Ghana. With these assumptions, time savings are the second-largest part of the total social benefits at ₹76,752.5 crore (see Table 3 below).

Table 3: Benefits of LPG and Electricity Interventions by 2030 (₹)

Benefit	**LPG and Electricity**
Health-related income effects (DALYs and deaths averted in terms of GDP per capita)	90% of [0.33 × GDP per capita × DALYs averted + GDP per capita × deaths averted] 0.9 × [0.33 × 142,603 × 2.1 + 142,603 × 0.06] = 96,642 crore
Averted healthcare expenditure	50% of the rural households not using LPG or electricity × average per capita treatment expenditure 0.5 × (0.6 × 17.24) × 15,600 crore = 80,683 crore
Output loss averted (gains in productivity)	90% of output loss (economic loss percentage × GDP) 0.9 × 0.0049 × 13,558,473 crore = 59,793 crore
Time savings (in terms of rural wages for women in agriculture)	Wages saved per rural woman per year × percentage of rural women making the transition 7,420 × (0.6 × 17.24) = 76,752.5 crore
Environmental effects (averted deforestation)	1,724,000 hectares (total deforestation averted by all rural households) × 2.4 lakh per hectare/year (economic value of forest) = 41,376 crore
Total social benefits of LPG and electricity	355,246.5 crore

Note: The total number of rural households is 17.24 crore and 60% still use solid fuels.

Source*:* GOI (2023), Pandey *et al* (2021), WRRI (2019), GOI (2020b), WLPGA (2018), CAG (2014)

9.3. Benefit–Cost Ratios and Net Present Values

The benefit–cost ratios for both interventions show that the universal provision of LPG has a benefit–cost ratio greater than the universal provision of electricity, although both interventions have greater social benefits compared to social costs (see Table 4 below). Due to the significant environmental costs of providing electricity, 70% of which is coal-based, the NPV is smaller for the electricity intervention compared to the LPG intervention. The NPV of the LPG intervention is significantly higher, indicating that it is more socially beneficial for the government to invest in the universal provision of LPG for rural households in India. In studies by Rivoal and Haselip (2017), Larsen, Dalaba, and Wong (2020), and Irfan, Cameron, and Hassan (2021), involving Tanzania, Ghana, and Pakistan, respectively, the benefit–cost ratio for LPG interventions, especially in the form of universal provision of LPG, was greater than one. However, Irfan, Cameron, and Hassan (2021) find that universal access to electricity for cooking in Pakistani households also has a benefit–cost ratio greater than one, although it is less than that for LPG, similar to the results in India.

Table 4: Summary of Results of Cost–Benefit Analysis of LPG and Electricity Interventions in 2030 (₹)

	Universal Provision of LPG	**Universal Provision of Electricity**
Present value (social benefit)	272,267	272,267
Present value (social cost)	138,151	163,178
Benefit–cost ratio	1.97	1.67
Net present value	134,116	109,089

Source: Calculated by the author based on the formulae given in Box 1.

As a part of the uncertainty analysis, this analysis considers two simultaneous changes in the cost to the government for LPG interventions due to an increase in cylinder prices and a decrease in the environmental costs of electric cooking resulting from an increase in the proportion of electricity generated from renewable resources. If there is a 10% increase in the cost to the government for LPG interventions and a 10% reduction in the environmental costs of electricity interventions, the total social cost of LPG interventions will be ₹196,877.2 crore and the total social cost of electricity interventions will be ₹201,460.5 crore. Table 5 shows the benefit–cost ratios and NPVs in this case.

Table 5: Summary of Results of Cost–Benefit Analysis at Higher Prices of LPG and Lower Environmental Costs of Electricity, 2019–2020 (₹)

	Universal Provision of LPG	**Universal Provision of Electricity**
Present value (social benefit)	272,267	272,267
Present value (social cost)	150,890	154,403
Benefit–cost ratio	1.8	1.76
Net present value	121,377	117,864

Source*:* Calculated by the author based on the formulae given in Box 1.

Reductions in the environmental costs of the electricity intervention increase the benefit–cost ratio of the universal provision of electricity to 1.76, also increasing the NPV significantly. Although the NPV of the universal provision of electricity is still lower than that of the universal provision of LPG, both interventions are socially beneficial with benefit–cost ratios greater than one and very little difference between the respective benefit–cost ratios. The 10% hike in cost to the government decreases the benefit–cost ratio for the universal provision of LPG by 9%, whereas the decrease in environmental costs by 10% increases the benefit–cost ratio for the universal provision of electricity by 5.4%. This implies that if the cost of importing and subsidizing LPG keeps increasing, the benefit–cost ratio for LPG interventions will fall more rapidly compared with the rise in the benefit–cost ratio of electricity interventions if the environmental costs of electricity keep decreasing by the same magnitude.

The cost of importing LPG is dependent on the import parity price of LPG, which is determined by the world LPG price and the exchange rate between the Indian rupee and the US dollar. The rest of the charges added to the import price of LPG to obtain the final retail price are determined by the government. In the last decade (from 2010–2011 to 2019–2020), the average price of an LPG cylinder has increased by 84%, and it shows an increasing trend (MoPNG 2019–2020). As a result, there is a possibility that the costs to the government for providing LPG will increase over the next decade and bring down both the benefit–cost ratio as well as the NPV of LPG interventions. In the case of electricity, from 2010 to 2018, generation from coal, oil, and natural gas has decreased from 80% of the total to 76%, and generation from renewable sources has increased from 16% to 21% of the total. Given the declining trend in fossil fuel–based power generation, including coal-based power, and the increasing trend in renewable energy–based electricity, there is a possibility that the environmental costs of universal provision of electricity for cooking will fall in the future. This can increase the benefit–cost ratio of interventions in which electricity is supplied to all rural households for cooking. Therefore, from the perspective of the government, the challenge is to decide whether to provide LPG or electricity as a cooking fuel to rural households.

However, given current trends, the more important question is whether an increase in rural demand for LPG or electricity can be supported at all. From 2009–2010 to 2019–2020, there has been a 72% increase in the total electricity generated. If all rural households consume 1,471 kWh in a year for cooking with electricity exclusively, the total electricity required is 253,600 GWh, which is 18.25% of the total electricity generated in 2019–2020. Therefore, the rural electricity generation required to support electric cooking in all rural households is a small part of the projected increase in electricity generation over the next decade. The bigger challenge, however, is the cost of increasing the installed capacity and strengthening the distribution and transmission network to make the availability of electricity adequate and reliable enough to be used as a source of cooking energy.

On the other hand, the challenge for LPG is not only increased demand pressure due to the increase in rural consumption of LPG but also the growing proportion of imports in the LPG available. The domestic consumption of LPG has increased more than 100% between 2010–2011 and 2019–2020. However, an increase in rural consumption will imply an additional requirement of 29,377 TMT of LPG, which will be 89.5% of the total domestic LPG consumption in 2030 (based on a time-based linear forecast). In 2019–2020, about 58% of the total available LPG in the country was being imported. If about 60% of the rural LPG consumption is met through imports, then imports for rural LPG consumption alone will constitute 50% of the total imports in 2030, and the value of the imports at the current import price of ₹33 per kg of LPG will be 69% of the total LPG import bill in 2030 (based on time-based linear forecasts). Hence, as the demand for LPG rises in rural households, there will be higher imports of LPG and, thus, a higher import bill. This can be pushed onto consumers by increasing the price of LPG since it is the government that decides the price of LPG cylinders.

10. CONCLUSION AND POLICY IMPLICATIONS

This paper tries to determine whether cooking with electricity or LPG alone can be a beneficial alternative to traditional fuels for rural households, both at the household and social levels. With the limited data available, and by using the framework for calculating the costs and benefits of energy interventions given by the WHO (Hutton, Rehfuess, and WHO 2006), this paper establishes that, for a household, the transition from traditional fuels to electricity may be more cost-effective compared to a transition to LPG, but it is more socially beneficial for the government to invest in universal provision of LPG compared to electricity. The universal provision of electricity for cooking for all rural households has a benefit–cost ratio greater than one and a significant NPV when the proportion of renewable energy in electricity generation increases and the environmental costs of electricity generation decrease.

At the household level, the cost of switching to electric cooking from solid fuels is lower than the cost of switching to LPG, and this is supported by Jain *et al.* (2015), where a multidimensional approach is used to find that LPG is the second-most expensive fuel option for households in energy-poor states in India. However, the number of households switching to electricity is extremely low, which is somewhat counter-intuitive to the economic rationale that a consumer maximizes utility by purchasing the commodity that is available at the lowest price. One reason for this is that although electricity is cheaper than LPG, the supply is erratic and inadequate, especially in rural areas. Banerjee *et al.* (2016) find that rural households use electricity as a secondary fuel, even in states where tariffs are low and induction cooktops are provided at subsidized rates. The high price of LPG cylinders plays a major role in the economics of the rural household, which is why even with LPG interventions such as PM Ujjwala, the rate of refills and the sustained use of LPG is low among beneficiaries (Kar and Zerrifi 2018; Kumar *et al.* 2019; Gill-Wiehl *et al.* 2021). In contrast, even though electricity is comparatively cheaper, rural households cannot ensure fuel security. As a result, the adoption of electricity as a cooking fuel is extremely low. Moreover, the overall cost of electricity may be lower than that of LPG, but the purchase of an induction cooktop and specific utensils for electric cooking poses an initial cost barrier for poor rural households, especially when LPG connections are provided for free or at subsidized rates. From the perspective of the government, it is socially beneficial to provide LPG to rural households rather than electricity, given India's high dependence on coal-based power generation. This justifies the policies and programmes in the last few years that have tried to increase LPG penetration and adoption rates.

Although the benefit–cost ratio of an LPG intervention for the universal provision of LPG for all rural households is greater than one, an increase in LPG cylinder prices leads to a fall in this ratio. Even in other developing countries such as Ghana, Tanzania, and Pakistan, it was found that LPG interventions have more social benefits than social costs (Larsen, Dalaba, and Wong 2020; Rivoal and Haselip 2017; Irfan, Cameron, and Hassan 2021). However, universal provision of electricity may provide almost the same amount of social benefits as social costs incurred owing to the intervention, any decrease in the environmental costs of the universal provision of electricity for cooking would cause the benefit–cost ratio to increase above one, making the electricity intervention socially beneficial. Therefore, the trade-off is between increasing dependence on LPG imports and a reduction in the environmental costs of electricity. The environmental costs of electricity are primarily due to 70% of the electricity being generated from coal, which has the highest carbon emissions among fossil fuels. If the proportion of coal-based electricity reduces and renewable power–based electricity increases, the environmental costs will come down, making universal electricity provision socially beneficial.

There are three major limitations to this paper. There is no discussion on income and, therefore, it is not possible to determine the cost of LPG or electricity (as a cooking fuel) as a percentage of the income of rural households. Income is an important factor when it comes to cooking fuel use patterns, and any analysis of cooking fuel use is incomplete without a discussion on income. Various studies study the effect of income on the transition to clean cooking fuels (Viswanathan and Kumar 2005; Farsi, Filippini, and Pachauri 2007; Cheng and Urpelainen 2010; Lewis and Pattanayak 2012; Jain *et al.* 2015; Sharma and Dash 2022), and they find that income has a positive and significant effect on the use of LPG and electricity. The second limitation of this paper is not incorporating state-wise differences. The price of LPG, the domestic tariff rates, and rural household incomes differ in every state. An agricultural household in Punjab earns much more than an agricultural household in Jharkhand, and even the price of LPG and tariffs in these two states are different. As a result, the cost of cooking with LPG and electricity will be different in these two states, and electricity may no longer be the cheaper alternative, as is the case of Karnataka, Maharashtra, and Rajasthan, where LPG prices are the lowest but domestic tariff rates are very high. Lastly, this paper does not include the effect of COVID-19. The prices and tariffs, along with the energy-use patterns, may be different with the pandemic and economic lockdown and, hence, the cost to the household, cost to the government, and the energy-use patterns of rural households for the period between 2020 and 2022 may have been completely different from that for other periods.

The transition to cooking with LPG or electricity in rural households is necessary to reap the social benefits in terms of better health, higher productivity, time savings, and environmental benefits. However, the critical issue is whether to continue promoting LPG alone and investing in the greater provision of LPG as a clean cooking fuel in rural households, as was done with PM Ujjwala and PM Garib Kalyan Yojana during COVID-19. An increase in the price of LPG will reduce the net social benefits of an LPG intervention. Hence, the question is: At which threshold level of import and price of LPG does universal provision of LPG cease to be socially beneficial? Electricity is completely produced domestically. Between 2015 and 2020, the investment in renewable energy for power generation and its share in electricity generation has increased. There is already potential for the environmental costs of electricity to reduce in the next few years—even a 30% decline in this cost can make universal provision of electricity for cooking socially beneficial. Electricity is a clean energy alternative that must be considered for rural households, especially because the first step of access to an electricity connection has already been achieved. Increasing investment in renewable energy would make electricity cleaner and the supply more reliable. There are also opportunities for exploring off-grid options for rural households located in remote areas.

Ethics Statement: I hereby confirm that this study complies with requirements of ethical approvals from the institutional ethics committee for the conduct of this research.

Data Availability statement: The data used to support this research is available in a repository and the hyperlinks and persistent identifiers (e.g. DOI or accession number) are stated in the paper.

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