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Impact of time expenditure on household preferences for cooking fuels

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ABSTRACT

Access to energy for cooking is one of the major challenges that rural India faces. Most of the rural households of North-Eastern India rely heavily upon fuelwood and traditional open-fire cookstoves for cooking activities. And everyday collection of fuelwood is time-consuming. Hence, women often gather fuelwood to make charcoal. While the use of charcoal has some advantages, it is not clear whether the investment of time in making charcoal is worthwhile. In this paper, we compare household time investments for fuelwood and charcoal production. The study is done using survey data on Napaam village situated in Sonitpur District of Assam, Northeast India. We developed a model to analyse fuelwood needed and time spent upon the introduction of improved cookstoves and/or charcoal production. This analysis reveals that improved cookstoves using fuelwood results in the least time expenditure on the production of cooking fuel. Whilst introducing charcoal marginally reduces the amount of fuelwood, but increases time spent on cooking, due to the time required to produce the charcoal. Hence, rural households who make their own charcoal spend more time on producing cooking fuel than those households relying on direct use of fuelwood.

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1. Introduction

Energy access is one of the basic issues of rural areas and is a key to socio-economic progress for developing nations. In rural areas it is not always possible to secure a continuous supply of energy where often there is no connection to a central grid. In most of the developing countries, bioenergy serves as the primary fuel for rural people [1]. In fact, bioenergy can provide independent and decentralized energy in rural areas [2–4].

Fuelwood is the most vital source of bioenergy, providing 9% of the global primary energy supply [5,6]. It is an essential energy source for cooking, for water and space heating, for cooking feed for livestock and for rice beer preparation in rural areas [7]. However, there are also several disadvantages to the use of fuelwood. First, the growing use of fuelwood leads to deforestation. Furthermore, for rural households, precious time is lost in the collection of fuelwood, thereby reducing time for other productive work which might help to increase their financial resources [8–12]. Yet, it can

be difficult to secure an adequate supply of fuelwood [13–15]. It is estimated that about 20% of the time per day is spent for the collection of fuelwood alone [16]. There is a steady growth of fuelwood consumption, though the growth has been slow in recent years [17].

Dependence on fuelwood often leads to drudgery for women and children and as a result prevents women from engaging in income-generating activities [18]. Therefore, various programs have been implemented to reduce biomass consumption by introducing efficient cookstoves and improved technologies to produce cooking fuel [19–22]. Several studies have investigated the energy transition of cooking fuels and time investment on fuelwood collection, focusing on financial, behavioral or technological aspects [23,24]. In general, these studies conclude that transition fuels like charcoal and briquette are more efficient and favorable choice for a cooking fuel. However, these studies were based on commercially available cooking fuels, which is not relevant for many rural households. If a household has to make their own cooking fuel, as in case of rural areas, the time spent on making cooking fuel i.e. charcoal must be taken into account. These studies confirm that there are significant amount of various cooking fuel

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available in rural areas. But, there is an ongoing dilemma among rural households on the preference of cooking fuel [25] and it depends on many factors. Thus, in this paper, we analyse the time factor involved in the production of cooking fuel. Therefore this paper only analyzes a single dimension of the ongoing dilemma among rural households on the choice of cooking fuel.

In this paper, we investigate the use of cooking fuel, i.e. fuelwood and self-made charcoal. First, we develop a hypothetical model of alternative cooking energy systems. Secondly, we report survey data on the village of Napaam to determine household-cooking energy needs and time spent on fuelwood collection. Finally, we study the time demand for fuel production with several different combinations of cookstove and cooking fuel.

2. Energy situation in India

It is estimated that about 40% of the total direct, commercial and non-commercial energy use in India is in the household sector [26]. In rural areas, cooking dominates most of the energy consumption [22]. According to recent figures from the National Sample Survey (NSS) [27], this cooking energy demand is met mostly by unprocessed biomass fuels (88.4%) viz., fuel wood, agricultural crop residues, dung cakes, etc. In India, almost 85% of rural households are still dependent upon firewood, crop residues or cow dung as their primary source of fuel for cooking [4,28]. Fig. 1 shows that Indian households in rural areas rely heavily on fuelwood, whereas urban consumers depend on electricity and LPG. There is a vast gap in energy use between rural and urban areas of India; in rural areas fuelwood is in high demand, whereas in urban areas electricity is mostly used.

While India has recently launched the National Biomass Cookstoves Initiatives (NCI) to develop new cookstoves and replace old traditional cookstoves [28], it appears that the use of transition fuels (charcoal, kerosene, and coal) is almost non-existent in rural areas.

The percentage of households depending on firewood and wood-chips for cooking exceeded 70% in rural areas in all major states except Punjab and Haryana [4]. Fig. 2 illustrates that fuelwood alone constitutes some 76% of primary energy in rural India.

2.1. Energy situation in Assam

Assam is situated in the North-Eastern part of India. It is predominantly rural and the economy primarily agrarian in nature, with almost 70% of the population directly dependent on agriculture as a source of income and another 15% of the population dependent on allied activities for their living [30]. Some 35% of the geographical area is covered by forest, but these are degrading at a very high rate. Some of the important forest products are industrial wood, fuelwood, bamboo and cane, which contribute to the

Fig. 2. Percentage distribution of households by primary source of energy used for cooking in rural India, 2009–2010 [27].

Fig. 3. Bottom 5-states using fuelwood or woodchips for cooking in Rural India, 2012 [27].

economy of the state also [31]. According to the Ministry of Statistics [27], as shown in Fig. 3, 81% of Assam households in rural areas depend upon fuelwood for cooking.

Table 1 gives more insight on firewood consumption. It shows that households in Assam mostly use firewood, which is followed by LPG. It appears that households of Assam have no access to a transition fuel like charcoal at all. Thus, there is more possibility for energy intervention like charcoal in Assam, as fuelwood is available.

2.2. Cooking fuel transition

Earlier studies have applied a common model “Energy ladder”, to describe the household fuel choices in developing countries. This model links the differences in energy-use patterns between households to the variations in economic status [32–35]. It suggests that as families gain socio-economic status, they abandon technologies that are inefficient, less costly and most polluting, i.e. ones lower on the ladder [36]. Recently, researchers have replaced the energy ladder model with the “energy stack” model [34,36,37].

Table 1
Per 1000 distribution of rural households in Assam by primary source of energy used for cooking, 2012 [27].

Cooking fuel	Per 1000 distribution of rural households in Assam
Firewood	850
LPG	142
Dung cake	0
Kerosene	5
Others	0
No arrangement	1

Fig. 1. Energy use disparity between urban and rural India, 2012 [29].

This model suggests that households do not fully abandon cooking fuels in favor of efficient ones, but rather they integrate those gradually into their households [38,39].

Studies have been done on rural household energy potential, energy resource allocation, cookstoves and fuelwood material [40–42]. Many studies have been done on different types of cookstoves using charcoal, examining efficiency and impact on health and environment [43]. Charcoal is considered a more efficient domestic fuel than fuelwood. Hence, charcoal consumption is increasing not only in rural areas but also in urban areas. In particular, people who migrate from rural areas to cities switch from fuelwood to charcoal [44]. Charcoal is often considered as the transition fuel because it is higher up the energy ladder and superior to firewood, which again is better than crop residue and dung [45]. In the production chain of fuelwood and charcoal, the main technologies are the traditional cookstove and the charcoal production kilns. In addition to technology, time needs to be considered. Since people from rural areas are involved in many time-consuming agricultural activities, each second of time is important for them. The question then is whether charcoal offers adequate efficiency to be adopted by households in rural areas.

3. Materials and methods

A hypothetical cooking energy system has been developed for the case study area. The selection of cooking energy system was based on the availability of cooking fuels and cookstoves in the case study area. The study starts with the analysis of the present cooking energy system. Thus, data were collected related to each household's fuelwood consumption and cooking time per day per household. Calculations were done to obtain each household's energy demand for cooking while using a traditional 3-stone fire for fuel combustion. Subsequently, other hypothetical cooking energy systems were taken into consideration by replacing the present fuelwood/cookstove combination with more energy efficient fuel and cookstoves like charcoal and improved cookstoves (ICS).

3.1. System analysis

This section will provide a step-by-step demonstration of the analysis, which starts with describing the fuelwood energy system, and then will show the opportunities for improvement in the cooking energy system.

3.1.1. Cooking energy systems

We developed a systematic approach for creating a hypothetical model to understand the feasibility of using efficient technology for cooking in rural areas. From the fuelwood consumption perspective, we considered Scenario 1, where we calculate the direct consumption of fuelwood for cooking, the time required for collection of fuelwood and the useful energy demand for cooking. Fig. 4, describes the methodology used for this study. It has been divided into four scenarios, which are briefly described below:

Fig. 4. Generalized flow diagram of useful energy production.

- a) *Scenario 1 (SN 1)*: This is the present situation in the village, where households collect fuelwood and then use it in a traditional cookstove (TCS) i.e., 3-stone open fire for cooking.
- b) *Scenario 2 (SN 2)*: This is a hypothetical fuelwood system, where the traditional cookstove (TCS) is replaced by an improved wood cookstove (IWC).
- c) *Scenario 3 (SN 3)*: This is the hypothetical charcoal system, where fuelwood is replaced by charcoal. In this scenario, charcoal is used with a traditional cookstove (TCS).
 - i. *SN 3 (a)*: charcoal is produced by using a 200-L horizontal drum kiln
 - ii. *SN 3 (b)*: charcoal is produced by using an Adam Retort charcoal kiln
- d) *Scenario 4 (SN 4)*: This is the last developed scenario, where charcoal is used in an improved cookstove (ICS).
 - i. *SN 4 (a)*: charcoal is produced by using a 200-lt horizontal drum kiln
 - ii. *SN 4 (b)*: charcoal is produced by using an Adam Retort charcoal kiln

In the last two scenarios SN 3 and SN 4, charcoal is produced by using two different charcoal kilns, i.e. a 200 lt-horizontal drum kiln for small scale production and an Adam Retort charcoal kiln for large-scale production.

The 200-lt horizontal drum charcoal kiln can be made by using two 200-lt Oil drums and a few bamboo poles for support. This technology can yield about 12–18 kg of charcoal from 60 to 80 kg of fuelwood giving an efficiency of about 20% [46,47]. It takes 1.3–9.4 h for carbonization, depending upon the type of wood and its size. This method for charcoal production is very beneficial for small family of 4–5 members.

An Adam retort charcoal kiln is a stationary charcoal kiln made of bricks. A 3 -m³ volume of wood chamber can be loaded with approximately 750 kg of wood with some moisture in it [48]. And, about 50 kg of waste wood is required in the whole process of charcoal production. The efficiency can be as high as 35–40% and noxious emissions can be reduced by 70% [47,49].

The useful energy demand from scenario 1 is taken as the reference value (i.e. energy demand) for the other scenarios. In scenario 2, the traditional cookstove is replaced by improved cookstove (ICS). Considering useful energy from scenario 1 as energy demand for scenario 2, the fuelwood required and time demand will be calculated. In case of scenario 3, charcoal is produced from two different kilns and a traditional cookstove is used for cooking. Similarly for scenario 4, an improved cookstove is used.

3.2. Study area

This paper draws on the 6-months of surveys conducted in Napaam, a village in the Sonitpur district, during 2009–2010 [50]. Throughout that period, data was collected for a project conducted by the Government of India [51]. The majority of the data were collected through a mixed approach, consisting of unstructured and semi-structured interview across the whole village. Fig. 5 shows an enlarged map of the Napaam village.

As per 2011 census, 91.11% population of Sonitpur district lives in rural areas. The total population of the Sonitpur district residing in rural areas is 1,754,835. There are 1748 villages within the Sonitpur district. And the case study done on this paper is one of the villages from Sonitpur, i.e. the village of Napaam. The total land area of this village is 93.32 ha. Out of this, 68 ha are crop land, 25.06 are yard land and 0.326 constitute water bodies [8,52].

Fig. 5. Enlarged view of Napaam village.

3.3. Data collection

During the observation period, each and every household were visited with a structured questionnaire and requested to indicate the amount of fuelwood collected every week, the time required for collection of fuelwood and the number of people participating in the collection from every household. During interrogation, some of the questions were about the areas from where a household normally collects their fuelwood and the purpose of its use.

This village has 178 households with an average of 5 persons per household with a total of some 870 people. The data collected was based on the number of persons per household, fuelwood collection per day (kg/day) and fuelwood use per day per household (kg/hhd/day).

Accordingly, fuelwood consumption was measured by using a weighted survey method [7,8,53]. Each household was given a weighted amount of fuelwood (i.e. 45 kg) and then requested to use fuelwood from the weighted stack. After 24 h, the remaining fuelwood was weighed again to measure the fuelwood consumed by the households.

3.4. Fuelwood demand

This study depends on the useful energy and fuelwood demand for different cooking energy systems. This section will give an in-depth description on the calculation of useful energy consumption and fuelwood demand for all the developed scenarios.

3.4.1. SN 1: Fuelwood with traditional cookstove (TCS)

The useful energy demand in Fig. 4, is calculated by multiplying the amount of fuelwood used per household per year with the energy density of wood and traditional cookstove efficiency, as

given in equation (1).

$$E_u = F_w \times E_w \times \eta_t \times \eta_k \quad (1)$$

where, E_u is the useful energy demand (MJ/hhd/yr), F_w is the fuelwood used per household per year (kg/hhd/yr), E_w is the energy density of the fresh wood (MJ/kg) and η_t is the cookstove efficiency of traditional cookstove (0–1) and η_k is the kiln efficiency (0–1). For scenario 1 and 2, there is no kiln, so η_k equals 1. The energy content of freshwood is assumed to be 16.8 MJ/kg [54].

3.4.2. SN 2: Fuelwood with improved cookstove (ICS)

In this scenario, we have considered an improved cookstove. There are various cookstoves available, but in this study we have specifically assumed a “Meghalaya cookstove”, since, it has been developed prominently for Northeastern part of India (Fig. 6), and it does not requires educational background for its construction. It has an efficiency of 24% [55]. This cookstove can use fuelwood, dung and agriculture residues.

The fuelwood demand for this scenario can be calculated by using equation (1), where E_u will be used from scenario 1, and thus, by changing efficiencies of cookstove, we can find the fuelwood required for scenario 2.

3.4.3. SN 3: Charcoal with traditional cookstove

Fig. 7, illustrates a detailed production chain of fuelwood and

Fig. 6. Meghalaya cookstove [55].

Fig. 7. Production chain of fuelwood and charcoal.

charcoal where fuelwood is the main feedstock for the cooking fuels.

As we discussed earlier, that in this study we have considered two technologies for charcoal production i.e. a 200-lt horizontal Drum Charcoal Kiln (for small-scale production) and an Adam Retort Charcoal Kiln (for large scale production). Both of these are economically viable for rural households and can be constructed with available materials like bamboo, drums and bricks.

The fuelwood demand for the charcoal production (F_{ch}) is given by:

$$F_{ch} = \frac{Eu}{E_{ch} \times E_c \times \eta_k \times \eta} \quad (2)$$

where E_u is the useful energy demand (MJ/hhd/yr), E_{ch} refers to the calorific value of fuel (MJ/kg), E_c is the final energy using cookstove (MJ), η_k is the efficiency of the kilns (%) and η is the efficiency of the cookstoves (%). In our study, the charcoal kiln efficiency for a 200-lt horizontal drum kiln is considered to be 20% [14,56] and for an Adam Retort charcoal kiln to be 40% [48]. The calorific value of charcoal is assumed to be 28 MJ/kg [19,28].

3.4.4. SN 4: Charcoal with improved cookstove

The fuelwood demand is calculated by using equation (2), by substituting the efficiency of improved cookstove. A charcoal cookstove has a thermal efficiency of about 30% [12,45].

3.5. Time estimation

3.5.1. Time estimation for fuelwood production (SN 1 and SN 2)

In the process of fuelwood collection, a household needs to make a trip either on a weekly basis or daily basis. The number of trips (N_t) required by households depends on the carrying capacity of fuelwood by the person. “One trip” for this study can be defined as the journey back and forth for fuelwood collection. It is calculated by using equation (3).

$$N_t = \frac{F_w}{F_c} \quad (3)$$

where N_t is the number of trips required for fuelwood collection (hhd/yr), F_c is the fuelwood collected in per single trip (kg) and F_w is the fuelwood demand for each scenario, which is calculated by using earlier equations.

The time required for fuelwood collection (T_w) can be calculated by the equation (4).

$$T_w = N_t \times T_c \quad (4)$$

where T_w is the time spent in collection of fuelwood by one household (hrs/yr) and T_c is the total time required in one trip (hrs).

3.5.2. Time estimation for charcoal production SN 3 (a & b) and SN 4 (a & b)

The time required in the production of charcoal is the sum of both the fuelwood collection time and the charcoal production process time. Wood charcoal production is a labour intensive activity, mainly carried out by men, employing people at different

stages of the charcoal process [57]. In this study, we have calculated time estimation in two different ways, i.e. Gross labour time and Net labour time. These can be determined in the following ways:

I. *Gross labour conversion time ($T_{co,G}$):* The time required for charcoal making in charcoal kiln throughout the whole process, which includes labour time and also charcoal processing time (i.e. time required in kiln).

II. *Net labour conversion time ($T_{co,N}$):* The time required for charcoal making in a charcoal kiln, only for all the activities requiring physical labour. In other words, this does not include the whole charcoal processing chain, but only those activities where manual labour has to be done.

Thus, equation (5) is used to calculate gross or net conversion time for charcoal production.

$$T_{co} = \frac{F_{ch}}{F_{in}} \times T \quad (5)$$

where F_{in} is the fuelwood input (in kg) inside the kiln to make charcoal, F_{ch} is the fuelwood needed for charcoal production (kg) and T is the gross or net labour time (in hours). The value of “ T ” depends on the type of kiln used in the production process. Gross labour time includes loading of fuelwood, unloading of charcoal, cleaning of the kiln and the whole processing time of charcoal, whereas, net labour time, excludes the charcoal processing time.

4. Results and discussion

The cooking energy survey for this study was done for a village named Napaam. This village has 178 households, and data sampling was done from each and every households. The average number of members per household is 5. The survey found that fuelwood was the major and nearly only fuel used for cooking. Few households reported using LPG, but mostly during some occasion, which is why in our study we found LPG usage nearly negligible. The average demand of fuelwood for cooking per households is approximately 6.57 kg/day. The average per capita consumption of fuelwood is about 1.45 kg/capita/day with standard deviation of 0.83 and variance 0.689. There are reports of other study from area near to our study area, says that, the per capita fuelwood demand is approximately 1 kg/capita/day [58].

The households in our study depend on the seasonal income from the subsistent farming. There is no fuelwood market available in the village; hence, they collect their fuelwood from open spaces and forest. The income from small occupation like selling vegetables and seasonal masonry work are used to cover household expenses like clothing etc. Thus, it is the time, which they have to spend to collect their cooking energy fuel for fulfilling their demand.

In this study, SN 1 is the baseline scenario for the other developed hypothetical system. From the surveyed data collection, we used the data to calculate the fuelwood demand and time required for fuelwood production for the present situation i.e. SN 1. We assumed that a person could carry a load of 25 kg of firewood in one trip. From the survey data, by using a 24 h weighing method, we found that a household requires on average about 7 kg of wood per day in Napaam village. Thus, a household requires 2588 kg of fuelwood per year, which results in about 104 trips per year. Hence, by using Equation (3), we found that it requires 828 h/yr for a household to collect fuelwood. By using equation (1), we found that the gross energy demand, which is the final cooking energy demand per household, is 43.4 GJ/hhd/yr. This gross energy demand is the final energy received by the cooking pot placed at the top of stove. But, in this study we have used only useful energy, calculated by considering cookstove efficiency. Since in SN 1, households are

Table 2
Annual energy demand and number of trips required for fuelwood collection.

Wood required per year (kg/hhd/yr) (F_w)	2588
Gross energy produced (GJ/hhd/yr)	43.4
Traditional cookstove efficiency (%)	10
Useful energy demand (GJ/hhd/yr)	4
No. of trips reqd. to collect fuelwood (hhd/yr)	104
Time required to collect fuelwood (hrs/yr)	828

using traditional cookstoves, thus, we assume it to be 10% efficient [28,45,59]. By using equation (1), we found that the useful energy demand for a household is 4 GJ/yr (see Table 2). This energy is the energy demand to calculate fuelwood demand for the developed hypothetical scenarios.

In India, the working hours of a service person is about 1960 h per year which accounts for 22% of total time in a year [16,17], and notably, from our study we found that in rural area one household has to spend 10% of their total time just to collect fuelwood. It is important to note that the person, who spends 1960 h/yr, earns money for their whole household that they spend to attain their domestic demands like fooding, clothing, education etc., but remarkably, a rural household has to spend 828 h/yr to collect feedstock for their cooking energy system. Thus, it seems that rural households has to expend most of their time in feedstock collection.

4.1. Fuelwood demand for developed scenarios

This study considers that charcoal is made from fuelwood. The cooking energy demand for SN 2–4 is 4 GJ/hhd/yr. By using equation (2), we found that charcoal produced by using 200-lt horizontal drum kiln and TCS for cooking, demands 7765 kg fuelwood per year.

According to the “energy ladder” model, if we opt to move higher along the ladder, then the next option for transition fuel after fuelwood is charcoal. However, more fuelwood is required to make charcoal. It is clearly noticeable from Fig. 8, that charcoal used in a traditional cookstove consumes 3 times more fuelwood than that of wood used in traditional cookstove. In case of SN 2, when ICS is used with fuelwood as cooking fuel, the demand for fuelwood almost reduced to half, i.e. 1079 kg. It seems that with a change in cookstove, there is a huge difference of fuelwood demand.

From literature, we found that normally 4–6 kg of fuelwood is required to produce 1 kg of charcoal [32,60]. But, using improved kilns for charcoal production, the fuelwood demand has decreased almost by a factor of 2. In SN 3, when charcoal is produced by 200-lt horizontal drum kilns and is then used in a traditional cookstove for cooking, the fuelwood requirement is 7765 kg. But, the interesting

Fig. 9. Time required for fuelwood collection for different scenarios.

fact is that, just by replacing a traditional cookstove with an ICS, the fuelwood demand decreases by 3-fold. The final hypothetical scenario, i.e. SN 4, indicates that the fuelwood demand for an ICS using an Adam retort charcoal kiln is almost equivalent to SN 2. Our research shows that, although charcoal has higher energy content than fuelwood, its production requires a lot of fuelwood. However, from all the scenarios it has been found that an improved cookstove has reduced the fuelwood demand to a large extent. Thus, it seems that rural households can save a lot of time just by opting for an ICS rather than for charcoal.

4.2. Time demand

According to our findings, currently a household has to invest about 828 h per year merely for fuelwood collection. Fig. 9 indicates the amount of time required for the various scenarios. The case of SN 3a requires the maximum amount of time, i.e. 2485 h per year for charcoal production. Interestingly, when a TCS for SN 3a is changed with an ICS, it requires only 828 h/yr, which is equivalent to SN 1. Clearly, the most efficient combination is an Adam retort kiln with an ICS (i.e. SN 4b), which demands the least time for fuelwood collection. Employing an ICS for cooking has the strongest influence in the time demand for fuelwood collection. But, remarkably in case of SN 4a, when an ICS is used, it nevertheless demands almost 4 times more time than SN 2. The hypothetical system SN 2 is the most efficient amid all developed scenarios. Fig. 9 shows that, if households cannot afford to opt for transition fuels, then introduction of an IWC for fuelwood energy systems can be more time efficient.

The process of charcoal production requires lot of time for households [61]. But as stated, it can be divided into gross and net labour time. It can be seen in Fig. 10, that the labour and gross time depends significantly on the charcoal kiln and cookstove type. In both labour and gross time, the scenario SN 3a requires highest time among all the scenarios. However, on comparing both SN 4 and SN 3, we found that charcoal produced by using a 200-lt horizontal drum kiln requires more time than an Adam retort charcoal kiln, regardless of the use of an efficient cookstove. From our analysis, we found that SN 4b scenario requires the least time in charcoal production for both labour and gross time i.e. 15 h/yr and 65 h/yr respectively. But for a household it is not advisable to opt for an Adam retort kiln, since it is usually used for large-scale charcoal production. Hence, if a single household decides to produce their own charcoal, then from Fig. 7, it indicates that a 200-lt horizontal drum with an ICS will be more feasible for them.

The total time requirement is the aggregate time demand in the cooking fuel production chain, which includes fuelwood collection time and charcoal conversion time. It is interesting to find that trend of fuelwood requirement for a household has the same time

Fig. 8. Fuelwood required and number of trips per year.

Fig. 10. Gross and labour time required in different kilns.

Fig. 11. Total time required in the production chain of cooking fuel.

demand. In Fig. 10, we found that scenario SN 3a requires the maximum amount of fuelwood, and similarly when considering the total time demand, SN 3a demands more labour as well as gross time (Fig. 11). In case of SN 1 and SN 2, we have only gross time because the fuelwood production chain does not have any other technology involved in it, which requires additional labour. Thus, it is interesting to find that, SN 2 is the most time efficient cooking fuel production option for rural households. It requires only 345 h per year, which is significantly less than other scenarios. It is a very noteworthy result, as it shows that irrespective of charcoal being a more efficient fuel than fuelwood, it requires maximum time for production.

Other studies have concluded that income is a significant factor, but, it does not confirm that it really affects the use of cleaner fuels. It is more important to understand the social and technological factors [62]. In earlier paragraph, it has already been stated that a service person works approximately for 1960 h per year. To get an overview of our study area economic scenario, we assume that a rural person works almost the same time as a service person (i.e. 1960 hrs per year), but it does not earn the same amount of money. From other study, we found that the average per capita monthly income of rural households is about INR 4167 [63,64] ($\approx \$ 65$ [65]). A survey near our study area, discovered that it has a market for fuelwood where per kg fuelwood cost about INR 3/kg ($\approx \$ 0.046$ [65]). Assuming the per capita income from other study and fuelwood market cost from our survey study of other village, we will analyze the trade-off between time cost and fuelwood cost. Table 3, describes that average per capita income and market cost of fuelwood, that we assumed for our village.

Assuming the same income level for our 178 households, we found that households using traditional cookstoves are

Table 3
Average income and market cost of fuelwood.

Average per capita income per hour (\$/hr)	0.40
Fuelwood cost per kg (\$/kg)	0.046

Fig. 12. Time cost and fuelwood cost for all the scenarios.

economically hampered. In 1 h a rural person normally earns about \$0.40. For the baseline scenario SN1, a household spending 828 h per year for cooking fuel collection, can earn about \$331 if they had opted to work for other purpose. However, if we consider the fuelwood market scenario SN 1, for 2588 kg of fuelwood, it will cost about INR 7764 ($\approx \$119$ [65]). But for SN 3a, the time cost is almost 3 times than that of SN1 i.e. \$ 994. Now, if a household opts for SN 3a scenario, they will have to spend just 18% of their annual income to buy fuelwood from market, or else they are almost losing 50% of their income in the time expended while collecting fuelwood. In all the scenarios, the cost of time spent in fuelwood collection is higher than the cost of fuelwood from market (Fig. 12).

Thus, in economic perspective, we can conclude that for all the scenarios, if there is a market available for household, then it's better to buy fuelwood than to produce its own cooking fuel. As there is a trade-off between the time demand and the choice of cooking fuel for households.

5. Conclusion

A comparative time investment study between two different sources of end-use energy i.e., fuelwood and charcoal with improved and traditional cookstoves has been done. In our analysis, we distinctively selected two different types of charcoal producing kilns. This hypothetical analysis of cooking fuels and cookstoves is done for a specific case study area.

As expected, we found that in the production of charcoal using any of the kilns, the fuelwood requirement is very high, which results in an increased number of trips for fuelwood collection by women.

An interesting result is that using fuelwood with an improved cookstove saves more time of women than by using charcoal with an improved cookstove. This could be one of the reasons that households still prefer to use fuelwood over charcoal, as charcoal production requires lots of time. This also shows that the “energy ladder” or “energy stack” model is quite evident when households buy their cooking fuel, but when they opt for producing their own cooking fuel, then these models are not valid.

Many Government projects failed to compel rural households to switch to cleaner energy. This research could be an insight to the problem of switching from traditional cookstoves to cleaner cookstoves. Government of India has already initiated projects related to ICS, by increasing its access and availability to rural households. One of such project is National Biomass Cookstove Programmes [27]. A recent study of ICS distribution in the Odhisa state of India indicated a 91% reduction in fuelwood use compared to that associated with traditional stove utilization [66]. Furthermore, these households without ICS lose twice the number of productive hours only on fuelwood collection, which they could use to improve their livelihoods by doing other income giving work.

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