Using renewable energy technologies for domestic cooking in India: a methodology for potential estimation

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Abstract

An attempt has been made to estimate the potential of using biogas plants, solar cookers and improved cookstoves for domestic cooking in India. Based on 1991 statistics on the bovine population and ownership pattern, the potential number of family size biogas plants comes out to be around 38 million in the optimistic scenario whereas, in the realistic scenario it is around 29 million. The potential of improved cookstoves is estimated at about 90 million and that of solar cookers is estimated at about 75 million.

Keywords: Domestic cooking; Biogas technology; Improved cookstoves; Solar cookers

1. Introduction

Cooking energy constitutes a major fraction of energy consumption in rural areas of the developing countries. In rural India, for example, energy for cooking end use accounts for a little over 80% of the total household energy consumption [1]. The cooking energy demand in rural areas of developing countries is largely met with bio-fuels such as fuelwood, charcoal, agri-residues and dungcakes.

Efforts have been made in India to develop and disseminate renewable energy technologies such as biogas plants and improved cookstoves to make efficient utilization of bio-fuels for domestic cooking. Attempts have also been made to supplement the existing options of domestic cooking with solar cookers. In spite of significant success reported in the case of biogas plants and improved cookstoves, it is opined that the cumulative numbers of biogas plants and improved cookstoves so far disseminated are far below their respective potential. Solar cookers are also expected to contribute considerably towards meeting domestic cooking energy requirement in a country blessed with abundant sunshine. It is in this context that an attempt has been made to estimate the utilization potential of these technologies for domestic cooking in India to facilitate a realistic assessment of their potential role in future policy planning of energy sector in the country.

It is worth mentioning that the actual potential of using renewable energy devices for domestic cooking may change with time due to changes in:

(i) number of households in the country;
(ii) availability of biomass feedstocks and other renewable energy resources;
(iii) purchasing power of households.

In this study 1991 census data has been used to exemplify the suggested potential estimation methods.

2. Potential estimation methodologies

2.1. Household biogas plants

Biogas technology is one option, which can meet the growing energy demand of rural areas in developing countries. The time variation of the cumulative number of biogas plants installed in the country is shown in Fig. 1(a). The bovine ownership pattern of households in different state [2] has been used to ascertain the number of households with a specific number of bovines. The daily dung yield from the bovine being different in different states (it also varies with breed and size of animal) an average value was taken [3]. The effective daily dung availability is estimated taking into account the degree of confinement of the cattle and the dung collection efficiency. Finally, using the specific biogas yield per unit amount of fresh dung, the daily gas production potential for the household with a given number of bovines has been estimated.

The daily gas production capacity as estimated above is rounded off to the nearest commonly installed capacity of biogas plants in the country (1, 2 and 3 m^3). In one of the estimation procedure it is assumed that, the user will supplement the bovine dung with other biodegradable materials such as kitchen waste, agricultural residue, human night soil etc. and thus an upward rounding off is considered. In contrast to the estimates of the above 'optimistic scenario' estimates of a 'realistic scenario' have also been obtained by rounding off the daily gas production capacities to the closest lower rated capacity. The bovine ownership pattern as shown in Table 1 [2] provides the number of households (expressed as a percentage of total rural house-

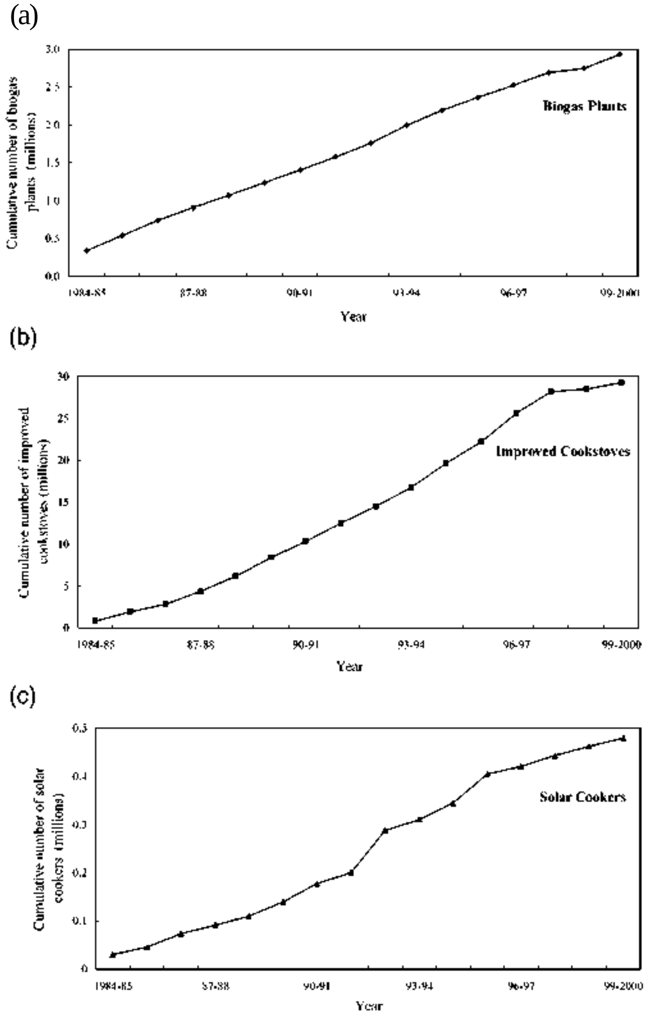

Fig. 1. (a) Time variation of cumulative number of biogas plants installed in the country. (b) Time variation of cumulative number of improved cookstoves disseminated in India. (c) Time variation of cumulative number of solar cookers disseminated in India.

holds in the state) possessing a certain number of bovines separately for different states. Table 2 summarizes the sizing criteria for household biogas plants.

2.2. Improved cookstoves

In India, due to a large rural population and its dependence on bio-fuels, there exists a substantial potential for diffusion of improved biomass cookstoves. Under the aegis of National Programme on Improved Cookstoves (NPIC), over 29 million improved cookstoves have reportedly been installed till 31 December 1999, since

Table 1
Pattern of bovine ownership in different states of India

State	% of households owning bovines	Rural 1lhouseholds owning ≥X bovines as a % of all rural households						
		X=3	X=4	X=5	X=6	X=7	X=8	X=10
Northern Region								
Uttar Pradesh	80	41	28	17	11	*1*	4	2
Rajasthan	72	52	42	31	24	18	14	8
Punjab	79	52	40	31	23	17	13	7
Haryana	79	52	40	28	20	14	10	5
Himachal Pradesh	84	68	57	42	30	21	15	7
Jammu and Kashmir	82	53	38	25	16	10	7	3
Eastern and Northern Eastern Region								
West Bengal	53	27	20	13	9	6	5	2
Bihar	59	25	17	10	6	4	3	1
Orissa	60	32	25	16	12	8	6	3
Assam	61	38	31	19	13	8	6	3
Southern Region								
Andhra Pradesh	52	29	22	15	12	8	6	4
Karnataka	61	38	29	21	15	11	8	5
Kerala	39	11	6	3	1	0.8	0.5	0.2
Tamilnadu	44	21	16	10	7	5	4	2
Western Region								
Madhya Pradesh	70	51	43	34	28	22	18	11
Maharashtra	49	30	24	17	13	10	7	4
Gujarat	62	40	30	20	14	9	6	3

Table 2
Sizing criteria for household biogas plants

S. No.	oRealistic Scenario		Realistic Scenario	
	Daily amount of wet dung collected d(kg)	Biogas plant capacity (m^3)	Daily amount of wet dung collected d(kg)	Biogas plant capacity (m^3)
1	rf<20	0	d<25	0
2	20≤d<37.5	1	25≤rf<50	1
3	37.5≤rf <62.5	2	50≤rf <75	2
4	62.5≤rf<87.5	3	75≤rf<100.0	3

its inception in 1983 [4]. Fig. 1(b) shows the time variation of the cumulative number of improved cookstoves disseminated in the country till the end of December 1999.

The elimination method is used for estimating the potential number of improved cookstoves for domestic cooking in India. It assumes that all households who do not have access to kerosene, liquefied petroleum gas (LPG), natural gas, biogas and electricity for domestic cooking are the potential users of improved cookstoves. Both availability and/or costs of these fuels essentially define their accessibility to the households. It is also assumed that all households using traditional cookstoves can, in principle, switch over to more efficient and less polluting improved cookstoves. It essentially means that sufficient designs and cost variations of improved cookstoves are available to satisfy the need and purchasing power of all these households.

The number of households using LPG for cooking is obtained from published literature [5,6] and for estimating the number of users of kerosene, softcoke and natural gas for domestic cooking the following formula is used

$$\text{Number of users of a fossil fuel for domestic cooking} = \frac{\text{Amount of the fuel used for cooking} \times \text{Calorific value of fuel} \times \text{Efficiency of fuel utilization}}{\text{Annual useful energy requirement per household}}$$

while the annual amounts of the different fuels used for domestic cooking have been obtained from published literature [7] a daily useful energy requirement of 12.13 MJ per household has been assumed for domestic cooking [8].

The realistic estimate of potential number of biogas plants has been used as the number of households using biogas for domestic cooking for estimating the potential number of households who can use improved cookstoves. Only 0.5% of urban households reportedly use electric stoves/ovens for domestic cooking [7], which is a very small fraction of the total households in the country. Therefore, these households have not been considered in the present potential estimation exercise.

2.3. Solar cookers

A significant portion of the cooking energy requirement is at low temperatures. Solar cookers are ideal for meeting such thermal energy requirement. Since most parts of the country receive annual mean daily solar radiation in the range 5-7 $kWh/m^2/day$ [9], solar cookers have a high potential of diffusion in the country. In India, only the box type solar cooker is somewhat standardized [10], which can be used for boiling and baking type of cooking only. Fig. 1(c) shows the time variation of the cumulative numbers of box type solar cookers disseminated in the country [4].

In the present work it is assumed that the following categories of households would be quite motivated to use a box type solar cooker for domestic cooking.

(a) Households located in areas with adequate sunshine ($>4\ kWh/m^2/day$). In the urban areas an additional condition of accessibility to solar radiation has to be satisfied. During certain periods (primarily rainy season of the year), a box type solar cooker may be rarely used. However, it is assumed that the household may be motivated to invest in the box type solar cooker if the cooker can be used during a major part of the year. Most of the locations in India have more than 275 sunny days in a year [9].

(b) Households above the poverty line (unless the Government provides subsidies on the purchase of solar cookers).

(c) Households with at least one adult member at home (since the use of solar cooker requires cooking during the daytime, it is assumed that the households in the rural and urban areas that may not have any adult member to attend the solar cooker during the day may not prefer to buy a solar cooker).

The total potential P_{sc} of using box type solar cooker for supplementing domestic cooking in India can be estimated as

$$\wedge_c = / i W /_3 /_{4r} + (i - /_2) /_3 /_4 /_{5u} \} \quad (i)$$

where N represents the total number of households in the country, f_1 the fraction of households living in the geographical areas with adequate solar radiation availability, f_2 the fraction of total households living in the rural areas of the country, f_{3r} and f_{3u} the fractions of households above the poverty line in rural and urban areas respectively, f_{4r} and f_{4u} the fractions of households with availability of at least one adult member at home to attend the solar cooker during the day in rural and urban areas respectively and f_{5u} the fraction of households in the urban areas, having access to solar radiation. In some cases, households belonging to the very affluent sections of the society (mainly in urban areas) also may not have sufficient propensity to use box type solar cookers. Since the total number of such households is likely to be a very small fraction of the total number of households in the country the same has not been included in this study.

The above potential estimation procedure is based on an inherent assumption that the solar cookers will not be able to completely replace any existing cooking option and will essentially save a certain amount of fuel presently being used for domestic cooking in the household. In other words it is assumed that all the households presently using other cooking devices and satisfying the conditions mentioned above for using solar cookers are its potential users.

3. Results and discussion

Using the available data on various input parameters (Table 3) to the simple methodology presented in this paper for estimating the potential of the renewable energy technologies for domestic cooking, some typical estimates have been obtained. Table 4 presents the estimated potential of using household biogas plants in India (based on the 1991 census data on the livestock holding and its distribution in sixteen states of India). It may be noted that there is a very large potential of biogas utilization at household level in India (as is expected in a country with largest bovine population in the world). There is however, considerable difference in the figures estimated for

Table 3
Values of different input parameters used in potential estimation

S. No.	Parameter	Symbol	Unit	Value	Reference
1	Average yield of bovine dung	–	kg	10.88	[3]
2	Average specific gas yield (per kg of fresh dung)	-	m^3	0.04	[14]
3	Collection efficiency	-	Fraction	0.75	[14]
4	Kerosene consumption in 1991 for cooking	–	mtoe	3.21	[5]
5	Softcoke consumption in 1991 for cooking	-	mtoe	0.3	[5]
6	NG consumption in 1991 for cooking	-	mtoe	0.1	[5]
7	Calorific value of oil	CV_{ofl}	MJ/kg	42.67	[15]
8	Total number of LPG consumers in 1991	–	Million	18	[9] [10]
9	Total number of biogas plants installed till 1991	-	Million	1.4	[11]
10	Daily useful energy requirement for cooking	E_u	MJ	12.13	[6]
11	Efficiency of kerosene stove	»7k	Fraction	0.45	[15]
12	Efficiency of NG stove		Fraction	0.50	[15]
13	Efficiency of traditional cookstove		Fraction	0.10	[15]
14	Total number of households in the country	N	Million	152.01	[13]
15	Fraction of households having adequate sunshine	f1	Fraction	0.96	[7,8]
16	Fraction of rural households	f_2	Fraction	0.73	[13]
17	Fraction of households above the poverty line in rural area	/*	Fraction	0.61	[12]
18	Fraction of households above the poverty line in urban area	/*,	Fraction	0.60	[12]

optimistic and realistic scenarios. In the optimistic scenario a total of about 65 million m^3 of biogas can be produced daily using bovine dung at the household level with about 38 million (about 18.5 million of 1 m^3, 12.1 million of 2 m^3 and 7.4 million of 3 m^3 capacity biogas plants). The realistic scenario estimates are 19.3 million 1 m^3 biogas plants, 6 million 2 m^3 biogas plants and 4 million 3 m^3 biogas plants totalling to about 29.3 million biogas plants capable of producing about 43.4 million m^3 biogas everyday. In both the scenarios the potential number of 1 m^3 biogas plants is far larger than the combined potential 2 and 3 m^3 biogas plants. With a properly maintained 1 m^3 biogas plant it may be possible to meet a major fraction of the domestic cooking requirement of a family of three to four adult members during most of the year. Efforts may therefore be made to encourage development and dissemination of low cost 1 m^3 biogas plants with minimum maintenance requirements. It may be noted that in the realistic scenario, the potential number of

Table 4
Estimated potential of household biogas plants in India

S. No.	States	Potential number of biogas plants (rounded to nearest thousands)					
		Optimistic Scenario			Realistic Scenario		
		1 m^3	2 m^3	3 m^3	1 m^3	2 m^3	3 m^3
1.	Andhra Pradesh	1446	929	620	1446	413	413
2.	Assam	639	437	202	774	168	101
3.	Bihar	1826	852	365	1583	365	122
4.	Gujarat	961	673	288	1009	288	144
5.	Haryana	452	339	188	489	169	94
6.	Himachal Pradesh	224	232	129	310	121	60
7.	Karnataka	944	722	444	999	333	278
8.	Kerala	328	103	21	213	25	8
9.	Madhya Pradesh	1521	1431	1610	1878	984	984
10.	Maharashtra	1204	926	648	1296	556	370
11.	Orissa	827	517	310	879	258	155
12.	Punjab	495	424	306	542	236	165
13.	Rajasthan	1171	948	780	1895	557	446
14.	Tamilnadu	928	506	337	928	253	169
15.	Uttar Pradesh	4326	2343	721	3785	901	360
16.	West Bengal	1247	713	446	1247	356	178
	Total	18537	12095	7416	19273	5984	4048

2 and 3 m^3 biogas plants has reduced considerably, whereas the potential number of 1 m^3 biogas plants has increased as compared to the corresponding figures in the optimistic scenario. This is primarily due to the fact that in the realistic scenario many of the households qualifying for the installation of a 2 m^3 biogas plant in the optimistic scenario can only justify to install a 1 m^3 biogas plant in realistic scenario. Thus, a large number of households falling under the category of 2 m^3 biogas plants in the optimistic scenario move over to the category of 1 m^3 biogas plants in the realistic scenario.

The cumulative number of total biogas plants installed as per the latest annual report of Ministry of Non-Conventional Energy Sources (MNES) was 2.93 million in December 1999 [4] which is about 10% of the total estimated potential in realistic scenario (based on 1991 data on bovine population). It is therefore critically important to identify all important barriers to the dissemination of household biogas technology in India and accordingly take appropriate policy measures for realization of the actual potential.

The estimated potential number of improved cookstoves is 90 millions (Table 5) against a total cumulative installed number of 29.3 million by the end of December 1999 [4]. Estimation of the potential of using box type solar cookers for supplementing existing options for domestic cooking can be made on the basis of Eq. (1). Authentic data for deduction of some of the parameters (f_{4r}, f_{4u} and f_{5u}) not being available and even other parameters likely to be affected by the inherent dynamics

Table 5
Potential of using improved biomass cookstoves for domestic cooking in India

S. No.	Fuel	Annual amount used for cooking (million tonne oil equivalent)	Number of users (million)
1.	Kerosene	3.21	13.94
2.	Softcoke	0.30	0.29
3.	Natural Gas	0.10	0.48
		Total	14.71
Number of LPG users [5,6]			18.00
Potential number of biogas users			29.30
Total number of households in the country (1991 census)			152.01
Potential number of improved biomass cookstove users in India =152.01 -(14.71+18.00+29.30)=90.00 million			

of demographics, the results for the case of solar cookers are presented in the form of two nomographs (Fig. 2(a) and (b)). The nomograph in Fig. 2(a) can be used to determine the number of total households in urban areas (as a fraction of total households) who can use box type solar cookers. The potential users of box type solar cookers in rural areas (again as a fraction of total households) can be estimated from the nomograph presented in Fig. 2(b) which also combines the results of

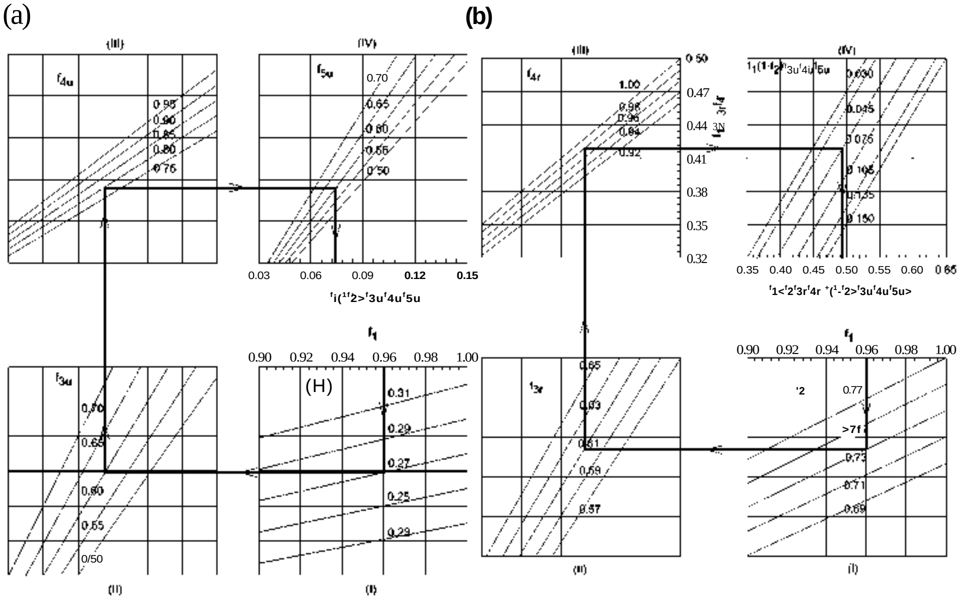

Fig. 2. (a) Nomograph for estimating the fraction of households that can use box type solar cookers in urban areas of India. (b) Nomograph for estimating the fraction of households that can use box type solar cookers in rural India along with the combined potential.

Fig. 2(a) to provide the overall potential estimates for box type solar cooker users. The procedure of using the nomographs is illustrated in Fig. 2 (a) and (b) in dark line with arrows for a typical base case for India. Using the available solar radiation data [9], the value of f_1 is estimated at 0.96. As per the 1991 census of India the fraction of total population living in rural area (f_2) is 0.73 [11]. The Task Force on Projection of Minimum Needs and Effective Consumption Demand [12] in 1979 has defined the poverty line as per capita monthly expenditure needed to obtain the consumption basket corresponding to the calorie norms of 2400 per capita per day in rural areas and 2100 per capita per day in urban areas in the base year 1973-1974. The poverty line so defined was Rs 49.10 for rural areas and Rs 56.00 for urban areas. The same poverty line was updated for subsequent years using suitable indicators of change in cost of living. The Expert Group constituted by Planning Commission in 1989 suggested the use of state specific price indices, which can reflect the changes in cost of consumption basket of the people around the poverty line. As there is no data available on the population above poverty line in 1991, the figure available for 1987-1988 has been used. The fraction of households above the poverty line as arrived by Expert Group is 0.61 for rural areas ($f_{3r}=0.61$) and 0.60 for urban areas ($f_{3u}=0.60$) respectively [12]. It is assumed that only 2% households in rural areas will not have an adult member to attend the box type solar cooker during the day ($f4_r$=0.98), whereas, for urban areas 20% of households will not be able to use solar cooker due to all working adult members in the family (f4u=0.80). Finally, it is also assumed that in urban areas about 40% households living in multi-storey buildings may not have access to solar radiation (i.e. f_{5u}=0.60).

The dark lines shown with arrows in Fig. 2(a) correspond to the relevant values described above. From plot IV of Fig. 2(a) it may be noted that about 7.5% of the total households in the country can use box type solar cookers in urban areas. With 1991 census data that translates to a total of 11.4 million households. Similarly from plot III of Fig. 2(b), it is noted that about 42% of total households in the country are potential users of box type solar cooker in rural areas with the corresponding number of households being as 63.8 million as per 1991 census data. The overall potential, as may seen from plot IV of Fig. 2(b), is estimated at about 49.5% of the total number of households in the country i.e. about 75.2 million households.

The number of solar cookers reportedly disseminated till December 1999 is merely 0.48 million [4] which is far less than the estimated potential of box type solar cooker use in the country. A variety of reasons may be attributed to the poor dissemination of solar cooker in the country [16]. Moreover, the estimate of 75.2 million households is based on the assumption that even though the box type solar cooker may not meet the entire cooking energy requirement, yet the households will be motivated to make its use for supplementing other existing cooking options. It may take considerable period of time for the common households in the country to actually adopt such a practice. Detailed techno-socio-economic evaluation of existing or other promising solar cooker designs be made to: (i) develop technologically appropriate and socially acceptable design(s) and (ii) formulate and implement suitable promotional strategies to make the solar cookers financially viable to the majority of households in the country.

In an attempt towards studying the sensitivity of the estimated potential of box type solar cooker users, to different parameters used in Eq. (1), expressions for the percentage change in the estimated potential due to 1% change in the input parameter(s) are presented in Table 6. Numerical values of the corresponding results as obtained for the chosen set of base values of input parameters specified in Table 3 are also given in Table 6. It may be noted that the estimated potential of box type solar cooker use is quite sensitive to the value of (f1), since the potential number changes by the same fraction as the uncertainty in f_1. Next to f1 the fraction of households above poverty line (f_{3r}) and the fraction of households with at least one adult member at home during the daytime (f_{4r}) in the rural areas of the country affect the potential estimates. The other factors, i.e. fraction of rural households (f_2), fraction of households above the poverty line in areas (f_{3u}), fraction of households having at least one adult member to attend the solar cooker during the daytime in urban areas (f_{4u}) and fraction of households in urban areas having access to solar radiation (f_{5u}) have a rather moderate effect on the total potential of solar cooker use in the country.

Table 6
Expressions for the sensitivity analysis of the potential number of solar cooker users

Variable		Percentage change in the estimated potential (P_{sc}) due to 1% change in the input variable	Numerical value (%) for base values of input parameters
Symbol	Description		
f1	Fraction of households having adequate sunshine	1	1
f2	Fraction of rural households in total population	$\left[1+\frac{f_{3u}f_{4u}f_{5u}}{f_2(f_{3r}f_{4r}-f_{3u}f_{4u}f_{5u})}\right]^{-1}$	0.44
A	Fraction of households above the poverty line in rural area	$\left[1+\frac{(1-f_2)f_{3u}f_{4u}f_{5u}}{MA}\right]^{-1}$	0.85
A	Fraction of households above the poverty line in urban area	$\left[1+\frac{M.A}{(1-/2/3/4/5u}\right]^{-1}$	0.15
A	Fraction of households having at least one adult member to attend the solar cooker during the daytime in rural area	$\left[1+\frac{(1-f_2)f_{3u}f_{4u}f\ .}{(\quad 1\ *}\right]^{-1}$	0.85
/*,	Fraction of households having at least one adult member to attend the solar cooker during the daytime in urban area	$\left[1+\frac{MA}{(1-/2/3/4/5,_1}\right]^{-1}$	0.15
/*,	Fraction of households in urban area having access to solar radiation	$\left[1+\frac{MA}{(I-////,_1}\right]^{-1}$	0.15

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