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Cooking Energy Conservation by Using Improved Stove: a Case Study on Thaipara Village of Magura Bangladesh

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Abstract
The study was conducted to investigate the energy efficiency of traditional and improved cooking stove, potential energy conservation using improved stove and overall environmental impacts of those stoves at Thaipara of Magura district in Bangladesh. In the study area, almost 100% of the households use biomass as their cooking fuel in traditional stoves. Questionnaire Survey (QS) was conducted to fulfill the research objectives. The result of the study showed that total biomass energy consumption is 14897 GJ per year, whereas, the per capita cooking energy consumption is about 4.82 GJ per year. The results also revealed that biomass: fuel wood, dung and crop residues are the 100% sources of the total energy used in the cooking sectors. The combination of high demand aggravated by low use efficiency has contributed to deforestation, rural poverty and the energy shortage in the study village. Results of the study stated that by introducing improved stove with higher level of efficiency, well ventilation and using good quality of fuel can reduce the harmful impacts of cooking energy utilization and cooking systems on environment significantly. In this regard, formulation and implementation of a nationwide high efficiency cooking stove dissemination program would be very promising for cooking energy conservation at rural sectors.

Key words: Biomass, Energy conservation, Environment, Fuel wood, Improved stove

Introduction

It is well documented that improving access to affordable and reliable modern forms of energy services is essential, especially for developing countries in reducing poverty and promoting economic development. (Barnes *et al*., 2011). In developing countries the major source of energy consumption is derived from biomass (fuel wood, charcoal, dung and agricultural residues) and it is about 43% of the total energy consumption in those countries (Modi *et al*., 2005; IEA, 2013). Household cooking consumes more energy than any other end-use services in developing countries like Bangladesh (Daioglou *et al*., 2012). In Bangladesh, energy sources comprise of commercial resources (natural gas, petroleum products, coal and electricity) and biomass resources (fuel wood, twigs and leaves, agricultural residues, animal waste and other organic wastes) (IEA, 2006). Only about 37% of the energy used in Bangladesh was supplied from commercial energy and 63% of the energy supply was obtained from biomass (Bala, 1998). The traditional fuel is used more than 39 million tons per year as estimated by Bangladesh energy commission in 1994 (Bonjour *et al*., 2013). Annual wood production in Bangladesh is estimated to about 9.5 million m^3 of which 80% is used for fuel and 20% covered primarily to sawn wood (Wang *et al*., 2013). About 80% of the production comes from private sources, mainly from homestead wood lots and the remaining 20% comes from state owned forests. However, about 20% of biomass energy is used for small-scale industries and other 80% for households (Rahman, 1998).

Bangladesh is an agricultural country and most of the peoples depend on agriculture for their living. About 80% of the population lives in the rural areas and most of their cooking energy (80%), because of its easy access and availability (Bruce *et al*., 2000). A large number of trees are being cut to meet the fuel requirement and the tendency of cutting trees is increasing at alarmingly day by day with the increasing population, which threatens depletion of biomass resources in the rural areas. At present, there is an acute crisis of biomass fuel in rural areas of Bangladesh (Malla and Timilsina, 2015). Extensive and unplanned consumption pattern of biomass fuels led the consumption beyond regenerative limit with serious environmental consequences. Continuous use of leaves, twigs, agricultural and animal residues as fuel deprive the soil from valuable nutrients and cause soil erosion (Islam, 1993). Furthermore, there is huge wastage of biomass energy due to inefficient energy budgets used and enormous misuse of energy due to ignorance problems. At present, cooking system in rural areas of Bangladesh is conducted on the simple, traditional three stone fire places (IEA, 2012). Using biomass as fuel also affects the health of women and children (Lim *et al*., 2012). Women often spend a lot of time for collecting fuels and low efficiency of those fuels takes too much time to cook food. Moreover, their children also often give them company instead of going to school (Azad *et al*., 2003). In this circumstance, this study was an attempt to assess the impact of improved stove on energy utilization in Thaipara village, Magura, Bangladesh. In order to intend this goal, the following objectives were carried out: (i) to determine the energy consumption status in cooking sector, (ii) to identify the energy consumption pattern of cooking fuel, (iii) to measure the energy efficiency of traditional and improved stove for cooking, (iv) to determine the amount of fuel saved due to use of improved stove, and (v) to find out the impact of cooking energy consumption on environment as well as human health.

Materials and Methods

Study area

The study was conducted at the Thaipara village of Magura, Bangladesh. The area of Magura district area 1048.61 Km^2, located in between 23°15' and 23°41' north latitudes and in between 89°15' and 89°42' east longitudes. Thaipara is about 3 km long and 0.75 km wide with a land area about 590 acres. The energy consumption pattern of this village comes from biomass energy sources. It is bounded by Rajbari district on the north, Jessore and Narail districts on the south, Faridpur district on the east, Jhenaidah district on the west (BBS, 2011).

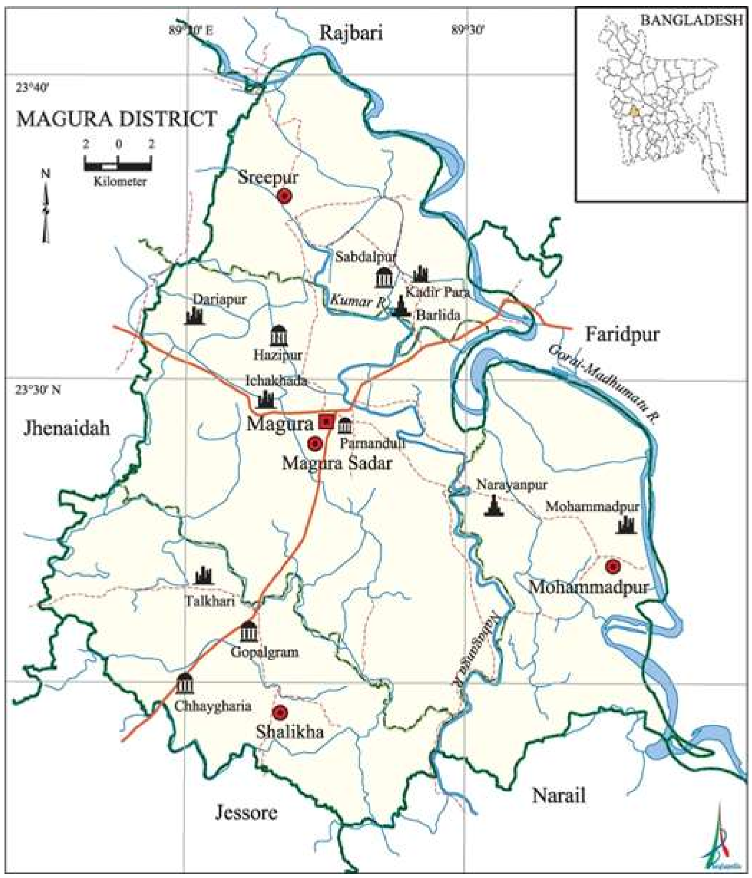

Fig. 1. Map showing the study area (Source: Modified from Banglapedia, 2015)

Data collection

The study was carried out as well as the data were collected through questionnaire survey (QS). For the fulfillment of the study objectives, Quota sampling (Non-probability sampling) technique was used. The sample size was fifty (50) and this size was determined for the convenience of data analysis. Samples were proportionately stratified on occupational groups of population. The occupational groups were classified on the basis of primary occupation. Primary occupation is identified based on highest duration of works in a year. For experimental analysis, only five fixed improved and another five traditional cooking stove (Chula) was selected.

Statistical analysis

The collected data were analyzed by using the MS Excel software, and the findings of the study were presented as charts and tabular forms.

Results and Discussions

Socio-economic structure of the study area

In Thaipara village, the numbers of inhabitants are almost 3500 and most of the people are dependent on agriculture. The land use pattern depicts that the dominance of agricultural (57%) and residential (34%) use in the land coverage. A large proportion (52%) of the inhabitants is engaged in agriculture. Most of the people (58%) belong to low-income group and few (36%) to middle class (Fig. 2 and 3).

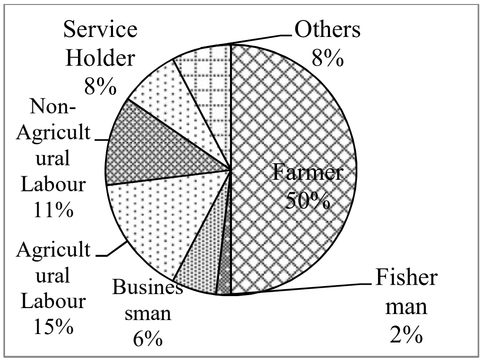

Fig. 2. Occupational pattern of study the area

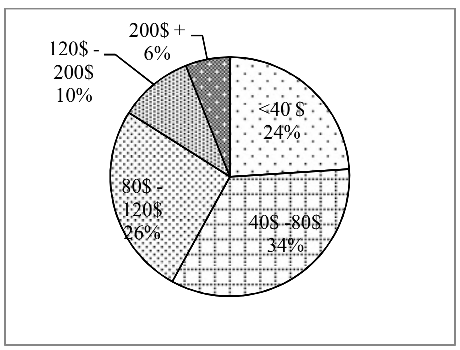

Fig. 3. Occupational pattern of study the area

Energy and cooking system in use

Cooking energy consumption by family size

The results of the study found that there is a positive relationship between cooking energy consumption and family size. Fuel wood consumption is more prevalent among households with large number of member (Fig. 4). All other biomass fuels such as agricultural residues, cow dung and rice husk consumption also increase with the increase in family size. Therefore, family size as well as population is important determinants of the demand of biomass fuel for cooking.

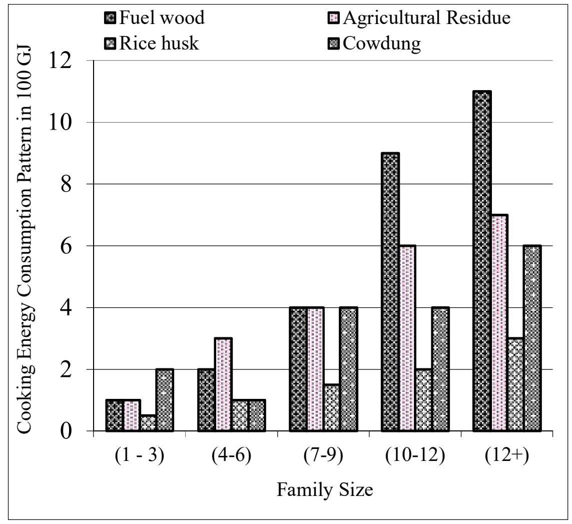

Fig. 4. Annual cooking energy consumption pattern by different family size

Cooking energy consumption with income

An increase in per capita income leads to an increase in the quantity of biomass fuel consumption (Fig. 5). Fuel wood consumption is high in economically better conditions families. Agricultural residue consumption is high in the middle income groups. They could not purchase fuel wood and are influenced to collect agricultural residues. Results of the study also reveal that cowdung is used highly by the lower class income group (Fig. 5) this might due to the farmers occupy more cattle.

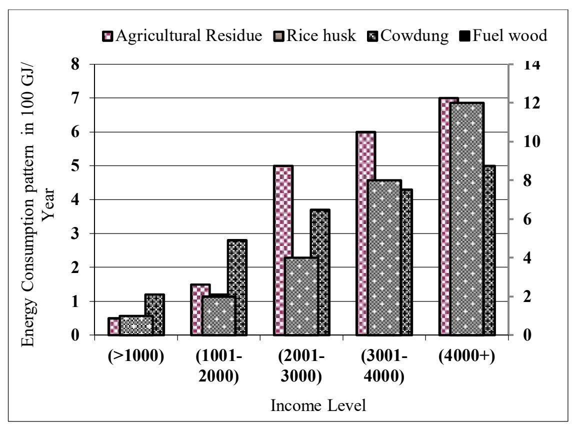

Fig. 5. Cooking energy consumption pattern by different income groups

Comparison of energy consumption

Estimated annual cooking energy consumption is 14897.2 GJ in this present study and per capita energy consumption is 4.82 GJ. However, Biswas (2001) estimated energy consumption in Kanpara (Mymensingh) is 6.15 GJ. Islam (1980) estimated energy consumption in the south part (Barisal) of the country, which is equal to 4.9 GJ. Quader and Omar (1982) estimated that the per capita energy consumption for cooking in the North West (Rangpur) part of the country is equal to 8.77 GJ. Such variation may be due to the location specific nature (type and availability of the resources, population size and percentage of different classes of people or estimation defaulters) of the study villages.

Pattern of cooking system

The Thaipara villagers use two types of stove: (i) traditional stove and (ii) improved stove. Traditional stove is under-ground based and three stones are only on the ground, totally mud made. A large amount of fuel is wasted for using traditional stove in Thaipara village. On the other hand, improved stove is made up of a chimney, releasing smoke from stick inside and middle portion for completely burning of fuel. Generally the function of improved stove is to generate and supply heat efficiently with lowest cost, comparatively short time and offers cleaner and safer kitchen. It is observed from the field survey that about 94% cooking systems are traditional stove and rest 6% is improved stove**.** However, the Thaipara village has no biogas stove and solar cooker.

Efficiency measurement of cooking system

Cooking efficiency is normally defined as the fraction of the energy in the fuel consumed which has been usefully employed during cooking. Efficiency was measured for both traditional and improved stove.

Efficiency measurement in case of food

A following formula was used to calculate cocking efficiency using food:

$$\text{Efficiency}, \varepsilon 1 = \frac{\sum_{i=1}^{n}((\text{MPiCPi} + \text{MmiCmi} + \text{MfiCfi})(\text{TCi} - \text{Ta}) + \text{MfiKfi})}{(\text{MwEw} - \text{MrEr})} \ldots\ldots (1)$$

The summation in Eq. (1) is different for food items as each item i, Mpi, Mmi, and Mfi are the masses and Cpi, Cmi and Cfi are the specific heats of the pots, cooking media, and foods, respectively. Ta is the initial temperature of the pots, cocking medial and foods (normally the ambient temperature) and Tci is the cooking temperature of item i. Kfi is the energy required for the chemical reactions which take place during cooking a unit of item i. Mw and Ew are the mass and calorific value of the fuel wood consumed, and Mr and Er are the weight and calorific value of any charcoal recovered upon completion of cooking.

Efficiency measurement in case of water

For the purposes of estimating the efficiency using water the following formula was used:

$\eta = (m_w c_w dT + m_s H) / m_f b_f$…………………(2)

Where, η = Efficiency ratio; m_w = Initial mass of water (Kg); C_w = Specific heat water (KJ/Kg^{0}C); d_T = Temperature difference (^{O}C); m_s = Mass of steam formed (Kg); H = Latent heat of vaporization (KJ/Kg); B_f = Heating value of fuel wood (KJ/Kg); m_f = Mass of fuel wood (Kg).The experimental method for efficiency measurement is done by Biswas (2003). The measured efficiency for both traditional and improved stove is shown in Table 1.

Table 1. Cooking energy efficiency (%) obtained from experiment

Stove Type	Efficiency (%)	
	Food Cooking	Water Heating
Traditional Stove	10.00	14.50
Improved Stove	24.00	42.00

Potential fuel saving using improved stove

When the households of the study village use traditional stoves for water heating they get 14.50% fuel wood efficiency, on the other hand, used improved stove, will get 42.00% cooking fuel wood efficiency, and the results depicted that they can save 27.52% fuel wood for water heating (Table 1). As the total cooking fuel consumption in the study village is about 14897 GJ per year, by using improved stove the villager can save about 4100 GJ per year (Fig. 6). For cooking of rice the households get 10.00% fuel wood efficiency using traditional stoves. But if they use improved stove for cooking rice they will get 24% wood fuel efficiency. Through using improved stove, the villagers can save wood fuel energy at about 2,063GJ per year (Fig. 6).

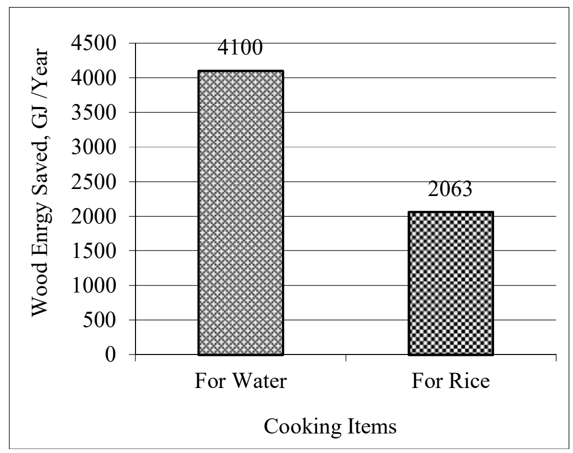

Fig. 6. Potential energy conservation using improved stove

Impact of present cooking system

For cooking energy, densely populated country like Bangladesh is heavily dependent on agriculture and natural resources and also dependent on low efficient cooking stoves which cause various types of environmental problems such as indoor air pollution, soil erosion and nutrient loss, deforestation associated with socioeconomic problems as modeled in Fig. 7.

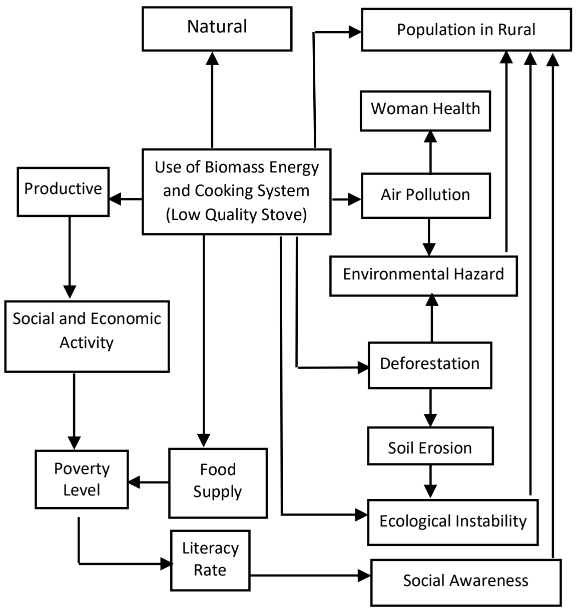

Fig. 7. Impact of biomass energy use and cooking system

Environmental impacts

Excessive and unplanned consumption of cooking energy has significant environmental impacts. Due to poor ventilation in the most kitchens in the study area, women have to compromise long time with dangerous level of various types of toxic pollutants emitting from cooking fuels in traditional stoves including suspended particulate matter (SPM), carbon mono-oxides (CO) and carcinogenic compounds, and they suffer from various kinds of disease. It is revealed that from the field survey, the women of the Thaipara village are affected by fever 26%, eye irritation 10%, headache 42%, asthma 14%, and skin diseases 8% (Fig. 8). The traditional stove emits more polluting substances and flue gas because of mainly two reasons: (i) the distance between cooking pot and fuel bed is large: loss of heat and need more fuel to cook. This leads to increase more disease causing substances. (ii) the distance between the down layer of pot and the zikha is so large that flue gas can easily come out and create more smoke that is responsible for respiratory problem. The emission factors for different pollutants by the type of biomass fuels are shown in Table 2.

Due to the over utilization of biomass fuel, homestead vegetation decreases, which enhances the process of soil erosion since vegetation root retains soil. Moreover, topsoil contains many materials, which retain soil fertility. In the study area, top soil is being eroded due to removal of the agricultural residues and cowdung cake. So the farmers of this village use vast amount of chemical fertilizers to grow their crops but this activity also responsible for soil, water as well as overall environmental problems. Rabindranath and Hall (1995) estimated that soil nutrients are removed through the utilization of bio-residues at the rate of 0.03 Kg N_2 / Kg of dry leaves.

Table 2. Emission factors for biomass energy use in traditional cook stoves in India

Fuel Type	Components (g/kg of dry fuel)						
	CO_2	CO	CH_4	PM	SO_x	NO_x	N_2O
Fuel wood	1705	80	9.0	9.0	0.34	2.34	0.070
Crop waste	1266	75	300kg/TJ	7.4	0.29	1.74	4.0kg/TJ
Cow dung	1060	83	300kg/TJ	20.0	6.0	7.0	4.0kg/TJ

***(Source:** Bhattacharya and Salam, 2002)*

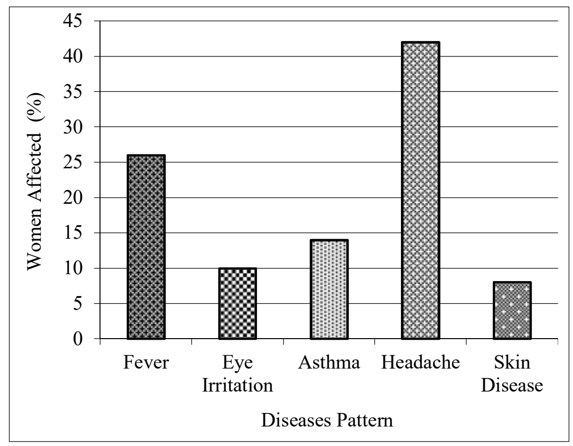

Fig. 8. Physical problems of woman using biomass fuel in traditional stoves

Socioeconomic impacts

Result of the study reveals that the housewives spend time at about 5 to 6 hours in a day for collection of fuel and cooking purpose. As traditional stove takes more time to cook as compare to improve stove, women do not get enough time to participate social, economic, and educational activities such as teaching their children. Therefore, majority of them do not get the light of education. Besides they suffer many diseases due to compromise with indoor air pollutants (Fig. 8).

Sustainable alternative cooking systems for energy conservation

Results of the field survey in the study area stated that all the households use biomass resources in their traditional cooking stoves, this activity is not sustainable for natural environment. So, the villagers should use any alternative cooking systems that are feasible and eco-friendly. Such cooking systems and alternative options are discussed below:

Biogas plant

Organic matters such as animal and human excreta, poultry dropping, garbage, agricultural and industrial waste, water hyacinth etc. when fermented under an anaerobic condition produce a combustible gas called Biogas (Abbasi and Abbasi, 2013). In Bangladesh, biogas is obtained by applying the simplest technology with minimum cost. The gas is a renewable source of energy and can be used for cooking, fighting, running engines, generation of electricity etc. without causing any environmental problems. The residue is left after gas evolution and is a good organic fertilizer rich in Nitrogen, Potassium, Phosphorus and micronutrients. There are three types of basic designs of biogas plants tried in Bangladesh: (i) floating cover digester, (ii) fixed cover digester, and (iii) plastic cover digester (Inam, 2013).

Improved stove

This kind of stove requires no zhika. So, when a pot is placed there is no gap between the oven and the pot. It has two mouths. Both two mouths are for burning wood and food is cooked with the direct heat of the wood from this mouth. Hot gas enters into the second mouth having diameter 12.5 cm and food is cooked with this gas.

The smoke and the hot gas are released through a chimney of diameter 7.5-cm. The mouth has a net 20-cm below it. The wood is burnt on this net. The 1st and 2ndstove has to mouths just below the net for entering air and removal of ashes. These have area of 12.5 x l2.5 sq. cm. This type of stove is very suitable for using wood (Inam, 2013).

Solar cooker

Solar cooker is one of the sustainable cooking systems, which has no ecological problem. Solar cooking devices fall into two main categories: (i) solar ovens and (ii) direct focusing solar concentrators (Saeed and Sharma, 2014). Solar ovens are essentially boxes with consisting of wooden bases and sides with glazed opening lids. A solar ovens interior is well insulated to prevent heat loss and often a secondary lid is incorporated with a mirrored inner surface, which can be angled to reflect solar radiation through the lid and into the box (Abbasi and Abbasi, 2013). There are many different designs of concentrating cookers, although almost all designs developed are based on the use of a parabolic dish reflector measuring 0.5-1.0 m in diameter which, when directed at the sun, reflects and concentrates solar radiation on to a central platform (raised above the reflectors surface) on which the cooking vessel is placed. Solar cooker are cost effective if the climatic and social factors are favorable with the use of these cookers (Sawhney, 2014: Nagpal, 2006).

Tree plantation

Thaipara village land is productive for growing vast amount of vegetation, crops etc. But at present, fuel wood is a serious problem for cooking food due to shortage of trees. Therefore, plantation is essential to conserve cooking fuel, which can be increased in the following way: plantation can be done surrounding the ponds, homestead, road side and along the canal; non-wood and other species can be grown within the kitchen garden; fast growing and economically important species can be raised; all vacant and suitable lands can be afforested as early as possible; farmers can be encouraged for agro-forestry and social forestry, and mass participation of the villagers for plantation program is essential (Inam, 2013).

Conclusion

Cooking energy resource, its utilization pattern, cooking fuel efficiency in cooking systems, potential energy conservation using improved stove and overall environmental impacts of those activities on a village in Bangladesh have been studied. The overall findings of the study could be summarized as: traditional stove has an average efficiency of about 10% for rice cooking and 14.5% for water heating, whereas those for improved stove are 24% and 42%, respectively. The study also concluded that by using improved stove the villagers can save fuel energy annually at about 2,063 GJ in case of rice cooking, and about 4100 in case of water heating. Government agency, NGOs and other organizations may encourage the villagers to use sustainable and highly efficient cooking systems for better utilization of indigenous cooking fuel energy resources. In this case, necessary financial, technical, operational along with mass motivational effort is more significance to accept new technologies.

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