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End use efficiencies in the domestic sector of Uttara Kannada District

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Abstract

End use efficiency experiments conducted in some households of Masur village (based on 4 days experiment) of Kumta taluk show that there is scope for saving 27–42% of energy by switching to improved devices, which are designed to maximise combustion rate (of fuel, ensuring the presence of sufficient oxygen), radiant heat transfer (from fire to vessels, keeping them as close to fire as possible), convection (to pass maximum hot gas over vessels, reducing drafts), conduction (heat is concentrated near the vessels by using insulating material for the stove) and user satisfaction (with user friendly design). The thermal performances of improved stoves designed at our Institute (ASTRA) have also been studied in the field. Irrespective of type of fuel, community, etc., improved stoves show significant saving in fuel. By switching to energy efficient devices 450,548 to 700,853 tonnes of fuel wood can be saved per year in the district.

Keywords: End use efficiency; Traditional cookstoves (TCs); Improved cookstoves (ICs); Education; Domestic energy; Adult equivalent

1. Introduction

Sustainable development of a region depends critically on the health of renewable resources such as soil, water, vegetation, livestock and genetic diversity. The integrated development of

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all these components is essential for environmentally sound development. This necessitates promotion of conservation activities among local communities and application of traditional environmentally sound technologies.

Primary energy demand can be reduced substantially, while maintaining a given level of energy services, through higher end use, transport and conversion efficiencies. Surveys conducted in the villages of Kumta, Sirsi, Siddapur, Mundgod and Ankola taluks show that bioresources represent about 82–88% of the energy supply. This extensive use of biofuels has resulted in serious deforestation, contributing to detrimental impacts on the environment. As the quantity and quality of forest and water resources decline, women and children spend more time in fuel and water collection. The severity of the energy crisis is quite evident in densely populated taluks, viz., Kumta, Ankola, etc., along the coastal belt. Most households still use three stone fire or home made mud stoves without proper combustion and heat transfer facilities. With deforestation, evident from barren hill tops, women and children have to walk 5–10 km every day to fetch fuel wood. Raising the efficiency of household fuel usage increases the available energy for basic needs in poor households, reduces women's workload in fuel collection and its use and releases time for more productive work. Hence, improving the efficiencies of traditional cookstoves (TCs) has attracted a lot of attention in energy programmes. As a response to these multiple problems, the Ministry of Non-Conventional Energy Resources, Government of India, initiated the national programme on improved cookstoves (ICs) with the following objectives: (i) conserve and optimise the use of fuel wood in rural areas, arresting the rate of resource degradation and eliminating the drudgery of women (removal of smoke in the kitchen, improvement in hygiene, etc.), (ii) provide employment to rural youth in construction and dissemination of stoves and (iii) accelerate research and development activities to improve the models and propagate new devices.

In this paper, household energy consumption patterns in five taluks of this district of Western Ghats, based on detailed field work for 18 months, and strategies to minimise the potentially negative impacts of energy systems on natural and human systems are discussed.

2. Objectives

1. Measure and estimate the daily per capita fuel wood consumption in traditional and improved stoves for cooking and water heating.
2. Determine the extent of use of ICs.
3. Determine the factors influencing acceptability of improved stoves.
4. Study the extent of fuel saved using alternate devices.

3. Methodology

A few households were selected from the Kumta and Sirsi taluks to conduct detailed cooking and water heating experiments (based on actual measurements of daily consumption — input/output measurements) in order to see the role of end use technologies on the variation in consumption patterns. These studies were conducted in the hamlets

- Sankuli, Masur, Halasmavu, Kalbavi and Hoskeri of Masur village in the Kumta taluk, and
- Sirsimakki, Vadgeri, Bellikeri and Mundgesara-Abrimane in the Sirsimakki-Mundgesara microcatchment, located in the Aghnashini basin of the Ghats, east of the crestline.

In order to assess the quantity and type of fuel and cooking devices used, a questionnaire based survey of the stratified random sample of 118 households from 6 hamlets of Masur village and 23 households from the Sirsimakki-Mundgesara catchment was conducted. Data pertaining to (a) type of stoves, (b) type of fuel — agricultural residues, etc., (c) mode of fuel collection/procurement, (d) cooking time and (e) cooking energy requirement was collected.

In order to measure fuel consumption (per day per household), the actual quantity of fuel required for a day's cooking was weighed beforehand (W1) and the leftover fuel was weighed (W2) next day using a single pan balance of 50 g accuracy. The difference in W1 and W2 would give the fuel consumption value. This experiment was conducted in sample households for 4 consecutive days to account for changes in quantity and type of food cooked.

The stratified random sampling technique, based on landholding categories, was adopted to give an insight into the inter-relationship among households and the use of non-conventional sources of energy (fuel wood, agricultural residues, biogas, etc.). Data collection was done with emphasis on:

- consistent measurement of consumption of different energy sources,
- accounting for different kinds of fuels—twigs, branches, logs, etc.,
- proper classification as fuel, fodder and building materials according to end use,
- time spent collecting fuels by human labour and
- efficiency measurement of different end use devices.

Similar experiments were conducted in all 82 households in the Sirsimakki-Mundgesara catchment and 22 households surrounding it, to find the fuel consumption for water heating.

3.1. Types of stoves

3.1.1. Conventional wood burning stoves (traditional stoves)

The size of stoves differed, depending on the number of persons per household. These stone and mud stoves are without proper air inlet and outlet systems. The three stone stove used in landless labour class households is the least efficient. Fuel efficiency studies revealed a low efficiency of 11% in these stoves.

3.1.2. Fuel efficient stoves (improved stoves)

Fuel efficient stoves, popularly known as ASTRA stoves, designed at our Institute, are characterised by complete fuel combustion with as little excess air as practicable to generate the highest temperature of flue gases [1]. This is achieved by combustion of fuel over a grate in an enclosed fuel box with ports of suitable size for entry of air. The grate helps in the entry of primary air below the fuel bed to burn the char and separate the ash. The air required for burning the volatile matter released as a consequence of fuel heating, called the secondary air, enters through a port at a level slightly above the grate. After generating the highest temperature of the flue gases, heat gets transferred by the mechanisms of conduction, convection and radiation for useful work, that is to the vessels. To reduce the transfer of heat to the walls of the stove, an inner lining of mud mortar with rice husk is provided, which gives a higher thermal insulation. A chimney of suitable height and diameter helps to create draught and disperse smoke away from the cooking zone. The efficiencies of these stoves are in the range of 32–41%.

3.2. Diffusion of stoves among the population

The exploratory survey revealed the per capita fuel wood consumption in this locality to be quite high, in the range of 2.5–4.25 kg/day, of which 1.26 kgs was used for water heating and 1.92 kgs for cooking. This requirement is met by minor forests, leaf forests (*soppinabettas*) and partly by areca and coconut residues. In order to reduce fuel wood consumption and, hence, pressure on forests, dissemination of fuel efficient stoves for cooking and water heating was undertaken by CES (Centre for Ecological Sciences) under an ecodevelopment programme which was done after consultations with the villagers and local NGOs (Non-Governmental Organisations). A few youths were trained to build stoves, taking into account the kind of vessel, etc., suitable for local requirements. This has also generated local employment in a limited sense, as some of the skilled masons have undertaken construction of fuel efficient stoves as a profession.

4. Study area

The study was performed in the following villages:

1. Masur village: Located at 14°28′ N lat. 74°23′ E long., 4 km from Kumta town, it is a cluster of 9 hamlets on an island in the estuary of river Aghnashini. This island is on a hillock, at an altitude of 75 m, surrounded by brackish water on all sides. The soil is lateritic, acidic and reddish brown in colour. The mean annual precipitation is 3200 mm, mainly from May to November [2]. The total area is 358.3 ha with minor forest for 103.0 ha, private grasslands 23.4 ha, upland paddy cultivation 22.3 ha, coconut groves 2.2 ha, freshwater paddy cultivation 55.3 ha, areca 2.0 ha, brackish water paddy field 87.6 ha and river course 62.5 ha [3]. This region has a population density of 949 per km^2 with 15 endogamous communities, the major ones being Patgars, Halakki Goudas, Havyak Brahmins, Ambigas and Madivals. The average landholding per family is 0.5 ha, and there are about 86 landless families.
2. Sirsimakki-Mundgesara: This study was conducted in the hamlets of Sirsimakki, Vadgeri, Bellikeri, Mundgesara-Abrimane in the Sirsimakki-Mundgesara microcatchment, located in the Aghnashini basin of the Ghats, east of the crestline, 5 km from Sirsi town and bounded on either side by the Sirsi-Kumta and Sirsi-Siddapur roads. It is at 14°35′ N lat. and 74°48′ E long., with an altitude ranging from 545 to 618 m spread over an area of 386.5 ha, of which 324.5 ha are hills. The whole terrain is greatly undulating with 26 peaks, with a mean

annual precipitation of 2600–3000 mm, mainly between June and October. Eighty-two households (with 661 people) are clustered in these hamlets with 316 males and 345 females. There are 105 children in the age group of 0–6 years. The major communities are (1) Havyak Brahmins (65 households—mostly arecanut land holders), (2) Goudas (8 households) and (3) Others (Naik—1, Devadiga—3, Adidravida—2, Shet—1, Uppar—1 and Poojari—1).

5. Methodology

5.1. Computation of PCFC

PCFC = FC/p, where FC = fuel consumed in kg/day and p = number of adult equivalents for whom food was cooked.

Computation of PCFC considering the following:

1. More than one type of fuel is used for cooking and water heating in any household. The quantity of fuel consumed is determined by subtracting the weight of the remaining fuel from its initial weight. The daily consumption of different fuels is calculated separately from the fuel weights of the consecutive days.
2. These daily consumption values in each household are converted to their equivalent dry weights using the measured moisture content values and then converted into equivalent value using the net calorific value of each type of residue. These are added to get the daily energy consumption for the households.
3. The daily energy consumption of each household is further converted to per adult energy consumption using the adult equivalent of the number of people, which is computed assuming the conversion factors listed below:

Standard adult equivalents used in analysis;

Family size	Standard adult equivalent
Men 18–59 yr	1.0
Women 18–59 yr	0.8
Men > 59 yr	0.8
Women > 59 yr	0.8
Boys 5–18 yr	0.5
Girls 5–18 yr	0.5
Kids 1–5 yr	0.35
Child < 1 yr	0.25

(iv) For each family, the daily per adult energy consumption is computed seasonwise. The average value, standard deviation, maximum and minimum values are computed for annual and seasonal consumption.

Table 1
Thermal efficiency and quantity of wood required (in kg) for heating 50 litres of water

Sampled household number	Time (min)	Burning rate of wood (kg/h)	Heat utilised (kcal)	Thermal efficiency	Quantity of wood required
1	27.69	2.50	921.0	19.34	1.15
2	13.20	5.09	1609.0	19.96	1.12
3	29.25	2.35	1656.0	19.54	1.14
4	16.05	3.12	1430.0	26.77	0.83
5	26.23	2.35	1458.0	21.77	1.02
6	15.76	2.59	1725.0	32.79	0.68
7	16.49	2.89	1135.0	28.06	0.79
8	27.04	2.64	1100.0	18.77	1.19
9	28.09	2.28	907.5	20.90	1.07
10	13.44	3.24	1771.0	30.80	0.72
11	12.25	3.16	2845.0	34.60	0.64
12	15.50	3.65	1919.0	23.66	0.94
13	28.00	2.66	1040.0	22.88	1.02
14	28.00	3.47	1140.0	17.35	1.21
15	35.00	2.91	1131.0	20.69	1.09
Avg.		2.99		23.86	
SD		0.69		5.21	

(v) Data is grouped based on household income, landholding, community and village separately. All the above parameters were computed for these groups.

6. Results and discussion

6.1. Efficiency measurements of end use devices

In order to take into account the efficiency of end use devices (for cooking and water heating) and day to day fluctuations in fuel consumption, detailed efficiency experiments were conducted in a few households located in Masur village. It is noticed that a considerable quantity of fuel wood could be saved by using an improved design. In this regard, the factors responsible for the adoption of energy efficient devices were studied.

6.2. Efficiency measurement of water heating stoves

The efficiency of water heating stoves in bathrooms is determined by water heating tests. The heat gained by 50 litres of water, heated from 27 to 44°C, is measured by burning a weighed quantity of wood, found to be 0.64–1.15 kg. The thermal efficiency of fuel efficient stoves is in the range $23.86 \pm 5.21\%$ (average efficiency: 23.86%, standard deviation: 5.21), while for traditional stoves, it is $7.89 \pm 3.22\%$ (average efficiency: 7.89%, SD: 3.22%). The results of fuel efficient stoves are listed in Table 1.

6.3. Fuel consumption pattern in cookstoves

In order to assess the quantity and type of fuel and the types of cooking devices used, a questionnaire survey, based on actual measurements, was conducted in the stratified random sample of 118 households in 6 hamlets of Masur village. The actual quantity of fuel required for a day's cooking was weighed beforehand, and the fuel leftover was weighed the next day using a single pan balance of 50 g accuracy. This experiment was conducted for 4 consecutive days (thus collecting 3 days cooking data) in order to account for the day to day change in type of food, quantity, etc. The cooking fuel needed in improved cookstoves (sample size 20) is 0.835 ± 0.225 (average value: 0.835, standard deviation: 0.225) and traditional stoves (sample size 98) is 1.151 ± 0.65 (average value: 1.151, standard deviation: 0.65) kg/person/day. This means that there is a 27.45% saving in fuel wood consumption by switching to fuel efficient cookstoves.

6.4. User reaction to improved cooking stoves

In order to assess the user's perception of energy efficient improved stoves, the survey and subsequent analyses reveal that:

1. Two-pan ICs were preferred by 65.2% of the households comprised of the Patgar, Naik, Halakki Gouda and Ambiga communities, while 34.8% preferred three-pan stoves (majority are Havyak Brahmins, Gouda Saraswat Brahmins and Deshbhandaris).
2. 31.25% of the households complained about a space problem in switching to ICs.
3. 46.87% of the households preferred traditional 3 stone stoves, despite the lack of energy efficiency, because of the needs of space heating, protection from insects provided by smoke and flexibility for using a variety of fuels (type and size) in different seasons.
4. Out of 92 stoves constructed by various agencies, the share of the Block Development Office is 73.91% (68) and CES 26.09% (24). It is found that 92% have modified the design to suit their vessels and cooking needs.
5. 8–10% of the households having thatched roofs expressed their fear of fire hazard due to the presence of the chimney in the ICs. During its usage, unburned particles often settle on the inside of the chimney due to the difficulty in maintenance and poor durability. These particles are highly flammable and often pose a fire hazard.

6.5. Comparison of fuel consumption in ICs and TCs

The average daily consumption of fuel wood in ICs is 0.835 kg/person, while in traditional cookstoves, it is 1.151 kg/person. A 27.45% reduction in fuel wood consumption is seen by switching to ICs. For statistically comparing sets of measurements for the ICs and TCs, the *t*-test was performed. The "*t*" value is computed by [4],

$$t = \frac{X_{\mathrm{TC}} - X_{\mathrm{IC}}}{\left[\frac{S_{\mathrm{TC}}^2}{n_{\mathrm{TC}}} + \frac{S_{\mathrm{IC}}^2}{n_{\mathrm{IC}}}\right]^{1/2}}$$

where X_{IC}, S_{IC}, n_{IC} are the mean, standard deviation and number of households for improved cookstoves, while X_{TC}, S_{TC}, n_{TC} represent the same for traditional cookstoves. The computed t value is compared to values in the student *t*-table to determine if the mean of one group is significantly greater than the mean of the other.

The *t*-table is used by comparing the calculated *t*-value to the numbers in the table at the appropriate degrees of freedom. It can be said that the mean from one group of tests is greater than the mean from the other, at a certain level of significance, if the computed *t*-value is greater than the number in the table at that level.

The t value computed for data from 20 households using ICs and 98 households using TCs is 3.79. There are 116 degrees of freedom (since 118 experiments were conducted) and two parameters (the mean for each group). Based on entries in the *t*-table at 116 degrees of freedom, the *t*-value is found to be greater than the number in the table at the level of significance of 0.5%. Thus, this test further confirms that households using ICs have a higher probability of saving fuel compared to those using TCs.

Confidence limits for the difference between means: The 95% confidence interval for the difference in means is computed by

$$X_{tc} - X_{ic} \pm t_{0.5(2),\ v} S_{Xtc-Xic} = (1.15 - 0.835) + (1.981) * (0.0829) = 0.4792$$

$$= (1.15 - 0.835) - (1.981) * (0.0829) = 0.1507.$$

At the 95% confidence interval, the difference in fuel consumption in households using traditional stoves and improved stoves is not lower than 0.1507 (or the probability of this difference being less than 0.1507 is 0.025).

6.6. Communitywise fuel wood consumption

In order to examine the variation in consumption pattern, if any, the data is further analysed based on community, number of persons in each house and type of fuel used. Table 2 lists communitywise fuel wood consumption. Only four communities use ICs in these villages.

1. The average fuel consumption in the Patgar community using ICs is 0.818 (SD = 0.258) and TCs is 1.066 (SD = 0.528) kg/person/day, showing a saving of 23.18% in fuel consumption. The *t*-value computed with data of the 14 Patgar households using ICs and the 52 using TCs is 2.46. From the *t*-table for 64 degrees of freedom, the computed *t*-value is greater than the number in the table at the level of significance of 1% but less than that of 0.5%. The change in average values for ICs and TCs and the lower mean for ICs illustrates the scope for fuel saving.

Table 2
Fuel wood consumption using TCs and ICs (Community-wise)

Community type	No. of households	Fuel consumption (kg/person/day)	
		Avg	SD
(a) Improved cook stoves (ICs)			
GOU	3	0.907	0.145
HB	1	0.846	
Naik	2	0.877	0.017
Patgar	14	0.818	0.258
Total	20		
(b) Traditional cook stoves (TCs)			
Ambiga	3	1.061	0.407
HB	9	1.355	0.523
Deshbhandari	2	1.231	0.053
GOU	15	1.137	0.483
Gunaga	4	0.955	1.346
Kodeya	2	1.453	0.216
Madival	2	1.085	0.207
Mukri	1	0.950	
Naik	5	0.908	0.358
GSB	3	1.377	0.358
Patgar	52	1.066	0.528
Total	98		

2. The average fuel wood consumption among Halakki Goudas (GOU) using TCs is 1.137 and ICs is 0.907 kg. The t-value computed for the data collected from the 3 households using ICs and 15 households using TCs is 1.53. For the degrees of freedom of 16, the computed t-value is greater than the t-table value at the level of significance of 10%, but less at 5%.

This series of statistical tests for various communities further illustrates the scope for saving fuel wood using ICs. The communitywise fuel wood saving by switching to ICs is 20.25% for Halakki Goudas, 23.18% for Patgars and 37.52% for Brahmins.

6.7. Number of persons per household

A scatter plot of per unit fuel consumption versus number of persons per household shows a declining trend for both households using TCs and ICs with an increase in the number of persons per household. A regression analysis of 3 days cooking data from 98 households using TCs and 20 households using ICs is performed. Based on the correlation coefficient and low percentage error, the linear relationship among the variables PCFC (per capita fuel consumption) and NOP (number of persons per household) per day is found to be the best relationship.

The relationship for households using ICs is

$$(\mathrm{PCFC})_{\mathrm{IC}} = 0.9368 - 0.012\ (\mathrm{NOP}),$$

with $R^2 = 0.442$, $R = 0.665$, % error of Y estimate = 13.42 and $n = 60$ (20 households data for 3 days). A plot of PCFC vs NOP revealed scatter, which could be removed by filtering.

With partial removal of scatter (removing scatter points beyond the range of [avg $\pm$ SD]),

$$(\mathrm{PCFC})_{\mathrm{IC}} = 0.8416 - 0.0106\ (\mathrm{NOP}),$$

with $R^2 = 0.542$, $R = 0.735$ and % error of Y estimate = 9.42.

For TCs,

$$(\mathrm{PCFC})_{\mathrm{TC}} = 1.615 - 0.065\ (\mathrm{NOP}),$$

with $R^2 = 0.516$, $R = 0.72$ and $n = 296$ (98 households data for 3 days) and % error of Y estimate = 8.68.

With partial removal of the scatter

$$(\mathrm{PCFC})_{\mathrm{TC}} = 1.590 - 0.0560\ (\mathrm{NOP}),$$

with $R^2 = 0.594$, $R = 0.77$ and % error of Y estimate = 6.67.

These results reveal that the per capita fuel consumption decreases both in TCs and ICs while cooking for a large number of persons. This decrease is due to the co-efficiencies of cooking and water heating that result from increasing their scales. Hence, proper design of stoves and size of vessels, taking into consideration the number of persons in a household, are the essential factors reducing fuel wood consumption. Table 3 lists the fuel consumption in ICs and TCs based on the number of persons per household. It is seen that for most of the categories, fuel consumption in ICs is lower than in TCs. For example, for a household of 4 persons, fuel consumption in the TC is 1.095 and in the IC is 0.967 kg/person/day. This study is performed to understand the impact of large and small families on fuel wood consumption.

6.8. Type of fuel used

Table 4 lists the type of fuel consumption in ICs and TCs, where ICs use fuel better than TCs. The difference in the level of fuel consumption is evident in households using species like *Terminalia paniculata* (TC = 1.093; IC = 0.765) and *Memecylon umbellatum* (TC = 1.231; IC = 0.786). It is evident from these results that fuel consumption is significantly lower in ICs

Table 3
Fuel consumption (in kg/person/day) based on number of persons per household

No. of persons per household	No. of households	Fuel consumption (kg/person/day)	
		Avg	SD
(a) Improved cook stoves (ICs)			
15	1	0.473	
14	1	0.757	
12	2	0.852	0.233
9	4	0.84	0.079
8	2	0.775	0.084
7	4	0.727	0.18
6	2	0.948	0.101
5	3	1.122	0.083
4	1	0.967	
Total	20		
(b) Traditional cook stoves (TCs)			
30	1	0.437	
20	1	0.977	
17	1	0.515	
16	1	0.837	
15	1	0.415	
14	1	0.507	
13	1	0.692	
12	5	0.858	0.139
11	2	0.550	0.182
10	3	1.150	0.420
9	7	0.931	0.232
8	6	0.822	0.204
7	13	1.104	0.514
6	20	1.083	0.292
5	15	1.191	0.453
4	7	1.095	0.406
3	7	2.175	1.500
2	5	2.076	0.623
1	1	1.850	
Total	98		

Table 4
Fuel consumption (based on type of fuel wood) in kg/person/day

Species	No. of households	Fuel consumption (kg/person/day)	
		Avg	SD
(a) Improved cook stoves (ICs)			
Acacia auriculiformis	1	0.690	
Cinnamomum zeylanicum	1	0.846	
Artocarpus integrifolia	1	0.847	
Memecylon umbellatum	4	0.786	0.119
Terminalia paniculata	5	0.765	0.200
Eugenia jambolana	3	0.896	0.336
Terminalia spp	2	1.021	0.264
Aporosa lindleyana	3	1.139	0.225
Total	20		
(b) Traditional cook stoves (TCs)			
Acacia auriculiformis	2	0.517	0.101
Spondias mangifera	1	1.355	
Areca catechu	1	1.661	
Caryota urens	6	0.930	0.232
Cocus nucifera	3	1.715	0.630
Cinnamomum zeylanicum	1	0.920	
Anacardium occidentale	3	0.942	0.261
Memecylon umbellatum	12	1.231	0.764
Terminalia paniculata	23	1.093	0.471
Pterocarpus marsupium	1	1.384	
Terminalia spp	13	0.985	0.271
Xylia xylocarpa	1	0.988	
Dillenia pentagyna	1	0.904	
Careya arborea	1	2.550	
Mappia oblonga	1	0.608	
Careya arborea	1	0.722	0.227
Mangifera indica	9	1.170	0.389
Eugenia jambolana	14	1.503	1.120
Ochrocarpos longifolius	2	0.709	0.076
Cocus nucifera	2	0.892	0.165
Total	98		

compared to TCs, irrespective of the various parameters such as (a) community, (b) number of persons per household and (c) type of fuel used.

7. Conclusions

Fuel efficiency studies reveal that there is scope for saving 27.45 to 42% of fuel wood by switching to improved stoves. The specific consumption of biomass fuels, used in the domestic sector in most of the villages of Kumta taluk, is quite high. Considering the low efficiency of devices at present, there is scope for improvement. In our sample of 1304 households, only 22 use improved stoves. Lack of knowledge, proper training and service backup facilities are the main contributing factors for not adopting efficient devices. By switching to energy efficient devices, such as ASTRA stoves, the saving of fuel wood in the domestic sector would be 450,548 to 700,853 tonnes per year.

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