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Modelling Household Energy Access in India

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Abstract

Improving access to affordable modern energy is deemed to be a critical factor in improving living standards in the developing world. Particularly rural households in India are relying mostly on traditional biomass to satisfy their basic energy needs with adverse effects on human health through indoor air pollution, but also on land degradation and labor productivity. This study presents a new generic modeling approach with the aim to explore response strategies for energy poverty eradication for India. The modeling approach explores characteristics of fuel consumption of the poorest through explicit representation of the main determinants of urban and rural energy fuel choice, including the effect of income distributions and capital scarcity on energy use as well as traditionally more intangible factors such as "inconvenience costs" or private discount rates. The methodology is applied to explore how different policy mechanisms such as fuel subsidies and microfinancing can enhance the diffusion of clean and affordable energy in India. This draft summarizes preliminary initial results focusing on the attainable transition to clean and modern fuels. As a next step, a sensitivity analysis for the main uncertain parameters and an assessment of the number of households and their exposure is planned. Implications for life-expectancy will be assessed through collaboration with APD.

Acknowledgments

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Modelling Household Energy Access in India

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1 Introduction

Providing clean and affordable energy reliably for the poor households in developing countries has been seen as an important prerequisite in the fight against poverty. For example the Millennium Development Goals aspire to reduce e.g. hunger and lack of infrastructure and shelter and promote education, health and environmental sustainability, all of which require improved energy supply as noted by Modi et al. (2005). Even though households often might have access to the traditional forms of energy - firewood, charcoal and agricultural residues - these fuels carry adverse effects such as exposure to respirable particulate matter. Gathering firewood also results with deforestation and environmental degradation, and e.g. IEA (2002) illustrated this with a aerial photographs from Africa. Gathering and using traditional fuels also consumes more time, thus reducing the prospects for more productive work.

The household energy consumption can be divided into thermal (cooking, water heating and also space heating to some extent), lighting and the use of electric appliances. While improving lighting can be seen as beneficial for education and the productivity of cottage industries, the health and environmental concerns are associated with traditional fuels in thermal energy consumption.

A large concentration of people without access to modern forms of energy can be found in India. Improving the access to modern energy has been on the agenda of the government of India for long. Electrification has especially received much attention and a summary of past electrification measures is presented in Bhattacharyya (2006). The targets of past electrification policies have been however slightly misaligned, and as a result 87% of villages are said to be electrified whereas 43% of the population is estimated by IEA (2002) to be actually connected. Although a recent change in the definition of village electrification and the aim for household electrification by 2012 are likely to improve the situation in electricity access, the objectives are not likely to address the issue on cooking fuels.

Some modelling studies have been made to analyze the issue of energy access, often focusing however on the supply side costs and not considering the heterogeneity of consumers. In practice however some consumers e.g. can find it hard to pay their electricity bills even though their livelihoods had been electrified. Thus improving the supply side does not suffice to improve the situation, but we must also understand the determinants of fuel choice of the households in more detail. This study intends to establish a framework for modelling the energy access on the demand side, taking into account differing

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economic conditions of different consumer groups. We consider five determinants for fuel choice and present a linear programming model of Indian household energy demand. As an application of the model we assess the effect of fuel subsidies and improved financing opportunities for the appliance investment costs on the adoption of modern cooking fuels.

1.1 Recent modelling efforts

Some attempts have been made to model energy access in depth with analytical models. An application of the TIMES modelling framework to a village in South Africa by Howells et al. (2005) explored the electrification of the village in five scenarios with two incorporating externalities from indoor air pollution and CO_2 emissions. The findings of the study indicated the reluctance to shift from inexpensive traditional biomass in cooking, even if electricity were available, and fuel switching appears to be reasonable only if the externalities are included in the costs. Grid electricity was found to be more cost-effective for lighting and appliances than other approaches.

Two studies from Kanagawa and Nakata assess the reduction of particulate matter exposure for rural women through introducing an opportunity costs for firewood gathering in an energy-economic model in Kanagawa & Nakata (2007), and the statistical dependence of literacy rate on household electrification with a scenario on village electrification in Kanagawa & Nakata (2008). Their analysis on cooking fuels showed that the level of opportunity cost for firewood that might be attributed for the rural rich would result with a complete switch from firewood to LPG by 2012, but for the rural poor no such switching would take place. Even though the paper on literacy and electrification portrays the positive social impacts from electrification, the study might be criticised for overly straightforward conclusions from statistical dependencies and a relatively simplified modelling approach for electricity access. While the scenario exhibits a fairly rapid adoption of electrical lighting based on high life-time cost of kerosene lighting, the authors note that in reality the higher initial investment costs prohibit the adoption of electrical lighting. Even though the same is argued in this study, it is good to note that Kanagawa and Nakata include only the investment costs of the light bulb and socket as investments costs - which are clearly very low - and not house wiring - which is truly prohibitively expensive for some households as noted e.g. in IEA (2002).

A less well-grounded approach is used in Reddy (2003), where a ten year scenario is drawn by extrapolating the shares of different fuels from statistics. A comparison of annualized costs for different residential energy technologies points that cooking with firewood and compact fluorescent lighting are the most economical options. The author however points out qualitatively a few important points on technology adoption of households, namely that the fuel choice is dependent on disposable income and consumers prefer to have low up-front costs than low running costs, which can be interpreted as high discount rates. Therefore even socially profitable measures for improving energy efficiency are often not carried out.

As a conclusion, all the modelling studies indicate that electricity is the most cost-effective for lighting and traditional biomass for cooking. However this does not correspond fully with reality as a variety of fuels is used for lighting and the majority of rural population in India relies on kerosene lighting. A characteristic feature in all studies mentioned above is that households with different economic conditions are treated the same, and often so called social planner's 5% discount rate is used. Clearly this is an oversimplification that usually exaggerates investments to efficient modern appliances and therefore also exposes to making wrong conclusions based on the model runs. Therefore in order to get better correspondence with models and reality and get more reliable results with

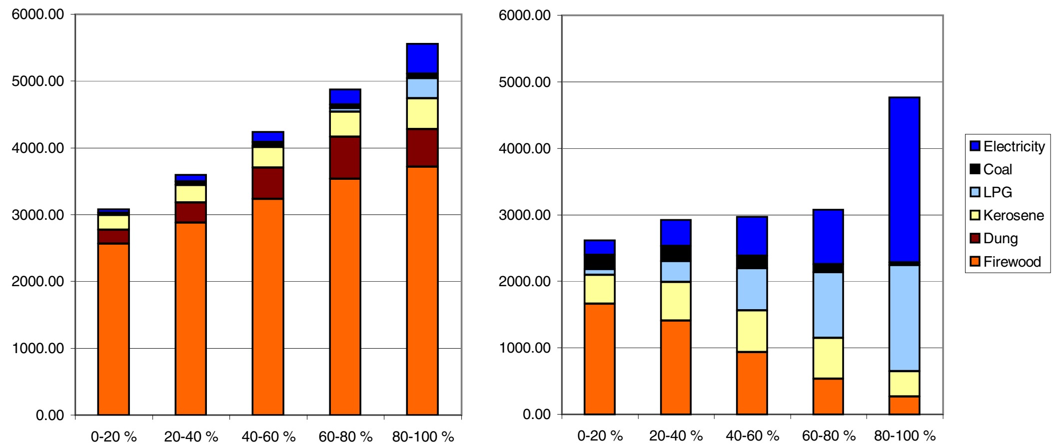

Figure 1: Household final energy consumption [MJ/cap/a] in rural (left) and urban (right) populations based on their expenditure levels, here divided to expenditure quintiles.

regard to possible demand side responses to different policy actions, we need to analyze the factors affecting household energy choices in more detail.

2 Household energy consumption in India

This study is largely based on a consumer expenditure survey, carried out by National Sample Survey Organisation (NSSO) of India between 1999 and 2000. In the survey the respondents were asked to state, among others, their energy consumption for different energy forms in energy and expenditure terms in the past 30 days. The energy consumption data has been analyzed extensively, and a more in-depth analysis can be found e.g. in Bhattacharyya (2006) and Gangopadhyay et al. (2005). The survey data was also used to estimate the own-price and cross-price elasticities of different energy forms by Gundimeda & Khlin (2008).

When the final energy consumption patterns are divided by household expenditure and urban/rural environments as presented in Figure 1, we can see that the energy consumption patterns of these different consumer groups are very distinct. Rural population relies largely on traditional fuels, and even though electricity, kerosene and LPG consumption increases with rising expenditure levels, traditional fuels dominate the fuel mix even after accounting for their lower efficiency. On the other hand in urban areas the switch from traditional to modern fuels is more genuine as the absolute amount of traditional energy is decreasing with rising expenditure. Of the total energy consumption traditional fuels, kerosene and LPG are used for cooking, water heating and heating; kerosene and electricity for lighting; and the rest of the electricity for numerous electric appliances, very rarely for cooking purposes. Households often use more than one energy form to fulfill the demand for a particular need.

Firewood and agricultural residues are not always collected by the end user, but traditional biomass is also traded. The sources of firewood for different consumer groups, as indicated by the NSSO survey, is illustrated in Figure 2. It can be seen that the poorer households tend more often to collect their traditional fuels freely, but also that some 20% is also purchased from the market even for the lowest income quintile.

Kerosene and LPG have been subsidized in India, both distributed through the Public Distribution System (PDS). While for kerosene there is a per household quota - the amount of which depends on the state - and a functioning private market with higher prices,

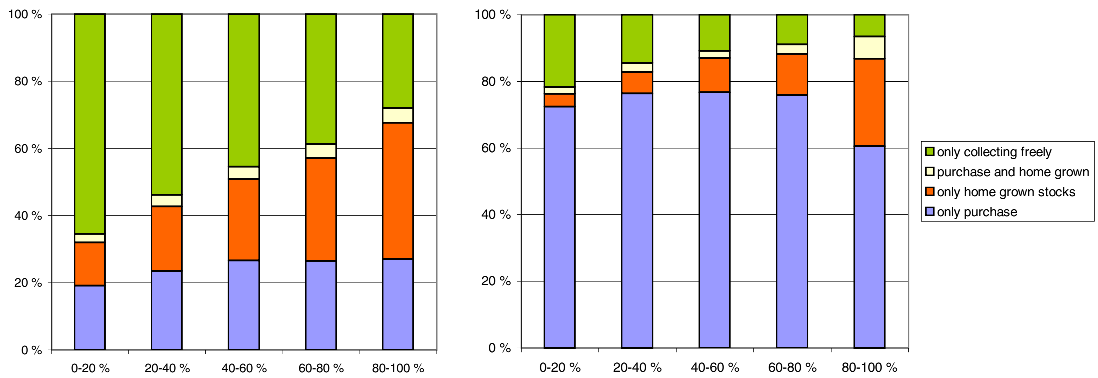

Figure 2: Sources of firewood for the expenditure quintiles in rural (left) and urban (right) populations.

virtually all LPG consumed by the households was provided with subsidized prices. As a result of the kerosene rationing, households that do not use kerosene might also sell their rationing cards for subsidized kerosene, as was noted in Gangopadhyay et al. (2005). Their analysis also showed that roughly half of the subsidized kerosene was illegally diverted away from the supply chain and never reached the households. The case is similar with electricity distribution, and power theft raises the losses of electricity distribution to over 25% according to IEA (2002).

3 Factors affecting fuel choice

A prerequisite for improving the detail in demand side modelling is to understand the factors that the households consider when choosing between different appliances to satisfy their energy demands. In classical demand theory the consumer demand for a given commodity is defined through consumer's budget constraint and her preferences. Therefore in addition to the cost, we must take into account budget constraints and measure somehow the preferences a consumer has for the different options to satisfy her energy demands. In the case of traditional fuels the consumer can however use some of the working time in order to gather cost-free fuel, thus giving rise to the need for considering the time consumption of gathering traditional fuels. As this study intends to take the heterogeneity of households into account, these factors are differentiated for consumer groups based on their expenditure levels and whether the household lives in urban or rural area. These two factors have been identified by Pachauri (2004) to be statistically the most important factors explaining the differences in energy requirements in India, thus presumably giving a good basis for differentiating household behaviour.

3.1 Costs of fuels and appliances

The most obvious factor in appliance choice is the price of appliances and fuels relative to their output of the desired energy service. For our modelling effort, average fuel prices were calculated from the NSSO survey, dividing the stated expenditure by stated consumption for different fuels. The prices were quite homogeneous for all consumer groups, apart from that biomass and electricity prices were somewhat higher in urban areas. From the original fuel division we have aggregated firewood, dung and charcoal into "Biomass" and coal and coke into "Coal". The average prices are stated in Table 1.

[1] Exchange rate: 42 Rs(2000) = 1 USD(2000).

Table 1: Average fuel prices [Rs/GJ][1] as implied by the NSSO survey.

	Coal	Electricity	Kerosene	PDS Kerosene	LPG	Biomass
Rural	85	373	282	112	270	62
Urban	85	415	282	112	270	80

The technological parameters for different end use technologies used in the study are presented in Table 2. Here the investment cost are stated as Rs per GJ of input energy. An important, though very uncertain, parameter here is the investment cost for electrical lighting. Numerous modelling efforts, including Reddy (2003), Kanagawa & Nakata (2008) and TERI (2006), have included the cost of a light bulb - possibly including the socket for the bulb - as the investment cost. However, if a household wishes to switch from kerosene lighting to electrical, the greatest cost arises from wiring the house, including the cost of a fuse box, a meter and other required devices. As no price estimates was found for this in India, it was estimated that it would cost roughly 2000 USD to electrify a house in the developed countries, which was then scaled down with a PPP factor of 3 from IMF to take into account the lower cost level in India and set for a household consumption of 3 GJ/a.

Table 2: Parameters for household end use technologies. Investment costs are in terms of Rs/GJ input energy.

	Efficiency	Inv. cost	Life [a]
Cooking:			
Biomass	15%	0.8	5
Coal	15%	3.3	5
Kerosene	45%	25	7
LPG	60%	160	20
Electric	75%	833	15
Lighting:			
Electric	40%	1478	30
Kerosene	6%	15.9	5

3.2 Time consumption for gathering biofuels

The time needed to gather a certain amount of fuel depends certainly on available biomass resources. This analysis is based on a study by Bhagavan & Giriappa (1995) which surveyed fuel consumption and time used for gathering traditional fuels in eight villages in three different climatic environments in India. On the community level the average pace for gathering traditional fuels was 38 MJ/h in the semi-arid region, 51 MJ/h in the moderate region and 62 MJ/h in the tropical region. The households used on average 8% of their working time for fuelwood gathering. When these numbers are compared to the fuel consumption and population statistics of rural and urban India, it could be calculated that in rural areas 44% and in urban areas 12% of the population would be needed to use the 8% of their working time to gather traditional fuels for the whole population.

As it was noted already from Figure 2, also traditional fuels are traded. The presence of the market for traditional fuels has two important implications. First, due to the possibility to purchase some of the fuel, the consumption of traditional fuels is not constrained by time consumption on the level of individual consumers but only possibly on the aggregate level. On this level only a fraction of the workforce is required to gather the fuel and thus time consumption is not a major constraining factor. Second, using freely gathered traditional fuels does not only consume time but also carries a monetary opportunity cost. Therefore the monetary value is also significant for those who collect their own firewood and acts as a factor for fuel choice.

3.3 Implicit discount rates

A general feature in all energy investments is that they include an up-front investment cost and fuel costs distributed for the technical lifetime of the appliance. This clearly gives rise to the need for weighting the costs occurring at different times, usually solved with net present value (NPV) approach by discounting the fuel costs. An implicit assumption behind this is that there is a financing opportunities present with the discount rates used and thus cash reserves do not constrain the investment. While this is often true for institutional investors, such opportunities are not always present for households, the discount rates can be higher or borrowing carries a transaction cost, resulting with scarcity of cash. Thus the method of discounting household's costs with the social planner's or institutional investor's discount rate is flawed.

Besides the possible hindrances in financing, also the implicit discount rates the households use might be inherently higher. If we assume that consumers have a decreasing marginal utility from money the utility loss from a large cost would be higher than from continuous small savings, as suggested in Frederick et al. (2002). Then a cash-scarce low-income household would weight the loss of utility from a large up-front investment against smaller annual savings in fuel expenditure in the future more than a wealthier one. In terms of discounting, this would be interpreted as a larger discount rate for money for the low-income household.

A large number of studies have been made in order to measure consumers' implicit discount rates. Compiling over 40 field and experimental studies in Frederick et al. (2002) the range of respondents' discount rates was found to vary from negative to infinity. Even if this is not a very practical range to be used in modelling work, it could be seen that the results from real field studies were much more moderate - from 0% to 300% - than in hypothetical experiments. A similar review on 14 studies on energy investments by Train (1985) reported a range from 3.1% to 89%, with all of the studies confirming the assumption that consumers' with more income have lower implicit discount rates.

The problem with these surveys with regard to this study is that they were all made in developed countries and therefore do not include very poor households. For the very poor we can however use the interest rates that the informal lenders in developing countries charge, roughly from 150% based on Kota (2007) to 300% based on Robinson (1996), as a reference point. The rationale in this is that if people do take loans with such interest rates, their own implicit discount rate must be higher than the interest rate.

3.4 Consumer expenditure

Obviously an important aspect is the household affluence, how much households are willing to spend on energy and how the expenditure will develop in the future. As the study focuses on taking households' different economic conditions into account, the shifting of income or expenditure distributions is essential for projecting changes in energy consumption patterns.

In order to model the expenditure distributions in future, lognormal distributions were first fitted to the NSSO data for 1999-2000, separately for rural and urban populations. The projections for average expenditure growth and expenditure distribution were based on the assumptions from TERI (2006) using a growth assumption of 6.7% p.a. for Indian GDP, that in turn are based on an extrapolation from 1993/1994 data to 1999/2000. Population growth up to 2020, separately for urban and rural, was taken from the B2 scenario developed at IIASA (2008).

It is interesting to note that the expenditure distributions for 1999/2000 in TERI (2006) are different, and for example the average expenditure reported by TERI is some 60% larger in rural areas and 70% in urban areas than in the distributions used in this study. Although TERI doesn't state in which year's currency it's distributions are presented, taking inflation into account wouldn't explain the difference in urban/rural expenditure disparity between the studies. Also, the change in expenditure variance is based on an extrapolation from 1993/1994 to 1999/2000 that projects decreasing expenditure inequality, which might be questionable. As the expenditure distribution projections are thus not very well-grounded, this area is still subject for major improvements. Nevertheless, the projections used by TERI depict a roughly 4% p.a. rise in average expenditure and a decreasing variance between 2000-2020. Figure 3 presents the expenditure distribution of the rural and urban populations in 2000 and 2020.

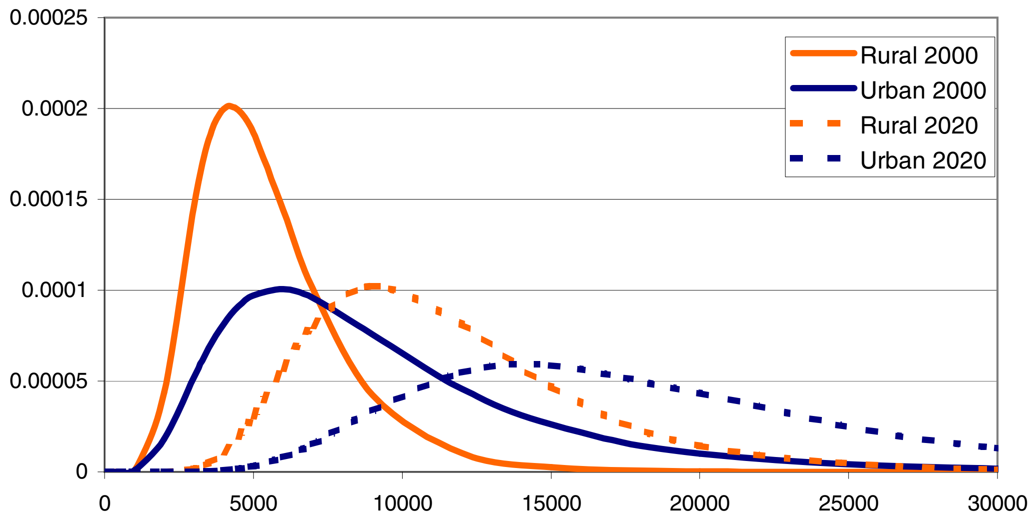

Figure 3: Expenditure distributions (in Rs.2000/cap/a) for urban and rural populations in 2000 (solid line) and 2020 (dashed line)

For each income category a fuel budget was defined, limiting the amount of expenditure households can use for energy. These were generally around 7-8% of total expenditure. In reality the fuel budget is not constant but energy consumption would depend on the prices of energy and other commodities. This is not however a major concern in the scope of this study. The effect of constraining the fuel budget would increase only with increasing prices, given that the own-price elasticity of aggregate energy consumption is above -1 i.e. the demand is rather inelastic. This is an appropriate assumption as there is no close substitutes for energy consumption and for example Gundimeda & Khlin (2008) reported that the Hicksian (compensated) own-price elasticities estimated from the NSSO data for different fuels were generally between -0.1 and -0.7. As the study is dealing mostly with effects from decreasing energy prices, this leads to a reduced importance of the fuel budget constraint.

3.5 Inconvenience of using fuels

As the intention is to sum up all of the decision criteria into a single monetary measure, we need to also define inconvenience costs for using different appliances that describe the consumer's preferences for using different fuels. The inconvenience cost enters the cost-minimization problem of the consumer as an operational cost, but it doesn't add to the fuel budget. As an example, biomass would be the most preferred fuel for cooking from pure economic sense, the inconvenience associated with making a fire, cleaning blackened pans and to suffer from smoke and particulate matter creates an incentive to switch to cleaner fuels, if the economic conditions of the household permit. An initial hypothesis is that inconvenience costs rise with income and increased consumption of the fuel in question and they are larger in urban areas than in rural. As no data for such inconvenience costs exists, the costs were estimated from the actual fuel consumption patterns captured by the NSSO survey.

As modern fuels and appliances are generally more expensive than traditional fuels - partially even in terms of useful energy - households pay a price premium for consuming modern fuels. This price premium serves as a basis for calculating the inconvenience cost. Let us assume that consumer group i consumes different fuels according to a vector E. The prices of the fuels are a vector p, the investment costs for associated appliances are $C_{I,i}$ (annualized with the consumers' discount rate, per unit of final energy) and efficiencies η. Then the inconvenience cost $C_{v,i,j}$ associated with a fuel j could be calculated as how much less the consumer would pay by using solely the fuel j per the consumption of the fuel j, or

$$C_{v,i,j} = \frac{(p^T + C_{I,i}^T)E - (p_j + C_{I,i,j})\eta^T E \eta_j^{-1}}{E_j} \tag{1}$$

Another approach could be to assume that the inconvenience cost is an increasing function in income and consumption of the fuel in question and that with the consumption level indicated by the statistics the marginal inconvenience cost equals the cost difference of a traditional fuel j and a convenient modern fuel k. Therefore this could be described as a market equilibrium approach. If we make a simplistic assumption that the marginal cost increases linearly with regard to consumption for each income group, we can calculate the average inconvenience cost of fuel j, were the demand satisfied solely with this fuel, as

$$C_{v,i,j} = \frac{\frac{1}{2}((p_k + C_{I,i,k})\frac{1}{\eta_k \eta_j} - (p_j + C_{I,i,j})\eta_j^{-2})E_j^{-1}(E_j\eta_j + E_k\eta_k)^2}{\eta^T E \eta_j^{-1}} \tag{2}$$

The assumption that the whole demand is satisfied with the fuel j can be justified with the tendency of LP models, such as MESSAGE used in this study, to use the least cost option to satisfy the whole demand.

4 Model and scenario specifications

4.1 Model design

Based on the analysis above, a demand-side energy system model for Indian households was developed using the MESSAGE modelling framework. MESSAGE is a linear programming energy system model developed at International Institute for Applied Systems Analysis (IIASA), described in Messner & Strubegger (1995), that has been used in numerous energy-economic scenario studies. The model developed in this study focuses solely on the demand side to isolate the demand side effects from the changes in the supply side. In order to do this, it is assumed that fuels can be supplied in unlimited quantities with predefined prices, and consumers are free to choose the appliances and fuels to satisfy their projected energy service demands. As an improvement to the previous models, the developed model differentiates the consumers into ten groups with different implicit discount rates, inconvenience costs, fuel budgets and also with different fuel prices in rural and urban areas. In longer term the model is to be integrated with the global MESSAGE model with a complete description of energy supply.

The population was split into five income groups both in urban and rural areas. The division was made with fixed expenditure intervals based on the expenditure quintiles in 2000. As a result the population in the lowest expenditure category decreases and in the highest category increases in time due to expenditure growth. For each consumer group a demand projection was defined based on the per capita energy consumption of cooking, lighting and appliance energy in 2000 and the population in each group based on our expenditure projection and the IIASA B2 population growth scenario. The rural population was assumed to grow annually by 0.7% and the urban by 2.8% on average between 2000 and 2020. Therefore the growth in energy consumption in the model arises both from population growth and households shifting to higher expenditure classes as the economy grows.

Energy and equipment prices, presented in section 3.1, were chosen to be constant throughout the time horizon to ease the interpretation of the results. Even though the prices of especially oil products have fluctuated wildly since 2000, making justified assumptions for future prices is next to impossible. Also, projecting the prices of traditional fuels based on the evolution of the income distribution would include large uncertainties. This simplification will however be corrected in the future when the access model is integrated to the full global MESSAGE model. The consumption of subsidized PDS kerosene was limited to the amount of statistical PDS kerosene consumption in 2000, separately for the urban and rural population, and scaled up with the population growth rates, mimicking the household quotas and trade in subsidized kerosene.

As the NSSO survey does include information only on the total amount of energy forms consumed, the consumption data has to be divided for the different energy services. The problematic energy forms are kerosene, which is used for lighting and cooking, and electricity, which is used for lighting and appliances. For splitting the kerosene consumption, the approach from Gangopadhyay et al. (2003) was adopted, where consumers were grouped with their stated main lighting and cooking fuels, which was also asked in the NSSO survey. Then the amount of kerosene lighting can be estimated from the consumption patterns of households that do use kerosene primarily only for lighting. Also the kerosene use for backup lighting can be estimated from households that do not use kerosene as a primary fuel neither for cooking nor lighting. For defining the amount of electricity used for lighting, the regression equations presented by Letschert & McNeil (2007) for the number of electric light points as a function of expenditure, was used.

4.1.1 Implicit discount rates

As our analysis suggested that implicit discount rates might range roughly from 5% to 200%, this range was assigned to the expenditure groups with the highest urban expenditure group having the 5% rate, the lowest rural group having the 200% rate and the rest distributed between these based on the average expenditure of the groups. The discount rates of the income groups are presented in Table 3.

As the model operates inherently on a single discount rate, the investment costs had

Table 3: Implicit discount rates (IDR) for the expenditure quintiles of rural and urban population.

	Expenditure quintile	Avg. expenditure [Rs/cap/a]	IDR
Rural	0-20%	2956	200%
	20-40%	4072	125%
	40-60%	5047	80%
	60-80%	6376	60%
	80-100%	10701	30%
Urban	0-20%	4073	150%
	20-40%	6018	70%
	40-60%	8041	40%
	60-80%	11116	20%
	80-100%	22037	5%

to be modified in order to take into account the different discount rates of the consumer groups. As said, the choice is based on the NPV of the lifetime costs of the appliance, and the appliance with lowest costs per useful output is chosen. On the other hand, we could annualize the up-front investment cost with the discount rate r_i of the consumer group i and compare the annual costs of the appliances in stead of the NPV's. Then, assuming that the appliances are used for the whole lifetime and running and fuel costs are constant, the same choice would be made than when comparing the NPV's. From the annual costs, we can again turn back to the investment costs, but now discounting with the model discount rate r_M. This gives us a factor, here with continuous time discounting, with which the actual investment cost C_I should be multiplied to have the investment cost $C_{I,i}$ that the consumer experiences if she would discount with the rate r_M. That is

$$C_{I,i} = C_I \, \frac{r_M^{-1}(1 - e^{-r_M T})}{r_i^{-1}(1 - e^{-r_i T})}, \tag{3}$$

where T is the technical lifetime of the appliance.

4.1.2 Inconvenience cost

Section 3.3 described two approaches for estimating the inconvenience cost of different energy forms. The concept was used in the model for cooking fuels, and Table 4 presents the inconvenience costs of biomass with both approaches. With the marginal cost approach, biomass has been evaluated against LPG, which is assumed to be the most convenient fuel.

As it can be seen, the price premium approach produces smaller inconvenience costs than the marginal cost approach for the rural population. Also, the price premium approach produces inconvenience costs that mostly rise with expenditure levels, as was assumed a priori. For the urban population the results are closer to each other, and both approaches produce negative costs for the two highest quintiles. This is due to that LPG, the convenient fuel, is actually cheaper than biomass with the higher price of biomass in urban areas and the lower discount rates of more prosperous households. Moreover, when used in the model the price premium approach produces results closer to the actual statistical consumption than the marginal cost approach, and was thus used in the scenarios.

Table 4: Inconvenience costs (Rs/GJ of final energy) for biomass calculated with the two approaches presented in section 3.3 for different expenditure quintiles of the rural and urban populations.

	Expenditure quintile	Price premium approach	Marginal cost approach
Rural	0-20%	1.9	42.0
	20-40%	1.2	22.5
	40-60%	1.5	18.8
	60-80%	2.2	15.3
	80-100%	5.2	11.0
Urban	0-20%	12.6	27.3
	20-40%	14.9	13.5
	40-60%	10.2	5.0
	60-80%	-31.4	-20.4
	80-100%	-218.8	-118.8

4.2 Policy scenarios

As an application of the model developed, the effect of different subsidy policies was evaluated with the intent to improve the market penetration of modern cooking fuels. In six policy scenarios reaching up to 2020 the price of either LPG or kerosene was reduced by 25%, 33% or 50%. For comparison, in 2000 the price of PDS kerosene was roughly only 40% of the market price, but the quantity of PDS kerosene supplied was limited. Thus especially the high subsidy scenarios can be seen as quite extreme. Our measure of policy effectiveness is the market penetration of modern cooking fuels (LPG and kerosene) in rural areas. The net present value of the subsidies was also calculated from the results to evaluate the cost-effectiveness of the subsidies. The measures were set to start in 2005 in the scenarios so that the subsidized prices would gradually decrease to the final level in 2015 in a linear fashion.

With the implicit discount rate being one of the determinants for fuel choice, a policy measure targeting this was also considered. It could be argued that as the very high discount rates of the poor consumers are likely to produce a socially suboptimal outcome, it would be beneficial to provide a funding scheme for appliance investments with interest rates closer to the social planners discount rate. Microfinancial institutes that provide loans for the poor in developing countries generally charge interest rates from 20% to 35% based on Robinson (1996), and this range was used as a reference interest level for discounting. The effect of providing improved financing opportunities was assessed both as the only policy measure and combined with the different subsidy levels for modern fuels.

5 Results

5.1 Baseline scenario

No additional policy measures were taken in the baseline scenario and as expected, the resulting scenario didn't exhibit any dramatic changes. Figure 4 presents consumed useful cooking energy from different sources in rural and urban areas. In the figure the year 2000 represents the NSSO statistics and from 2001 the model solution. As it can be seen, the model reproduces the consumption patterns seen in the statistics fairly well. Biomass dominates cooking in rural areas supported by small shares of LPG and PDS kerosene.

LPG is phased out as the existing appliances depreciate and substituted by kerosene. On the other hand in urban areas the share of LPG grows with the increasing household expenditure, and biomass phases out by 2015.

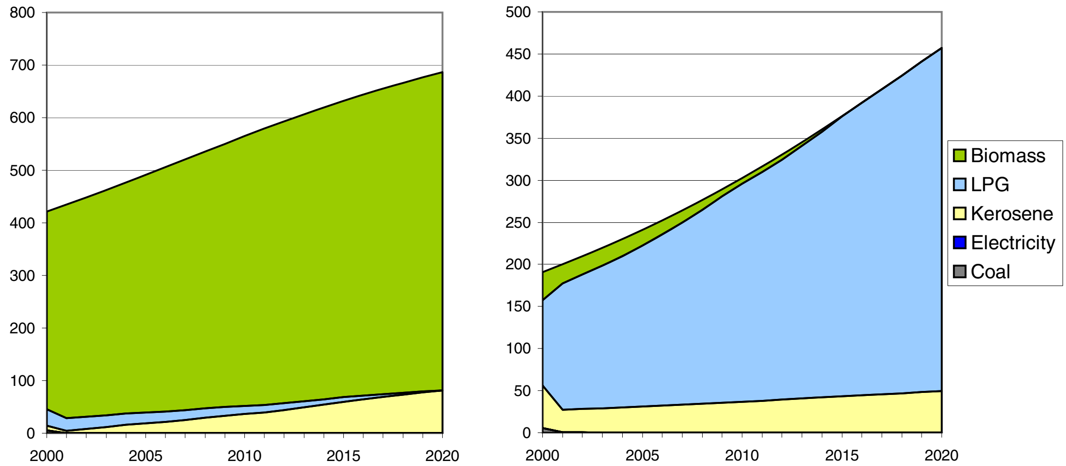

Figure 4: Cooking fuel consumption in terms of useful energy [PJ] in rural (left) and urban (right) areas.

Figure 5 portrays lighting energy consumption. The urban kerosene consumption calculated by the model is very close to the statistical value for year 2000, and decreases gradually to zero by 2013. In rural areas the model calibration is not as perfect and deviates from the statistics roughly by 25% due to the highest expenditure category immediately switching to electric lighting. As electric lighting has far better efficiency, the switch increases energy efficiency and thus results also with a fall in final energy demand seen in the figure. Following mostly from economic growth, the use of kerosene for lighting is reduced to nearly zero by 2020 in rural areas. However in reality the consumers are also forced to use kerosene lighting due to insufficient supply, which was not considered in the model.

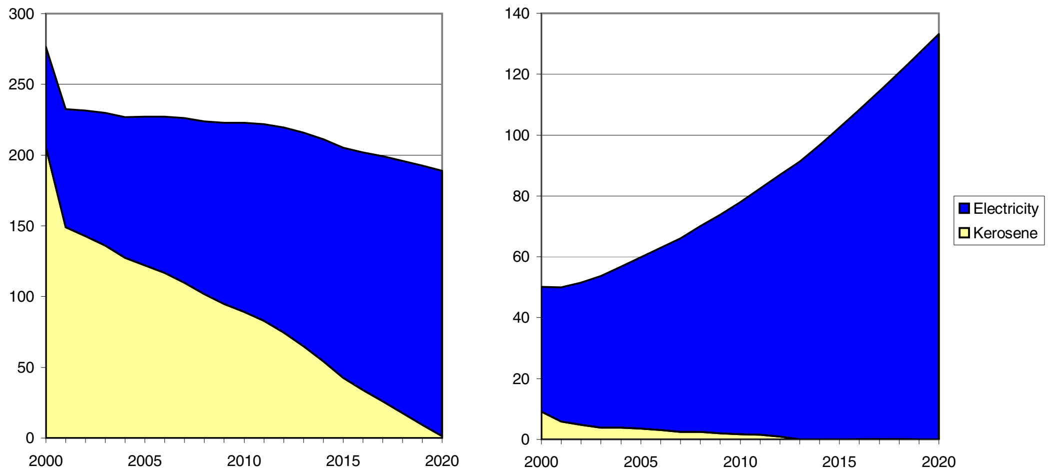

Figure 5: Final energy consumption [PJ] for lighting in rural (left) and urban (right) areas.

5.2 Policy scenarios

Using three different subsidy levels for two fuels with or without improved financing, plus a scenario without the subsidies but only improved financing opportunities, a total of 13 policy scenarios were calculated with the model. As the scenarios resemble each other, it is not relevant to go through all of the scenarios in detail. The main difference is the timing and the extent of fuel switching, with the fuel switched to being the subsidized fuel. In the scenarios with a kerosene subsidy, kerosene mostly takes over the whole cooking fuel market. With a LPG subsidy, a small share of PDS kerosene still remains in the market.

Our main point of interest, the market penetration of modern cooking fuels within the rural population, in the policy scenarios is summarized in Figure 6. The three figures present the combined share of LPG and kerosene relative to total useful cooking energy demand with the top figure having a 25%, a 33% or a 50% subsidy level, respectively from top to bottom. As we can see, the LPG subsidy is more effective with smaller subsidy levels than kerosene, producing a penetration rate over 75% in 2015 already with a 25% subsidy. Moreover, resulting from the high initial investment and lower running costs, improving the financing for acquiring the stove is more effective when combined with an LPG subsidy than with a kerosene subsidy. This effect is particularly important to extend the switching effect to the poorer consumer groups, manifested by penetration rates very close to 100%. The subsidy on kerosene would have to be very large to induce extensive fuel switching in the rural areas. This would however also prompt the urban population to switch to kerosene from LPG, and therefore the effect of a kerosene subsidy might not be targeted solely to the rural population.

Figure 7 presents the penetration rates in 2015 along with the net present costs of the subsidy scheme. The cost is calculated as the NPV from the price differential between the subsidized and market prices times the fuel consumption at different periods, discounted with the social planners 5% discount rate to 2000. No costs or returns was estimated for the financing measures. The most cost-effective schemes were the 25% subsidy on LPG, with or without financing improvements. As the financing scenario increases the adoption of LPG stoves, the costs of the policy inevitably increase. However the level of the subsidy would have to be considerably higher in order to reach the high penetration rate that is attained in the scenario with financing.

6 Conclusions and discussion

Improving the prospects for energy use is an important prerequisite for improving the conditions of the poor in developing countries. Particularly providing access for modern cooking fuels would reduce the exposure for respirable particulate matter, mitigate deforestation and save time for more productive work. In a short literature review it was stated that previous modelling work on energy access has not been comprehensive enough to sufficiently describe the demand side behaviour. This study has considered the different determinants of household decisions on energy consumption, described a linear programming model of Indian household energy demand that differentiates consumers with different socio-economic conditions, and evaluated the implications of policy measures - fuel subsidies and improved financing - in order to promote the adoption of modern cooking fuels in rural India.

Drawing from both the cost-minimizing solution concept of various energy system models and preference and budget constraint approach of classical demand theory, we considered five factors for fuel choice determinants. Costs of different energy forms and appliances is an obvious factor. Time required for gathering traditional biomass was not

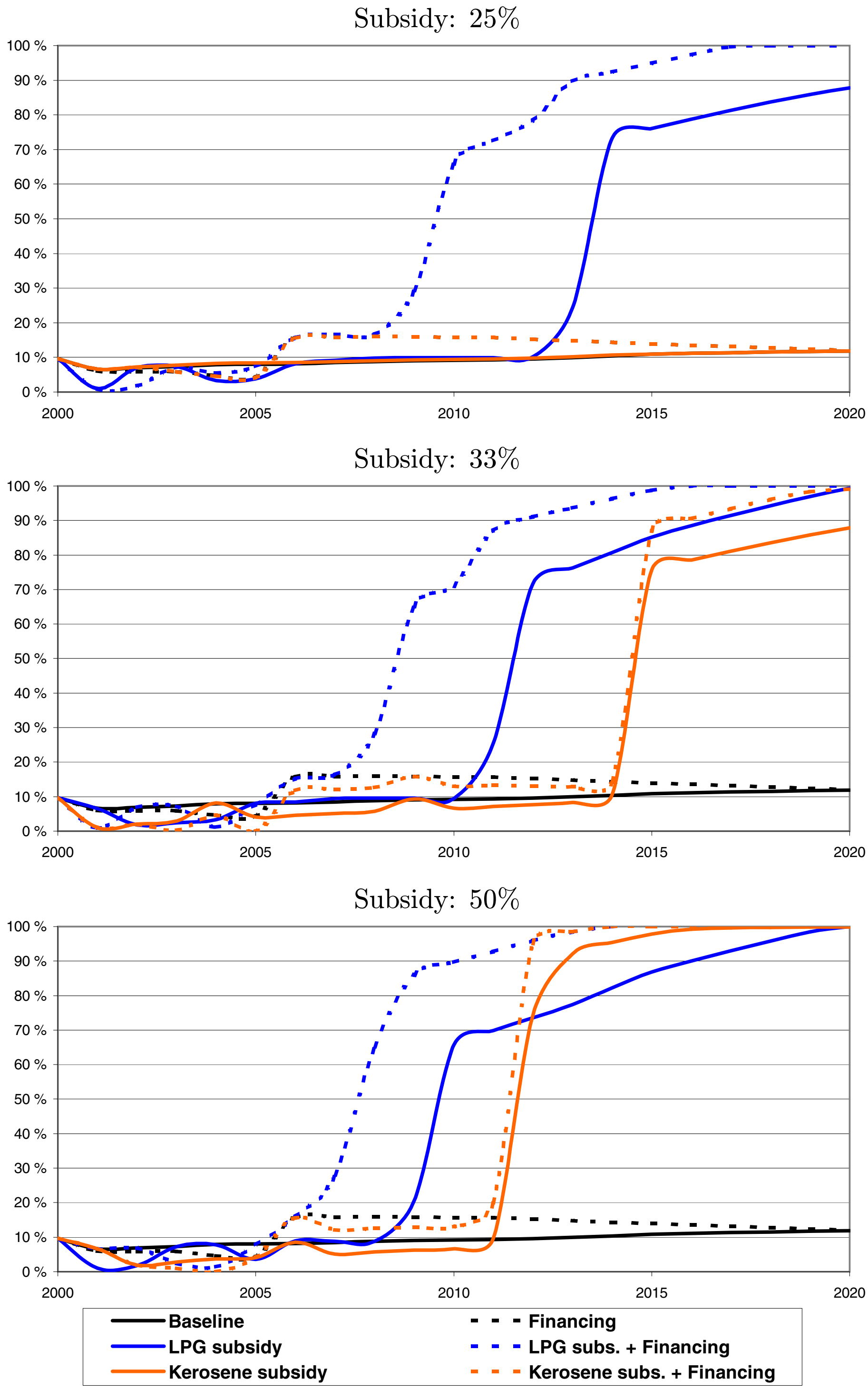

Figure 6: Market penetration of modern cooking fuels in rural areas with subsidized prices set to 75% (top), 66% (center) or 50% (bottom) from normal price.

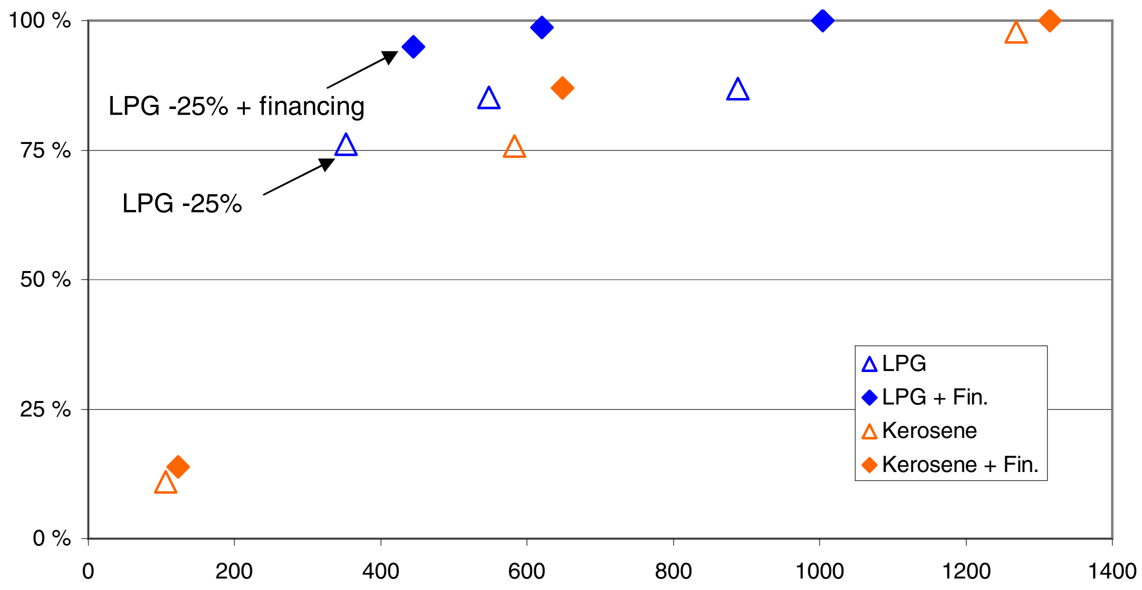

Figure 7: The market penetration of modern cooking fuels within the rural population in 2015 in different policy scenarios as a function of total net present cost of the subsidy scheme [mln Rs.].

considered to be a limiting factor for consumption in the case of India: on the level of individuals, one can always buy the biomass from market as traditional fuels are also traded, and on the aggregate level a small fraction of the workforce actually has to gather all the biomass consumed. Discount rates are an important factor due to the need for balancing up-front investment costs and running costs. Resulting from the scarcity of cash and worse financing opportunities, the poorer households tend to have higher implicit discount rates, which affects their energy related choices. The fuel budget constraint was estimated from NSSO statistics for 2000, and using assumptions for economic growth it was projected how expenditure distributions might shift in the future. The final determinant is the consumer preferences, adopted to the cost-minimization paradigm as an inconvenience cost, for which two possible estimates were presented.

Along with a baseline scenario with no new policies, 13 policy scenarios with subsidies for LPG or kerosene with and without improved financing opportunities were created with the model developed. Without any policy measures, the rural population is unlikely to adopt modern fuels in cooking, thus underlining the need for policy intervention to reduce the adverse effects from traditional fuel use. However the growing income levels would induce a complete shift to electric lighting by 2020, assuming that reliable supply is present.

In the policy scenarios, a larger market penetration was acquired with LPG subsidies due to the similar prices of LPG and kerosene and the better efficiency of LPG stoves. As the investment cost for LPG stoves is considerably higher than for the other fuels, the market penetration could be enhanced through providing improved financing opportunities, such as microfinance, thus lowering the discount rate used in the cost-optimization. The LPG subsidy was also seen as more cost-effective than a kerosene subsidy for affecting the rural fuel choices, contrary to what e.g. Gangopadhyay et al. (2005) have argued.

While the developed model increases the detail and accuracy in energy access modelling, some simplifying assumptions still had to be made. The developed model considered only the demand side and assumed unlimited supply with constant prices for fuels. The constant price assumption was made for simplicity and also due to lack of data, particularly for the costs of traditional fuels. Including a supply side in the model would however shed light also on the optimal production-consumption pattern of the whole energy chain.

Further improvements of the model include the introduction of elastic demands and stepped supply costs for biomass. The former would raise the costs of subsidy scheme, resulting from increased consumption, and would highlight some of the loss in economic efficiency due to the subsidy. The latter, though difficult to calibrate in a justified way, would increase the realism on biomass supply, as with reduced demand the resources become more abundant and prices decrease for the households that do not switch from traditional fuels. As the model is to be integrated with the full MESSAGE model in the future, the stepped biomass supply costs would be also necessary to balance the varying costs of modern fuels determined by the supply sector.

A few important points must also be taken into account when interpreting the model results. It has been claimed that the price of LPG bottles is already restrictively high for low-income households, thus decreasing the LPG adoption potential. A remedy might be smaller bottles, even though this might raise the costs of LPG somewhat. What was already implied above with the stepped production function for biomass, in reality the costs of biomass - market or opportunity - would decrease with diminishing biomass demand. This would also slow down the adoption of modern fuels. Moreover the rural poor who are likely to gather and sell the firewood might see their income decreasing as the more affluent rural household would reduce firewood consumption.

The most material critique is however that as the government is already struggling financially with current subsidy schemes and rising prices, sustained subsidies are likely not a viable option. Another way to shift the price balance between traditional and modern fuels would then be to increase the opportunity costs of traditional fuels by improving the income level of the poor. If the marginal supply prices for biomass were assumed to be increasing, this would also be a requirement were the poor to adopt modern fuels as they are likely to be more reluctant to switch away from cheap biomass than the wealthy households. Thus as a conclusion, economic development and modern fuel adoption are very likely to go hand-in-hand and it is hard to improve one without improving the other.

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