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An Analysis of Cross-sectional Variation in Energy Consumption Pattern at the Household Level in Disregarded Rural Bangladesh

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ABSTRACT

This study aims to examine household energy consumption pattern in disregarded rural areas of Bangladesh. Total 240 households from four upazilas located in four distinct agro-ecological zones were selected through multistage sampling techniques. Data were analyzed with different statistical tests to show the variation in pattern and quantum of household total energy and bioenergy consumption. The study revealed that all rural households used various types of biomass fuels, 98% used kerosene, 56% used electricity, 10% used candle and only 4% used LPG for their primary energy sources. The consumption of biomass fuels was 219 kg household^{-1} month^{-1}, where the largest share derived from firewood, which amounted 94 kg household^{-1} month^{-1}. The consumption of biomass fuels varied in regions and by socio-economic groups. The total energy consumption from all types of fuel was 3.16 GJ household^{-1} month^{-1}, whereas the share from biomass fuels was 2.95 GJ, which accounted more than 93% of the total primary energy supply. The study estimated that household per capita total energy consumption was 6.45 GJ person^{-1} year^{-1} whereas the share from biomass fuels was 6.03 GJ. The energy expenditure was 506.58 BDT household^{-1} month^{-1}, whereas the expenditure for biomass fuels was nearly one-third of the total energy expenditure. The analysis showed that family size, per capita income, per capita homestead area and per capita agricultural land influenced household biomass fuels consumption. The study identified that due to limited supply of firewood many rural households selected inferior types of biomass fuels, which were unsustainable and inefficient. Thus, the study recommends for improving the current biomass fuel consumption pattern with more efficient and sustainable practices. The information from this study is helpful to formulate policies support tools to take into account the future challenges for demand of biomass fuel resources, their sustainable utilization, promotion, and development.

KEY WORDS: Household, Energy, Biomass fuels, Consumption, Bangladesh.

1. INTRODUCTION

More than half of the world's population live in rural areas, who depend mostly on biomass for their energy supply, and have no access to modern form of energy (Demirbas and Demirbas 2007). In many developing countries in Asia like India, Pakistan, Myanmar, Nepal and Bangladesh, the rural household energy consumption constitutes over 70% to the national energy use (ADB 1998; Koopmans 2005). Therefore, rural energy is important for assessing future demand and supply of the national energy. In Bangladesh the rural households mainly depend on biomass fuels, kerosene, electricity, candle and LPG (liquefied petroleum gas) for their primary sources of energy supply (Asaduzzaman et al. 2010; Miah et al. 2010). However, the contribution of biomass fuels to total primary energy supply in Bangladesh is about 60% (LGED and FAO 2006; MoPEMR 2008). The country is one of the most densely populated countries in the world. Population density is about 990 persons per km^2 and the population growth rate is 1.54% per annum (BBS 2010). Due to the increasing population growth, per capita arable land area decreased from 0.07 ha in 1990 to 0.05 ha in 2009 (BBS 2010). Nevertheless, per capita energy consumption increased from 5 GJ (giga joules) in 1977 to 6.2 GJ in 2009 (Kennes et al. 1984; IEA 2009). The combination of high population growth with decreasing arable land as well as growing energy demand put immense pressure on biomass resources. Likewise, low per capita income and slow economic growth are considered to be the major impediments in transforming biomass energy into more modern energy forms in the near future (Bari et al. 1998). Therefore, the country is expected to remain heavily dependent on biomass resources for energy supply in the near future.

In Bangladesh, about 77% of the population resides in rural areas and they need energy for their everyday life like cooking, crop processing, lighting, agricultural industries, social welfare and commercial purposes. Biomass fuels are the predominant sources of energy supply in rural areas contributing over 90% to the primary total energy supply (BBS 2010). Biomass fuels are mainly consisted of firewood, leaves and twigs, agricultural crop residues such as rice straw, rice husk, jute stick, sugarcane bagasse, and cow dung (WB and BCAS 1998). Rural households use biomass fuels mainly for domestic cooking, rice parboiling, cloth washing, jaggery making, and to some extent for food preparation for livestock. The consumption pattern of biomass fuels depend on regional availability as well as household size, education status, income, socio-economic categories and land ownership (Sarkar and Islam 1998; Rao and Reddy 2007). Furthermore, various socio-economic driving factors like economy, socio-demography, availability of modern fuels, and lifestyles significantly influence fuel choice and total energy consumption by the rural households (Pachauri 2004). Thus, assessment of energy consumption as

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well as the interaction and balance between different sources and end-user sectors at the household level are prerequisites for formulation of bioenergy policies at regional and national level.

A number of studies have been conducted on various aspects of the use of biomass fuels in Bangladesh. Kennes et al. (1984) investigated household energy consumption pattern in Bangladesh. Sarkar and Islam (1998) studied biomass fuels situation in three villages at the northern region of the country. Bari et al. (1998) studied biomass energy use at household level in two villages in the northwestern dry region. Akhter at al. (1999) studied the homestead biomass fuels energy situation of a forest rich district Cox's Bazar of southeastern region. Miah et al. (2003) studied biomass fuels use by the rural households at four villages of Hathazari upazila of Chittagong region. Jashimuddin et al. (2006) investigated the preference and consumption pattern of biomass fuels in four villages of Sandwip and Noakhali Sadar upazila of southern coastal region. Akther et al. (2010) conducted a survey on domestic use of biomass fuels in eight villages in Raipura upazila of central region. Miah et al. (2010) carried out a study on the rural household energy consumption pattern in disregarded villages at Chandanaish upazila of Chittagong region. Asaduzzaman et al. (2010) described rural energy realities in Bangladesh based on 2004 BIDS (Bangladesh Institute of Development Studies) periodical survey. However, most of these studies focused on either specific area or village level or dealt with lesser extent to supply and consumption pattern of biomass fuels. Apart from these studies, there is little information available on current rural household energy consumption pattern in terms of types of fuel, physical quantity and amount in energy unit of the fuels, sources of fuels, and energy expenditure. Moreover, current information on rural household energy consumption pattern in different agro-ecological zones (AEZ) of Bangladesh is still lacking. In this study, household survey was carried out in *disregarded* (areas are situated far from natural gas supply) four *upazilas* (government administrative unit under a district) located in four different AEZs of Bangladesh to understand the cross-sectional variations in energy consumption pattern and their driving factors at the rural household level. The study quantifies the knowledge and understanding of the rural households' total energy and bioenergy consumption pattern, types and sources of fuels, and energy expenditure. In addition, to find out the relationship between bioenergy consumption and different socio-economic variables such as household size, household income, homestead area, agricultural land, educational status, and housing types of the rural households. The outcomes of this study are expected to be useful for sustainable energy planning and development in Bangladesh and many other developing countries.

2. MATERIALS AND METHODS

2.1 Ecological and geographical description

Field study was carried out from September to December 2010 at four upazilas located in four distinct AEZs of Bangladesh. Administratively the country is divided into 64 districts and physiographically into 30 AEZs (BBS 2010). However, the four upazilas were purposively selected for the study, namely Kalaroa upazila of Satkhira district, Nachole upazila of Chapai-Nabwabganj district, Nakla upazila of Sherpur district and Chakaria upazila of Cox's Bazar district. Kalaroa upazila is situated at 22°52.5′N latitude and 89°2.5′E longitude and lies in High Ganges River Floodplain region (AEZ ID 11). This region includes the western part of the Ganges River Floodplain, which is predominantly high land to medium highland. The general soil types are predominantly calcareous alluvium, calcareous dark grey floodplain soils, and calcareous brown floodplain soils. Soils are slightly alkaline in reaction and general fertility level is low. The Nachole upazila is situated at 24°43.8′N latitude and 88°25.2′E longitude, being a part of Barind Tract. The upazila is constituted of two major physiographic zones: the Level Barind Tract (AEZ ID 25) which covers 91% of the area, and the Ganges Floodplain (AEZ ID 10), which covers 9% of the area mostly located on the western side. In Level Barind Tract, the landscape is almost level and locally irregular along river channels. The general soil type is terrace soils and characterized by low moisture holding capacity, slightly acidic, and low soil organic matters. On the other hand, the general soil characteristic of the Ganges Floodplain is a complex mixture of calcareous sandy, silty and clay alluvium. Soils content low organic matters and mildly alkaline in reaction.

The Nakla upazila lies at 24°59′N latitude and 90°11′E longitude. It is located at the central-northern part of the country, about 40 km south of the foot hills of the Meghalaya State of India. The upazila lies at Old Brahmaputra Floodplain region (AEZ ID 9), which consists of broad ridges and basins. The soils of the area are predominantly silt loams on the ridges and clay in the basins. The climate of the upazila is tropical but influenced by subtropical climate. The Chakaria upazila is located at 21°79′N latitude and 92°08′E longitude. The upazila is situated at the Chittagong Coastal Plain region (AEZ ID 21), which is characterized by river, tidal and estuarine floodplain landscape. The general soil types are non-calcareous grey floodplain soils, non-calcareous alluvium, and acid sulphate soils. The general climate data such as monthly average maximum and minimum temperature, relative humidity (R.H.), and annual precipitation of the study area are given in Table 1. Nevertheless, all these upazilas are situated far from natural gas supply area and hence they are referred as *disregarded*.

2.2 Sampling procedure and data collection

The study involved a socio-economic survey on household energy consumption pattern in the selected four upazilas of Bangladesh. Prior to the final survey, a preliminary reconnaissance survey was conducted in order to have an overview of the study sites. The information of the preliminary reconnaissance survey was primarily collected from the respective Upazila Statistics Office (Table 1). For the selection of the households, the study followed a two-stage random sampling technique where the upazilas served as the primary sampling units and the households of the villages served as the ultimate sampling unit. The sequence of sampling was from upazila to union (local government unit under *upazila*), from union to village, and then from village to households. Two unions from each upazila and two villages from each union were randomly selected. The information of the reconnaissance survey on the number of households, landholding, and the households' income from each selected villages were obtained from the concerned *union parishad* (local government office). Based on household income, the households of each selected villages were broadly categorized into three socio-economic groups (BBS 2010): rich (income more than 12000 BDT or 120 € or 160 \$ month^{-1}), medium (income between 6000 to 12000 BDT or 60 to 120 € or 80 to 160 \$ month^{-1}), and poor (income less than 6000 BDT or 60 € or 80 \$ month^{-1}). The reconnaissance survey showed that in the study areas about 8% of the households were rich, 32% were medium and 60% were poor. Nonetheless, from the household socio-economic group tables, a minimum of 15 households (five households from each socio-economic group) from each village were randomly selected. After selecting the villages and households, location of the households were identified with the help of the local volunteers (in most cases, the respective ward member of the union parishad) provided by the belonging union parishad office. With the help of local volunteers, the final locations of the households were determined and thus data collection was completed. The final sample consisted of 240 households from 16 villages under 8 unions and 4 upazilas. The list of selected unions and villages for the study is given in Table 2.

Table 1 Profile of the study area

Basic information	Name of upazila			
	Kalaroa	Nachole	Nakla	Chakaria
Area (km^2)	232.64	283.68	172.29	643.46
Population	221596	97119	176703	503390
Population density (person/km^2)	953	342	1026	782
Urban population (%)	12	2	9	10.0
Distance from district headquarter (km)	22	30	19	40
Number of union	12	4	9	17
Number of village	141	220	117	340
Number of household	50625	16940		84434
Literacy rate (%)	45.59	24.7	67.4	31.03 %
Number of river flow	2	1	2	7
Agriculture land (ha)	14681	20524	10079	4080.57
Forest land (ha)	0	0	0	5081.87
***Monthly average max. temp. (°C)**	35.5	37.5	34.0	33.9
***Monthly average min. temp. (°C)**	12.8	11.6	13.2	15.9
***Monthly average min. and max. R.H. (%)**	67-84	58-85	64-86	61-90
***Annual precipitation (mm)**	2287	1239	11653	3299

Source: BBS (2010); *Climate data based on nearest meteorological station

Table 2 Selected unions and villages for the study

AEZ Classification ID	Upazila	Union	Village
AEZ ID 11	Kalaroa	Sonabaria	Uttar Sonabaria, Madra
		Koila	Koila, Alaipur
AEZ ID 25	Nachole	Nezampur	Tikoil, Bansbaria
		Fatipur	Takahara, Amlaine
AEZ ID 9	Nakla	Chandrakona	Bandatiki, Huzurikanda
		Talki	Bibirchar, Shailampur
AEZ ID 21	Chakaria	Badarkhali	Badarkhali East, Badarkhali West
		Ilishia	Chuarphari, Darbeshkata

Primary data were collected through household surveys. The head of the household was interviewed using a semi-structured questionnaire consisting of 20 questions (both open and closed ended questions). The interview was based on memory recall and estimates. The respondent was asked to provide their socio-demographic information such as their family size, occupation, education level, homestead area, total land holding, type of housing, and monthly income. Subsequently, they were requested to provide the information on types and sources of energy use, monthly consumption of different energy fuels, type and sources of biomass fuels, monthly consumption of various biomass fuels, purposes of different biomass fuels use, monthly expenditure for different energy fuels, and some general trend of fuels supply. While exploring their energy expenditure, the households were requested to provide the actual amount (amount in Bangladeshi Taka (BDT); 100 BDT= ~ 1 € = ~ 1.33 \$ based on December 2010 rates) per month as they directly paid for the energy fuels.

All data were collected through interviewing the head of the household and direct observations. Some of the information (10% of the total household information that means altogether 24 households; 2 households from each of the 3 socio-economic groups in each upazila) provided by the head of the household were cross-checked through spot measurement with the help of local volunteers as well as from the members of the respective households. The facts were mainly types and purposes of energy use, monthly amount of different energy and biomass fuels consumption, and monthly household energy expenditure. While assessing the monthly different biomass fuels consumption, the data were adjusted with further discussion with the respective households.

2.3 Data processing and analysis

In order to calculate the household monthly primary energy consumption, the physical quantities of direct consumption of energy fuels were collected from the household surveys. Physical data for five energy fuels were recorded in a number of different physical units, e.g. kilogram (kg) for biomass and candle, liter (l) for kerosene and LPG, and kilowatt hour (kWh) for electricity. Thus, at the first step, the energy contents of different energy fuels were converted into a uniform physical unit MJ (mega joules). In this study, the energy value of per unit electricity, kerosene, LPG and candle were considered as 3.60 MJ/kWh, 37.60 MJ/l, 26.0 MJ/l, and 42.0 MJ/kg respectively, followed by available energy conversion unit. The energy content of all major indentified biomass fuels at 25-30% moisture content level with LHV (lower heating value) were considered for the analysis. In this study, the energy value of firewood, leaves and twigs, bamboo, rice husk, rice straw, jute stalk, other crop residues, and cow dung was considered as 15 MJ/kg, 12.50 MJ/kg, 15 MJ/kg, 12.760 MJ/kg, 12.24 MJ/kg, 12.76 MJ/kg, 12.60 MJ/kg and 11.60 MJ/kg respectively, for the estimation (see Kennes et al. 1984; BBS 1998; Eusuf et al. 1987; Hossain et al. 1994; Zaman 2006; Hassan et al. 2011 for details of energy content in different biomass fuels). In this analysis, the physical quantities and energy value of wood residues were adjusted with firewood. In addition, all agricultural crop residues except rice and jute crop were denoted as other crop residues. However, in the second step, the consumed total energy and bioenergy quantities in MJ were converted into GJ (giga joules) and subsequently divided by the number of family members to arrive at per capita primary total energy and bioenergy consumption in GJ. The data processing and analyses were performed with the statistical package SPSS version 19.0. ANOVA and Pearson correlation tests were carried out to understand the differences and relationship between the variables. Finally, a linear regression model was constructed to show the relationship between household bioenergy consumption and different socio-economic parameters such as household family size, household income, homestead area, agricultural land, educational status, occupation, and housing types.

3. RESULTS

3.1 Socio-economic background

The household respondents were 73% male and 27% female. The average family size of the household was 6.08 persons household^{-1}. The average income of the household was 11815 BDT month^{-1}. The income of the rich, medium, and poor household was 20888 BDT, 10150 BDT and 4408 BDT month^{-1} respectively. The average homestead area was only 0.11 ha household^{-1} of which in rich, medium and poor household it was 0.20 ha, 0.09 ha, and 0.03 ha respectively. The average agricultural land holding was 0.91 ha household^{-1}of which in rich, medium and poor household it was 1.97 ha, 0.68 ha and 0.09 ha respectively. The literacy rate of the respondents was about 63% of which approximately 40% belonged to the primary level, 15% to the school level and 8% to the university level education. About 35% of the respondents practiced farming, 20% labor, 12% business and 11% service. The housing pattern of the respondents was 41% kacha (earthen), 44% semi-pucca (brick and clay) and only 15% pucca (brick and cement). There was a significant relationship ($R=0.60$; $p<0.01$) between household income and dwelling pattern.

3.2 Types of fuels

Most of the rural households use more than one type of fuel for their everyday domestic energy needs. The major sources of energy supply in the study area were identified as biomass, grid electricity, kerosene, candle and LPG. Biomass constituted the predominant source of energy supply of the study area. All household respondents reported to use biomass for their energy sources. On an average 98% of the households used kerosene, 56% had access to grid electricity, 10% used candle and only 4% used LPG. No household was found to use LPG in Nachole upazila. All socio-economic household groups (rich, medium and poor) indiscriminately used different types of biomass fuels for household cooking, rice parboiling, jaggery making, and for others purposes such as water boiling and preparing food for livestock. Kerosene is mainly used for lighting by both non-consumer and consumer households of the grid electricity. About 96% of the rich, 98% of the medium and all poor households reported to use kerosene. However, the rich and medium households were the main consumers of grid electricity. About 86% of the rich, 68% of the medium and only 14% of the poor households used grid electricity for lighting. Use of candle for lighting was restricted to the rich and the medium households. One-fourth of the rich households and only 5% of the medium households reported to use candle for lighting. The rich households exclusively used LPG whereas approximately 13% of them reported to use it mainly for tea preparation, milk simmering, and heating of food.

3.3 Consumption of fuels

The average consumption of biomass fuels was about 219 kg household^{-1} month^{-1} (Table 3). Consumption of biomass fuels was highest in Chakaria (252 kg household^{-1} month^{-1}) and lowest in Nachole upazila (197 kg household^{-1} month^{-1}). The average consumption of biomass fuels among the rich, medium and poor households were about 266 kg month^{-1}, 222 kg month^{-1}, and 168 kg month^{-1} respectively (Table 4). However, monthly average kerosene consumption was 2.39 l household^{-1} month^{-1} whereas such consumption was highest in Chakaria (3.08 l household^{-1} month^{-1}) and lowest in Kalaroa (1.89 l household^{-1} month^{-1}). There was no remarkable difference in monthly kerosene consumption between the socio-economic groups. The average household electricity consumption was 29.63 kWh household^{-1} month^{-1}, and such consumption was highest in Nakla upazila (38.08 kWh household^{-1} month^{-1}) and lowest in Chakaria upazila (16.83 kWh household^{-1} month^{-1}). The average electricity consumption in rich, medium and poor households were 53.31 kWh month^{-1}, 30.43 kWh month^{-1} and 5.15 kWh month^{-1} respectively. The average consumption of candle was only 0.04 kg household^{-1} month^{-1}. One-fourth of the households in Nakla upazila were reported to use candle for lighting. The average candle consumption in the rich and medium households was only 0.10 kg month^{-1} and 0.01 kg month^{-1} respectively. Due to high fuel price and uncertain supply, rural households consumed less amount of LPG and the average consumption was only 0.27 l household^{-1} month^{-1}. Only 8 rich households (4 from Nakla, 3 from Kalaroa and 1 from Chakaria) reported to use LPG and the average consumption was only 0.8 l month^{-1}. The consumption of electricity, candle, and LPG significantly varied between the socio-economic groups (df=2; F=76.76, 15.30, and 11.09 respectively; $p<0.01$).

Table 3 Monthly fuels consumption by rural households

Upazila	Biomass (kg)	Kerosene (l)	Electricity (kWh)	Candle (kg)	LPG (l)
Kalaroa(N=60)	206.77(±48.93)	1.89(±0.60)	30.90(±26.35)	0.02(±0.06)	0.43(±1.65)
Nachole (N=60)	197.00(±68.35)	2.20(±0.63)	32.70(±30.30)	0.02(±0.10)	0.00(±0.00)
Nakla(N=60)	216.23(±72.43)	2.40 (±0.81)	38.08(±38.46)	0.10(±0.23)	0.53(±1.80)
Chakaria (N=80)	255.00(±64.39)	3.08(±1.47)	16.83(±25.73)	0.03(±0.02)	0.12(±0.90)
Average(N=240)	218.75(±67.45)	2.39(±1.03)	29.63(31.44)	0.04(±0.14)	0.27(±1.31)

Note: Parenthesis denotes the standard error of mean

Table 4 Monthly fuels consumption by socio-economic household groups

Socio-economic groups	Biomass (kg)	Kerosene (l)	Electricity (kWh)	Candle (kg)	LPG (l)
Rich (N=80)	266.34(±67.49)	2.47(±1.26)	53.31(±32.16)	0.10(±0.22)	0.81(±2.18)
Medium (N=80)	221.48(±54.44)	2.49(±1.05)	30.43(±24.47)	0.01(±0.04)	0.00(±0.00)
Poor (N=80)	168.44(±37.16)	2.21(±0.69)	5.15(±13.48)	0.00(±0.00)	0.00(±0.00)

Note: Parenthesis denotes the standard error of mean

3.4 Consumption of biomass fuels

Firewood, leaves and twigs, bamboo, rice husk, rice straw, jute stalk, other crop residues, and cow dung were the main biomass fuels of the rural households. It was found that about 30% of the households used bamboo, 22% used rice husk, 88% used rice straw, 49% used jute stalk, 72% used other crop residues, 60% used cow dung, and 16% used wood residues. No household reported to use jute stalk for energy purposes in Nachole and Chakaria upazila. The reason is that the farmers of these upazilas do not cultivate jute crop. It was observed that the households of Nakla upazila did not use cow dung for energy purposes. They mostly used cow dung as manure for agriculture. Many households reported that they deposited cow dung in a small shady ditch for decomposition and seasonally they sold it for cash.

Firewood appeared to be the most dominant biomass fuel followed by leaves and twigs. However, in Nachole upazila, cow dung formed the second dominant biomass fuel followed by leaves and twigs. Nevertheless, the average consumption of firewood was 94 kg household^{-1} month^{-1} (Table 5). Due to better supply of firewood from the neighboring government owned forests, the consumption of firewood was high in Chakaria upazila (156 kg household^{-1} month^{-1}). In contrast, due to fewer forest resources in Nachole upazila, the consumption of firewood was low (49 kg household^{-1} month^{-1}). Furthermore, the consumption of firewood in rich, medium and poor households was 118 kg month^{-1}, 95 kg month^{-1}, and 70 kg month^{-1} respectively (Table 6). Consumption of firewood among different socio-economic groups was highly significant (df=2; F=19.44; $p<0.01$). It was observed that many rural households usually preferred to have low-cost or free of cost fuels. In this perspective, higher amount of leaves and twigs consumption for energy use in the study area can be validated. The average consumption of leaves and twigs was 59 kg household^{-1} month^{-1}. The consumption of leaves and twigs among socio-economic groups was significantly different (df=2; F=5.33; $p<0.05$). The households, who had limited access to firewood, mainly depended on leaves and twigs, and agricultural crop residues for their biomass fuels. However, the average consumption of bamboo was about 4 kg household^{-1} month^{-1}, rice husk was 2 kg household^{-1} month^{-1}, rice straw was 8 kg household^{-1} month^{-1}, jute stalk was 7 kg household^{-1} month^{-1}, and other crop residues was 8 kg household^{-1} month^{-1}. The result showed that the consumption of bamboo, rice husk, and jute stalk among different socio-economic groups were significantly different (df=2; F=93.86, 21.41, and 15.03 respectively; $p<0.01$).

However, the consumption of rice straw, and other crop residues among the groups were not significantly different and indicated that rice straw, and other crop residues were indiscriminately used by all social groups. Nevertheless, cow dung is one of the most important traditional biomass fuels in rural Bangladesh. The average consumption of cow dung was about 37 kg household^{-1} month^{-1}. Higher amount of cow dung was used as fuel in Nachole upazila, where the average household consumption was 78 kg household^{-1} month^{-1}. The consumption of cow dung among socio-economic groups was significantly different (df=2; F=3.86; p<0.05).

Table 5 Monthly consumption of biomass fuel by rural households (biomass fuel in kg)

Upazila	Firewood	leaves and twigs	Bamboo	Ricehusk	Ricestraw	Jute stalk	Other crop residues	Cowdung
Kalaroa (N=60)	76.57 (±23.88)	58.05 (±12.59)	2.28 (±2.52)	4.43 (2.79)	5.10 (±3.65)	9.95 (±3.69)	20.30 (±7.75)	30.08 (±24.80)
Nachole (N=60)	48.68 (±22.40)	50.60 (±14.73)	3.97 (±3.84)	1.98 (±2.71)	11.40 (±6.76)	0.00 (±0.00)	2.30 (±2.81)	78.07 (±33.53)
Nakla (N=60)	96.15 (±37.68)	83.28 (±23.46)	4.12 (±4.44)	1.18 (±1.13)	4.57 (±4.62)	18.15 (±12.19)	8.78 (±5.44)	0.00 (±0.00)
Chakaria (N=60)	155.89 (±50.18)	42.83 (±15.56)	5.13 (3.98)	0.00 (±0.00)	9.77 (±12.04)	0.00 (±0.00)	1.15 (±4.68)	40.23 (±36.90)
Average(N=240)	94.32 (±52.83)	58.69 (±22.80)	3.88 (±3.88)	1.90 (±2.40)	7.71 (±8.02)	7.03 (±9.90)	8.13 (±9.36)	37.10 (±39.33)

Note: Parenthesis denotes the standard error of mean

Table 6 Monthly consumption of biomass fuel by socio-economic groups (biomass fuel in kg)

Socio-economic groups	Firewood	leaves and twigs	Bamboo	Ricehusk	Ricestraw	Jute stalk	Other crop residues	Cowdung
Rich (N=80)	118.41 (±53.41)	64.86 (±28.64)	6.96 (±3.93)	3.15 (±2.83)	9.31 (±9.41)	11.24 (±13.43)	9.53 (±10.20)	42.88 (±47.86)
Medium (N=80)	94.61 (±52.45)	57.81 (±20.12)	4.00 (±2.85)	1.88 (±2.57)	7.03 (±7.27)	6.70 (±8.35)	8.33 (±9.38)	41.13 (±38.92)
Poor (N=80)	69.94 (±40.62)	53.40 (±16.74)	0.66 (±1.35)	0.68 (±1.60)	6.79 (±7.03)	3.14 (3.61)	6.55 (±8.26)	27.29 (±26.98)

Note: Parenthesis denotes the standard error of mean

3.5 Sources of biomass fuels

Rural households collect their biomass fuels from mainly homestead, government forests (both reserve forests and secondary plantation areas), and local market The study showed that 42% of the households collected firewood from their own homestead, 1% from neighbors, 4% from government forests, 3% from market, and 50% from more than one sources. About 53% of the households collected leaves and twigs from their own homestead, 2% from neighbors, and 45% from own homestead, neighbors and other sources. Approximately 30% of the households used bamboo as fuel of which 28% collected it from their own homestead, and 2% from neighbors. Only 21% of the households used rice husk as fuel and they mainly collected it from their own farms. On the other hand, 88% of the households reported that they used rice straw for energy specially for rice parboiling. About 53% of them collected rice straw from their own agricultural land, 22% from open agriculture fields, and about 12% from both own agricultural land and open agriculture fields. Jute stalk is collected after being separated from jute fiber during retting. About 49% of the households reported that they used jute stalk as energy source of which 33% of them collected jute stalk from their own farmland, 10% from neighbors, and 6% from both the sources. About 72% of the households used other crop residues as fuel. Approximately 49% of them collected other crop residues from their own farmland, 18% from neighbors, and 5% from both the sources. About 62% of the households reported that they used cow dung as fuel of which 46% of them collected cow dung from their own farms, 9% from neighbors, 5% from both the sources and only 2% from market. Nearly 16% of the households used wood residues for fuel. Sawmills and local markets are the main suppliers of wood residues. About 14% of the households collected it from local markets and only 1% from their own farms.

3.6 Rural household energy consumption

Bioenergy dominates in rural household energy consumption. The average household total energy and bioenergy consumption was 3.16 GJ month^{-1} and 2.95 GJ month^{-1} respectively (Figure 1). Highest household energy consumption was observed at Chakaria upazila, where the total energy and bioenergy consumption was 3.73 GJ month^{-1} and 3.55 GJ month^{-1} respectively. The lowest household energy consumption was observed in Nachole upazila where the total energy and bioenergy consumption was 2.72 GJ month^{-1} and 2.52 GJ month^{-1} respectively. However, the total energy consumption among the rich, medium and poor households was 3.93 GJ month^{-1}, 3.18 GJ month^{-1}, and 2.36 GJ month^{-1} respectively, whereas the average household bioenergy consumption was 3.61 GJ month^{-1}, 2.98 GJ month^{-1}, and 2.26 GJ month^{-1} respectively (Figure 2). Both total energy and bioenergy consumption in different socio-economic groups was highly significantly (df=2; F=78.67 and 62.67 respectively; p<0.01). The relationship between household total energy and bioenergy consumption was highly significant (R=0.99; p<0.01). It indicated that the total energy consumption of the rural households depend on the consumption of bioenergy.

Per capital energy consumption in the study areas was very low. The average household per capita total energy and per capita bioenergy consumption was 0.54 GJ month^{-1}and 0.50 GJ month^{-1} respectively (Figure 3). Per capita total energy and per capita bioenergy consumption was highest in Kalaroa upazila where the average consumption was 0.58 GJ month^{-1} and 0.55 GJ month^{-1} respectively. Per capita total energy and per capita bioenergy consumption was lowest in Nachole upazila, which was 0.50 GJ month^{-1} and 0.47 GJ month^{-1} respectively. Per capita total energy consumption among the rich, medium and poor households was 0.59 GJ month^{-1}, 0.54 GJ month^{-1}, and 0.49GJ month^{-1} respectively, while per capita bioenergy consumption was 0.54 GJ month^{-1}, 0.50 GJ month^{-1}, and 0.47 month^{-1} respectively (Figure 4). Per capita total energy and per capita bioenergy consumption significantly varied within socio-economic groups (df=2; F=19.89 and 11.65 respectively; $p<0.05$). The results showed that there was a significant relationship between household per capita total energy consumption and per capita bioenergy consumption ($R=0.99$; $p<0.01$). While converting the per capita energy consumption from person^{-1} month^{-1} to person^{-1} year^{-1}, the result showed that the average household total energy consumption was 6.45 GJ person^{-1} year^{-1} of which the share from biomass fuels was 6.03 GJ person^{-1} year^{-1}. The result indicated that the consumption is still on subsistence level.

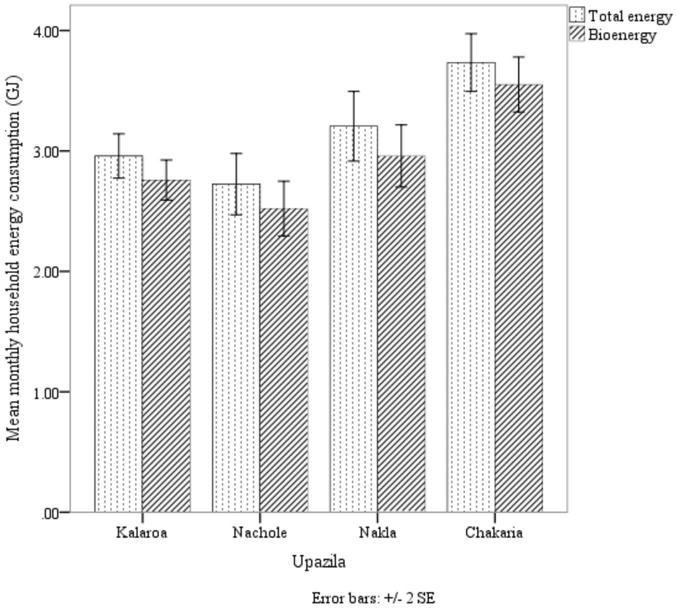

Figure 1 Mean monthly total energy and bioenergy consumption by rural households

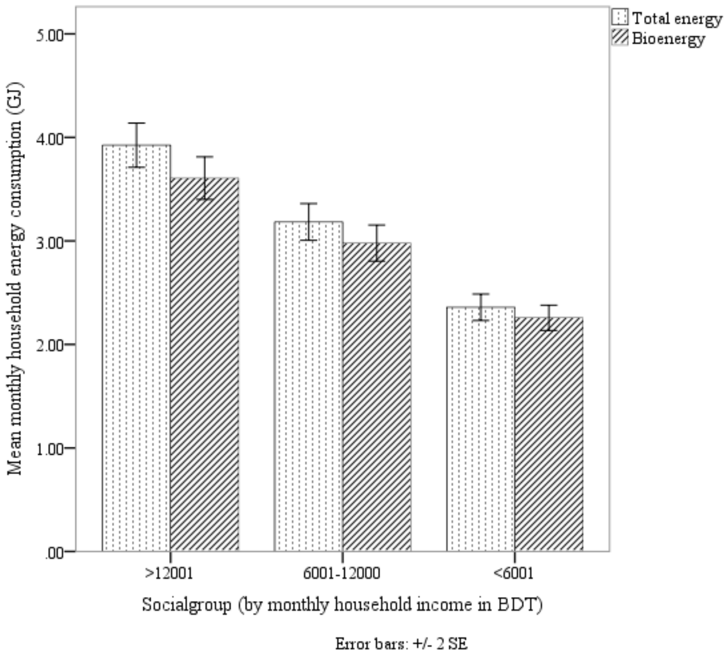

Figure 2 Mean monthly total energyand bioenergy consumption by socio-economic groups

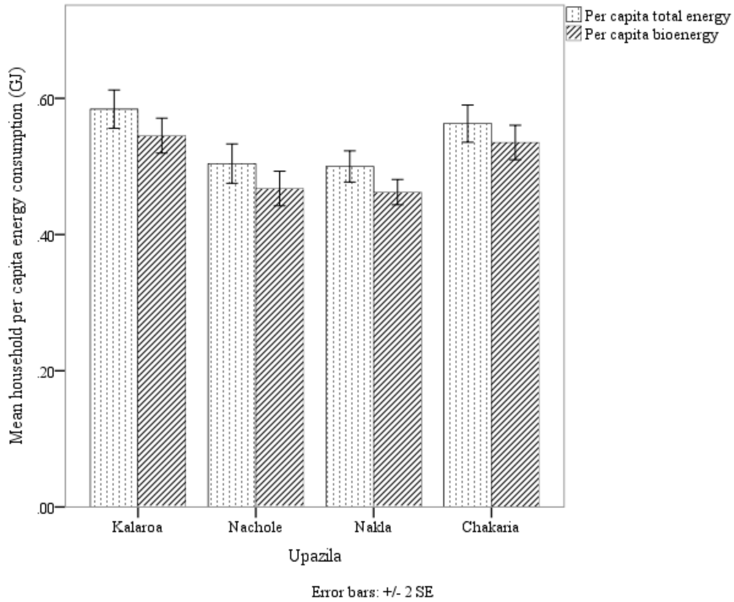

Figure 3 Mean monthly percapita total energy and bioenergy consumption by rural households

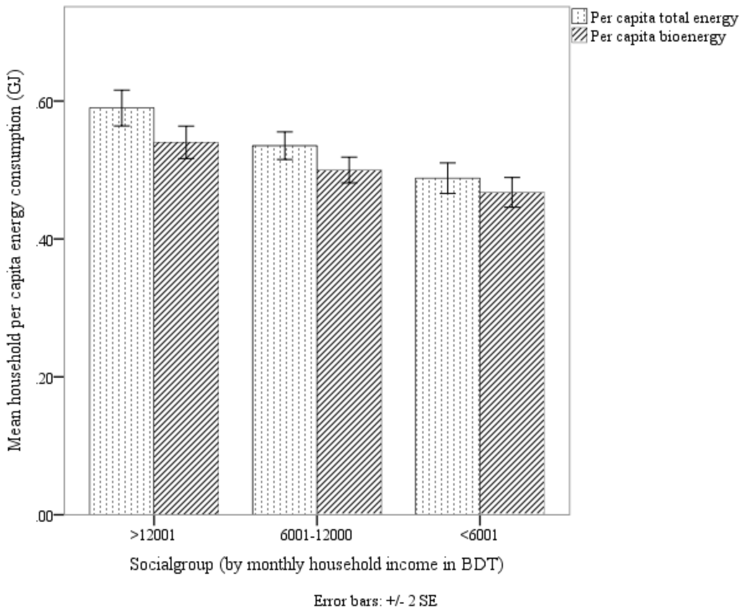

Figure 4 Mean monthly percapita total energy and bioenergy consumption by socio-economic groups

3.7 Share and purposes of fuels

Biomass fuels contributed about 93% in household total primary energy consumption. Commercial fuels amounted approximately 7% of household energy supply of which the share of 3.5% from grid electricity and 3% from kerosene, while candle and LPG together constituted nearly 0.5%. Except LPG, all commercial fuels are used for lighting purpose. LPG is used for household cooking. The rural households did not report use of kerosene stove for cooking. Nevertheless, all biomass fuels were used for household cooking, rice parboiling and for other uses such as water boiling, jaggery making, and food preparation for livestock. Cooking energy is vital which amounting about 94% of the total energy consumption. On an average 88% of biomass fuels was used for cooking, 10 % for rice parboiling and 2% for other uses (Table 7). In Chakaria upazila, the households used 99% of the biomass fuels for cooking, whereas in Kalaroa upazila the households used about 84% of the biomass fuels for the same purpose. In Kalaroa upazila, the households used about 13% of the biomass fuels for rice parboiling, whereas in Chakaria upazila such practice is entirely non-existence. Furthermore, the households of Kalaroa upazila used a considerable percentage of biomass fuels for other uses, specially, for jiggery making. It was found that the poor used 91% of their biomass fuels for cooking whereas the medium and the rich used 87% and 86% respectively of their biomass fuels for the same purpose (Table 8). The result showed that there were significant differences in biomass fuels used for cooking, rice parboiling and other use between the socio-economic groups (df=2; F=12.55, 6.23 and 28.54 respectively; $p<0.01$).

Table 7 Purpose of biomass fuel used by rural households (in %)

Upazila	Cooking	Rice parboiling	Other uses
Kalaroa (N=60)	83.50(±4.24)	12.87(±2.40)	3.63(±2.63)
Nachole (N=60)	85.70(±3.68)	12.67(±2.97)	1.65(±1.36)
Nakla (N=60)	85.45(±3.25)	12.60(±2.57)	1.97(±1.75)
Chakaria (N=60)	99.02(±1.35)	0.00(±0.00)	0.98(±1.35)
Average(N=240)	88.42(±7.01)	9.53(±5.97)	2.05(±2.08)

Note: Parenthesis denotes the standard error of mean

Table 8 Purpose of biomass fuel used by socio-economic groups (in %)

Socio-economic groups	Cooking	Rice parboiling	Other uses
Rich (N=80)	86.41(±7.04)	10.50(±6.19)	3.15(±2.08)
Medium (N=80)	87.41(±7.14)	10.45(±6.21)	2.10(±1.81)
Poor (N=80)	91.42(±5.84)	7.65(±5.06)	0.93(±1.73)

Note: Parenthesis denotes the standard error of mean

3.8 Energy expenditure

The rural households spent on an average about 5% of their income for their primary energy supply. Most of the rural households collected substantial amount of biomass fuels with free of cost from their homegardens, agricultural farms, and to some extent from neighbors and forests. High proportion of the households' income was spent for energy purposes in Chakaria upazila (about 9% of households' income) and low portion was observed in Nachole upazila (3% of households' income). The poor households spent about 6% of their income for their energy supply whereas the medium and the rich households spent about 5% and 4% recpectively of their income for the same purpose. The average total energy expenditure was about 507 BDT household^{-1} month^{-1} consisted of the expenditure for biomass fuels about 80 BDT, electricity 150 BDT, kerosene 143 BDT, candle 6 BDT, and LPG 27 BDT (Table 9). The expenditure for biomass fuels was considerably high in Chakaria upazila where the expenditure was 548 BDT month^{-1} household^{-1}. On an average, rural households spent about 36% of their monthly energy budget for biomass fuels, 29% for electricity, 28% for kerosene, 1% for candle and nearly 5% for LPG. Two households from Chakaria reported that they did not use any commercial fuels for lighting because they were dependent on solar panel for lighting. However, the study showed that there was a positive relationship between household income and household energy expenditure ($R=0.54$; $p<0.01$), indicating that households with higher income could afford to consume various modern fuels. The rich households spent nearly double for energy supply than that of the poor. The monthly energy expenditure for the rich, medium and poor households was about 736 BDT, 500 BDT, and 284 BDT respectively (Table 10). There were significant differences in total energy expenditure among the rich, medium and poor households ($df=2$; $F=39.68$; $p<0.01$) but no significant differences among the socio-economic groups for biomass fuels expenditure. The results showed that there were negative and significant relationships between biomass expenditure and households' homestead area ($R=0.18$; $p<0.01$), and between biomass fuels expenditure and households' landholding ($R= -0.23$; $p<0.01$). It indicated that if a household owned bigger homestead and large agricultural landholding, then they might have collected maximum biomass fuels from their own farms. Therefore, they did not need to pay for biomass fuels resulting in less expenditure for biomass fuels.

Table 9 Monthly energy expenditure by rural households (expenditure in BDT)

Upazila	Biomass	Electricity	Kerosene	Candle	LPG	Total
Kalaroa (N=60)	74.58 (±83.34)	155.33 (±131.80)	113.25 (±35.73)	3.07 (±10.32)	43.33 (±165.05)	389.57 (±259.48)
Nachole (N=60)	14.17 (±47.02)	165.17 (±149.22)	133.25 (±38.38)	3.87 (±15.69)	0.00 (±0.00)	316.45 (±169.61)
Nakla (N=60)	84.58 (±90.33)	190.42 (±192.28)	144.33 (±50.09)	15.87 (±37.54)	53.33 (±179.89)	488.53 (±329.51)
Chakaria (N=60)	548.33 (±330.89)	88.75 (±130.71)	182.50 (±91.14)	0.53 (±4.13)	11.67 (±90.37)	831.78 (±434.55)
Average (N=240)	180.42 (±278.10)	149.92 (±156.68)	143.33 (±63.14)	5.83 (±21.78)	27.08 (±131.20)	506.58 (±369.17)

Note: Parenthesis denotes the standard error of mean

Table 10 Monthly energy expenditure by socio-economic groups (expenditure in BDT)

Socio-economic groups	Biomass	Electricity	Kerosene	Candle	LPG	Total
Rich (N=80)	217.50 (±354.37)	271.88 (±154.85)	148.88 (±76.18)	16.20 (±35.02)	81.25 (±218.21)	735.70 (±426.36)
Medium (N=80)	196.88 (±280.75)	154.00 (±121.52)	148.00 (±66.34)	1.30 (±6.67)	0.00 (±0.00)	500.18 (±298.34)
Poor (N=80)	126.88 (±158.17)	23.88 (±65.96)	133.13 (±41.22)	0.00 (±0.00)	0.00 (±0.00)	283.88 (±195.17)

Note: Parenthesis denotes the standard error of mean

3.9 Socio-economic drivers and empirical model of bioenergy consumption

Different socio-economic characteristics influenced total energy and bioenergy consumption. The parameters included household family size, household income, homestead area, agricultural land, educational status, and housing types. In general, the relationship between the household size, total energy and bioenergy consumption was strongly correlated (R= 0.85; $p<0.01$ and R=0.86; $p<0.01$ respectively). This means that the number of family members positively attributed to both total energy and bioenergy consumption, as the number of family member increases, the probability of energy consumption increases. Household income is an important parameter that influences both household total energy and bioenergy consumption. The relationship between household monthly income, monthly total energy and bioenergy consumption was highly significant (R=0.66; $p<0.01$ and R=0.61; $p<0.01$ respectively). The results indicated that households with higher income consumed more energy than households with lower income. However, there was a positive and significant weak relationship between per capita income and the consumption of total energy and bioenergy (R=0.19; $p<0.01$ and R=0.14; $p<0.05$ respectively). Households with higher per capita income are likely to have wider scope to choose different energy fuels. Nevertheless, homestead area was one of the important parameters for household bioenergy consumption since homestead is the main source of firewood supply for the rural households. The study showed that there were significant and positive relationship between homestead area, total energy and bioenergy consumption (R=0.44; $p<0.01$ and R=0.40; $p<0.01$ respectively). Per capita homestead area also considerably influenced both total energy and bioenergy consumption. There were positive and significant weak relations between per capita homestead area and consumption of total and bioenergy (R=0.20; $p<0.01$ and R=0.15; $p<0.05$ respectively). Also there was significant and positive relationship between landholdings and the consumption of total and bioenergy (R=0.38; $p<0.01$ and R=0.34; $p<0.01$ respectively). Similarly, per capita agriculture land also somewhat influenced on both total energy and bioenergy consumption (R=0.18; $p<0.01$ and R=0.13; $p<0.05$ respectively). It indicated that higher the per capita agriculture land, the bigger probability for consumption of crop residual biomass increase. It was also found that the educational status of the head of the household positively influenced both in total energy and bio energy consumption (R=0.19; $p<0.01$ and R=0.16; $p<0.05$ respectively). It means that, as the educational status of the household member increases, the probability of opting for comforts in terms of better quality fuel consumption and energy consumption increases. One important finding was the relationship between housing type with total energy and bioenergy consumption that was significant that implying somewhat linear relationship (R=0.34; $p<0.01$ and R=0.29; $p<0.01$ respectively). In other words, the households with better quality house (pucca) are likely to use more fuels (better quality biomass fuel like firewood, and modern fuels like electricity, and LPG) than that of households having kacha housing. Based on different socio-economic parameters, the study constructed an empirical model for monthly household bioenergy consumption.

The model appeared to be significant (F=239.35; Adjusted R^2=80; $p<0.01$). The model provided with estimates for the coefficients of several household demographic parameters such as number of family member, per capita monthly income, per capita homestead area and per capita agriculture land for household monthly bioenergy consumption in rural areas of Bangladesh. In the model, the key parameter was the number of family member of the household, which explained the maximum values of the variables. To compute step-wise differences, the model excluded two parameters- per capita homestead area, and per capita agriculture area. It means that the inclusion of the parameters per capita homestead area and per capita agriculture in the model are important but do not influence enough in household monthly bioenergy consumption.

4. DISCUSSION

The study provides a comprehensive overview of the total energy and bioenergy consumption pattern at the household level in rural areas of Bangladesh. The survey methodologies applied here were similar to previous studies (Howes 1985: Rao and Reddy 2007; Akthar et al. 2010; Miah et al. 2010). In our study, the questionnaire survey was carried out with a relatively large sample. However, there were some uncertainties involved in the estimation since the respondents were requested to provide information concerning energy usage, expenditure and so on from a previous week or month. It was observed that most of the households had a tendency to over-estimate the consumption of biomass fuels. Probably, they did not consider the moisture content level in the fuels while making the estimation. This was observed after the spot measurement when the differences between the fresh and air-dried weight of the fuels were measured. Thus, the information on household energy used may not always be accurate. However, it provided an approximation, which was validated by the spot measurement. Regarding the energy expenditure, the households provided almost correct figures as they actually spent that amount per month for different energy fuels. Spot measurement in this case could also provide us with an actual figure. However, it becomes challenging for a large study like the present one as it involves much labor and cost. Therefore, in this study about 10% of the household information was verified through spot measurement. The importance of spot measurement to obtain accurate information of the household energy use was also emphasized in previous studies (see Morgan et al. 1980; Bhatia and Sharma 1990; Bari et al. 1998).

The study showed that biomass was predominantly used as the cooking fuel by the rural households in Bangladesh. The use of LPG as the primary cooking fuel was non-existent among the rural households in the study areas except in some rich households who used it occasionally for cooking. The rich and medium rural households primarily used electricity, kerosene and candle for lighting purposes while most of the poor households used kerosene for lighting. It was noted that the consumption of electricity, kerosene and candle was constantly growing. At the same time, other renewables especially solar photovoltaic (PV) and biogas plant are gaining acceptance in the study area. The study revealed that all the rural households used biomass fuels and kerosene, slightly more than 50% of them had access to grid electricity, and only a minority of them used candle and LPG. Such type of fuel consumption pattern was consistent with the previous findings in the context of rural Bangladesh (see Asaduzzaman et al. 2010; Miah et al. 2010; BBS 2010). However, this study indicates that various socio-economic conditions of the households and accessibility of modern fuels are important factors in the selection of the fuels for primary energy use.

Although biomass fuels dominate the rural energy supply in the study area, the availability of biomass fuels is not similar in all regions, which affects their consumption. Asaduzzaman and Latif (2005) found that biomass fuels consumption in rural areas of Bangladesh was 244 kg household^{-1} monthly^{-1}. Higher amount of biomass consumption was reported by Akther et al. (2010) in the rural areas of the Meghna floodplain zones where the consumption was about 665 kg household^{-1} month^{-1}. This amount of biomass consumption is extremely high if they did not take into account the moisture content of the biomass fuels at air-dried level (air-dried moisture content level varies between 25-30%). In contrast, Miah et al. (2010) observed lower amount of biomass fuels consumption. They found that the consumption was only 66 household^{-1} kg month^{-1}. A more consistent picture of biomass fuels consumption was reported by LGED and FAO (2006). Based on supply and demand balance, LGED and FAO (2006) estimated that per capita biomass fuel consumption was about 214 kg household^{-1} month^{-1}. However, our findings corroborated with the findings by Asaduzzaman and Latif (2005), and LGED and FAO (2006).

Among biomass fuels, firewood is the largest source of rural energy in terms of quantity and energy unit. Asaduzzaman and Latif (2005) found that the average consumption of firewood in rural Bangladesh was about 99 kg household^{-1} month^{-1}. Akther et al. (2010) reported that the consumption of firewood was about 144 kg household^{-1} month^{-1}. The present study revealed that the average firewood consumption was about 94 kg household^{-1} month^{-1}, which is somewhat similar with the findings of Asaduzzaman and Latif (2005). Brouwer and Falcão (2004) estimated that the average firewood consumption in Maputo city was about 90 kg month^{-1} household^{-1}. Firewood was always found to be preferred by the households to other biomass fuels, however, the supply was not sufficient. In fact, many areas particularly in Nachole upazila had acute shortage of firewood. Due to the short supply of firewood, many households were found to choose other inferior types of biomass. The general practices were to compensate firewood shortage by storage of firewood before rainy season and by reducing the frequency of cooking during crisis period. It was observed that homestead was the main source of firewood supply in Kalaroa, Nachole and Nakla upzilas whereas government forests were the main source of supplying firewood in Chakaria upazila. People traditionally collect firewood from neighboring government forests and sell it to the local markets. Such practice for firewood collection is a great concern for the health and sustainability of the neighboring government forests. It was observed that rice-husk briquettes were also available in the local markets. However, due to the high price in comparison to firewood, rural households could not buy them for household cooking. Presently, rice-husk briquettes are mostly used as fuel in tea stalls, hotels and restaurants. Rural households who are rich and have higher educational background prefer using firewood to other biomass fuels. On the other hand, households with lower income use inferior types of biomass fuels such as rice straw, leaves and twigs, and cow dung. Such type of household trend in the selection of biomass fuels was also reported in previous studies (see Bhatt and Sachan 2004a; Gupta and Köhlin 2006; Rao and Reddy 2007; Van Ruijven et al. 2008; Joon et al. 2009; Akther et al. 2010; Miah et al. 2010).

Kerosene and electricity are the main non-biomass fuels in the rural Bangladesh (Asaduzzaman et al. 2010). Our results revealed that approximately 54% of the household lighting energy is derived from electricity, 45% from kerosene and 1% from candle. The electricity distribution is still uneven in many parts of Bangladesh. There are many villages in Nachole, Nakla and Chakaria upazila that do not come under electrification network. The households of these areas mainly depend on kerosene for lighting. In addition, a major reason for the prominent use of kerosene resulted from the frequent power disruption. Asaduzzaman and Latif (2005) found that the average consumption of grid electricity, kerosene and candle by rural households were approximately 12 kWh, 2.42 l and 0.04 kg household^{-1} month^{-1} respectively while Miah et al. (2010) found that the consumption were 47.89 kWh, 1.81 l, and 0.21 kg household^{-1} month^{-1} respectively. The present study showed higher household electricity consumption than Asaduzzaman and Latif (2005), but lower than Miah et al. (2010). Household consumption of kerosene and candle for lighting corresponds with the findings of Asaduzzaman and Latif (2005). However, most of the households who have electricity facilities claimed to use kerosene lamps. Although households with electricity facilities prefer electric lighting to kerosene, however, unreliable supply influence them to use kerosene lamps frequently as an alternative in case of power failure. However, the study found that the consumption of different non-biomass fuels by rural households was still low and varied between regions.

The results showed that the total energy consumption by socio-economic groups varied from 2.36 GJ to 3.93 GJ household^{-1} month^{-1}. Indeed, more than 93% of the rural household energy is supplied from biomass fuels. Kennes et al. (1984) examined that rural household energy consumption by socio-economic classes varied from 2.30 GJ to 3.67 GJ household^{-1} year^{-1}, which was extremely low at the subsistence energy demand threshold of 5 GJ person^{-1} year^{-1} (Parikh 1978; Pachauri 2004). Study from rural areas of Gaibanda (a non-forested district of northern Bangladesh) showed that the biomass fuel consumption varied from 1.9 to 2.5 GJ person^{-1} year^{-1} depending on fuel types and family size (Sarkar and Islam 1998). Asaduzzaman et al. (2010) stated that the household energy consumption has considerably increased during the last 25-30 years at a 2.6% annual rate, which is higher than the average growth rate in per capita income. They estimated that the household energy consumption was 8.90 GJ person^{-1} year^{-1} in 2004. In our study, we found that the average household total energy and bioenergy consumption were 6.45 GJ and 6.03 GJ person^{-1} year^{-1} respectively. Studies from Bangladesh Energy Study (BES 1976), Tyers (1978) and Briscoe (1979), showed that the rural household energy consumption varied from 2.8 to 7.9 GJ person^{-1} year^{-1}. Islam (1980), Quader and Omar (1986), Islam (1987) and Alam et al. (1988) found that the energy consumption varied with specific location and the consumption varied from 4.46 to 8.81 GJ person^{-1} year^{-1}. Based on countrywide rural energy survey, Douglas (1981) estimated that the rural energy consumption was 4.82 GJ person^{-1} year^{-1}. Taking into account the economic and energy growth over the past years of the country, our results appear to be more relevant with the previous studies. A somewhat lower per capita household total energy and bioenergy consumption was observed in Nachole upazila (6.05 GJ and 5.61 GJ person^{-1} year^{-1} respectively) as a possible result from less amount of firewood consumption. The region is one of the least tree cover areas of the country (BBS 2010).

Biomass fuels are mainly used for cooking, rice parboiling and other household purposes. Asaduzzaman et al. (2010) estimated that about 90% of biomass fuels were used for household cooking and the rest for rice parboiling. In this perspective, the proportion of biomass fuels used for cooking and rice parboiling in the present study can be relevant. It was also observed that rice-parboiling was entirely non-existent in Chakaria upazila. In contrast, Sarkar and Islam (1998) reported that the households of the northern regions used considerably higher percentage of biomass fuels for rice parboiling. They found that about 60% of biomass fuels were used for cooking and 23% for rice parboiling. Miah et al. (2010) showed that rural households in eastern region used 97% biomass fuels for cooking and less than 1% for rice parboiling. However, it was observed that rural households in Kalaroa upazila used a considerable amount of biomass fuels for jaggery making from sugar candy that was derived from dates and palm trees. Such type of biomass fuels consumption for non-cooking purpose by rural households is rare in Nachole, Nakla and Chakaria upazilas.

Kennes et al. (1984) stated that the rural households of Bangladesh spent about 70% of their income for food and 30% for non-food items. They spent nearly 9% of their income for energy purposes. The present study showed that the rural households spent less. They spent about 5% of their income for energy supply purposes. Many rural households collect biomass fuels free of cost from their homestead, neighbors, government plantations, and even from open agriculture fields resulting less energy expenditure. Asaduzzaman et al. (2010) showed that rural households spent about 38% of their energy budget for biomass fuels especially for firewood. The present study found that the expenditure for biomass fuels was 36%. However, the consumption and price of non-biomass fuels especially for electricity and kerosene for lighting have considerably increased over the years. This has influenced households to spend more for energy related expenses. Household energy expenditure depends on many factors such as availability and pricing of goods, and household income. Our study examined only household energy consumption and income. It shows that the relationship is positive, which means households with higher income would spend more for their total energy consumption and use higher priced fuels like firewood and other modern fuels such as electricity and LPG. Unlike the expenditure for total energy consumption, the study found that the households with bigger homestead area spent less for biomass fuels since they collected biomass fuels from their own farms and resulting less expenditure for them. Similar phenomenon of rural household energy expenditures have been reported by many previous studies (see Bhatt and Sachan 2004a; Rao and Reddy 2007; Akther et al. 2010; Miah et al. 2010).

Previous studies (Sarkar and Islam 1998; Bari et al. 1998; Kituyi et al. 2001; Bhatt and Sachum 2004b; Pachauri 2004; Rao and Reddy 2007; Miah et al. 2010) have witnessed that family size greatly influence total energy consumption at rural household level. Our study also corresponds with this finding. It was also found that per capita energy consumption decrease with the increase of family size. In other words, per capita energy consumption increases with the decrease of family size. Such type of household energy consumption pattern was also reported by Sarkar and Islam (1998) and Bari et al. (1998) in rural areas of the northern part of Bangladesh. Apart from family size, household per capita income, per capita homestead area and per capita agricultural land are important factors for determining both total energy and bioenergy consumption. The study revealed that the relationships between the variables were positive. The inference is that households with higher per capita income, higher per capita homestead area, and higher per capita agricultural land are likely to use more energy. It is quite evident that, poorer household cannot afford modern fuels if per capita income is low (see Bhatt and Sachan 2004b; Rao and Reddy 2007). On the other hand, households with high per capita income have a great choice in selecting varieties of energy fuels and many of them opt for cleaner and more efficient modern energy fuels such as electricity and LPG. However, as time changes and society becomes more egalitarian this choice based on income may disappear. The study showed that biomass fuels dominate in rural energy supply. The bioenergy consumption model, which has been constructed in the study, is interpreting the theoretical framework of the expected determinants, which largely depend on family size and per capita income. Therefore, policy interventions must need to be directed towards altering the socio-economic factors.

One of the most important findings of the study is that firewood still appears the single largest source of rural energy supply in Bangladesh. About 90% of firewood is collected from homestead and about 10% from government forests (FAO 1998). The recent studies showed that since 1990 the production of firewood and other wood-based fuels in the country have been gradually decreasing (see BBS 2010; Mondal and Denich 2010; Hassan et al. 2011). It is important to note that the current consumption pattern of firewood in the study area does not match with the current supply. Such unsustainable consumption pattern of firewood is leading to tremendous pressure on existing resources, thus accelerating degradation and deforestation both in homestead and government forest resources. The growing population in the country will increase the demand of firewood that may bring formidable challenges in biomass fuel supply. Previous studies (see Asaduzzaman et al. 2010; Miah et al. 2010; Akther et al. 2010) have found that the gap between the demand and supply of firewood has become severe in many parts of Bangladesh. Due to the scarcity of firewood many rural households use all types of combustive biomass from their own homestead, neighbor's homestead, nearby government forests and plantation to fulfill their fuel demand. The study also found that a large portion of the households used leaves and twigs, rice straw, rice husk, other inferior types of crop residues and cow dung as energy sources. Different studies reported that inefficient consumption pattern of such biomass is rapidly depleting soil fertility and ultimately threatening the agricultural production system and causing ambient air pollution, health hazards (see Bhatt and Sachan 2004a; WHO 2006; Asaduzzaman et al. 2010; Miah et al. 2010). In Bangladesh, there still exists a wider prospect for sustainable utilization of biomass resources for clean energy services (Islam et al. 2005; Islam et al. 2006; Mondal and Denich 2010). Long-term research and development of bioenergy project is important as it could offer new possibilities to shift from the current inefficient and unsustainable consumption pattern of biomass-based fuels to a more sustainable one.

5. CONCLUSION AND RECOMMENDATION

The study provides information on current pattern of total energy and bioenergy consumption at household level in rural Bangladesh. The study showed that all rural households use biomass fuels for cooking while kerosene and electricity are used for lighting. Nearly half of the rural households have no access to grid electricity. In addition, the rural households who have access to the grid electricity are also facing troubles due to frequent power failure. However, the use of other non-biomass fuels like candle and LPG are mainly restricted to the rich households. Biomass fuels have clear dominance in rural energy supply over others and the share is more than 93% of the total primary energy consumption. Biomass fuels are mainly consisted of firewood, leaves and twigs, different crop residues, and cow dung while only few households use bamboo for cooking fuel. However, the study estimated that the energy consumption of rural household is still at subsistence level. A major portion of household energy is consumed for cooking and a minor one for lighting. Furthermore, large portion of biomass fuels are used for cooking and small portion for rice parboiling. Generally, the rural households spend slightly over one-third of their total energy expenditure for biomass fuels and many of them collect it free of cost. The study found that different socio-economic parameters like number of family member, per capita income, per capita homestead area and per capita agricultural land influenced bioenergy consumption. The consumption pattern and types of biomass fuels vary with different socio-economic groups. The availability of biomass fuels also vary with different regions, which greatly influences the consumption pattern. However, the homestead and agricultural crop residues are the main suppliers of biomass fuels for the rural households. Due to heavy dependency and biotic pressure on biomass fuel resources, firewood is becoming scarce in many areas of Bangladesh. This affects the sustainability of the existing biomass fuel resources. Inefficient consumption of agricultural residues and cow dung lead to indoor pollution, health hazard, decrease in the soil fertility, and cause substantial green house gas emission to the atmosphere (LGED and FAO 2006). However, in the context of Bangladesh, extensive cultivation of fast growing fuelwood tree species through afforestation and reforestation programmes in both government forest and non-forested land, as well as in private land is essential. Free seedling distribution among the rural households may be included in such programmes so that the households could plant in their farmland. In addition, various agricultural residues, cow dung and other bio-waste could be utilized for clean energy services through improved bioenergy technologies like biomass based solid (briquette, pellet), liquid (ethanol, methanol, butanol), gaseous (biogas) and electricity production. Such biomass technologies could create opportunities for clean energy services and could improve living standards of the rural households. At the same time, the bi-products of those systems can be used for other purposes such as manure for agriculture. Policy support together with research and development are therefore essential before widespread adaptation of such technologies and to ensure sustainable utilization of the resources. In addition, effective measures should be taken to increase the income and education levels of the rural households. There is also need to strengthen the rural infrastructure that could enable them to shift from the current inefficient and unsustainable consumption of biomass fuels to more sustainable practices.

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REFERENCES

1. Demirbas, A. H., Demirbas, I., 2007. Importance of rural bioenergy for developing countries. Energy Conservation and Management 48:2386-2398.
2. Asian Development Bank (ADB), 1998. In: Asia Least-cost Greenhouse Gas Abatement Strategy (ALGAS): Bangladesh. ISBN: 971-561-186-9, ADB, Manila, the Philippines.
3. Koopmans A., 2005. Biomass energy demand and supply for South and South-East Asia - assessing the resource base. Biomass and Bioenergy 28:133-150.
4. Asaduzzaman M., Barnes D. F., Khandker S. R., 2010. Restoring Balance: Bangladesh's Rural Energy Realities. World Bank Working Paper No. 181. The World Bank, Washington, D.C.
5. Miah M. D., Kabir R. R. M. S., Koike M., Akther S., Shin M. Y., 2010. Rural household energy consumption pattern in the disregarded villages of Bangladesh. Biomass Bioenergy 38:997–1003.
6. Local Government Engineering Department (LGED) and Food and Agriculture Organization of the United Nations (FAO), 2006. Reducing greenhouse gas emissions by promoting bioenergy technologies for heat applications. Report No. EP/RAS/106/GEF. Country report: Bioenergy Study-Bangladesh. Available at http://www.lged-rein.org/archive_file/Bioenergy%20Study-Bangladesh.pdf. Accessed: 7 September 2008.
7. Ministry of Power, Energy and Mineral Resources (MoPEMR), 2008. Renewable Energy Policy of Bangladesh. Power Division, Govt. of the People's Republic of Bangladesh.
8. Bangladesh Bureau of Statistics (BBS), 2010. Statistical yearbook of Bangladesh 2009. Statistics Division, Ministry of Planning, Govt. the People's Republic of Bangladesh.
9. Kennes W, Parikh J. K., and Stolwijk H., 1984. Energy from biomass by socio-economic groups – a case study of Bangladesh. Biomass 4:209-234.
10. International Energy Agency (IEA), 2009. Key world energy statistics. Available at http://www.iea.org/textbase/nppdf/free/2009/key_stats_2009.pdf. Accessed: 29 May 2010
11. Bari M. N., Hall D. O., Lucas N. J. D., and Hossain S. M. A., 1998. Biomass energy use at the household level in two villages of Bangladesh: Assessment of field methods. Biomass and Bioenergy 15 (2):171-180.
12. World Bank (WB) and Bangladesh Centre for Advanced Studies (BCAS), 1998. Bangladesh-2020: A Long Run Perspective Study. Bangladesh development series. World Bank, University Press Limited. Dhaka. p. 68-90.
13. Sarkar M. A. R. and Islam S. M. N., 1998. Rural energy and its utilization in Bangladesh. Energy 23 (9):785-789.
14. Rao M. N., Reddy B. S., 2007. Variations in energy use by Indian households: An analysis of micro level data. Energy 32:143-153.
15. Pachauri S., 2004. An analysis of cross-sectional variations in total household energy requirements in India using micro survey data. Energy Policy 32:1723-1735.
16. Akhter J., Millat-e-Mustafa M., Khan N. A., Alam M. S., 1999. Household biomass fuels energy situation of a forest rich district of Bangladesh. Bangladesh Journal of Agriculture 24 (1):55-65.
17. Miah M. D., Ahmed R., Uddin M. B., 2003. Biomass fuels use by the rural households in Chittagong region, Bangladesh. Biomass and Bioenergy 24 (4/5):277-283.
18. Jashimuddin, M., Masum, K. M., Salam, M. A., 2006. Preference and consumption pattern of biomass fuels in some disregarded villages of Bangladesh. Biomass and Bioenergy 30 (5):446-451.
19. Akther S., Miah M. D., Koike M., 2010. Domestic use of biomass fuels in the rural Meghna floodplain areas of Bangladesh. iForest 3:144-149.
20. Bangladesh Bureau of Statistics (BBS), 1998. Statistical yearbook of Bangladesh 1998. Planning Division, Ministry of Planning, and Govt. of the People's Republic of Bangladesh.
21. Eusuf M., Bhuiyan T. A., Haque M. S., and Khan A. T., 1987. Heating values and proximate analysis of some traditional fuels of Bangladesh. Bangladesh J. Sci. Ind. Res. XXII:123-132.

22. Hossain S. M. I, Zaman M. A., Huq M. M., and Abdullah M., 1994. Potential of sugarcane as a renewable source of energy in Bangladesh. J. Agril. Mach. & Mech. 1(1):47–52.
23. Zaman M. A., 2006. Biomass and bioenergy potentials of selected agricultural crops. Paper presented at the national seminar on renewable energy: Biomass/Bio Energy, Dhaka, Bangladesh. 24 March 2006.
24. Hassan Md. K., Pelkonen P., Pappinen A., 2011. Assessment of bioenergy potential from major crop residues and wood fuels in Bangladesh.
25. Howes M., 1985. Rural energy surveys in the third world. International Development Research Centre (IDRC), Ottawa, Canada.
26. Morgan W. (eds.), 1980. Rural energy systems in the humid tropics. Proc. 1st Workshop of the UN University. Rural Energy Syst. Project. UNU. Tokyo, Japan.
27. Bhatia R. and Sharma R., 1990. Energy and agriculture: a review. In Pattern of Energy Use in Developing Countries. Deshai A. V. (Ed.). Wiley Eastern. New Delhi, India. pp. 205-251.
28. Asaduzzaman M., and Latif A., 2005. Energy for Rural Households: Towards rural energy strategies in Bangladesh. Bangladesh Institute of Development Studies. Dhaka.
29. Brouwer R., Falcão M. P., 2004. Wood consumption in Maputo, Mozambique. Biomass and Bioenergy 27:233-245.
30. Bhatt B. P., Sachan M. S., 2004a. Firewood consumption pattern of different tribal communities in Northeast India. Energy Policy 32:1-6.
31. Gupta G., Köhlin G., 2006. Preferences for domestic fuels: analysis with socio-economic factors and Rankings in Kolkata, India. Ecological Economics 57:107-121.
32. Van Ruijven B., Urban F., Benders R. M. J., Moll H. C., Van der Sluijs J., De Vries B., Van Vuuren D. P., 2008. Modeling energy and development: an evaluation of models and concepts. World Development 36 (12):2801-2821.
33. Joon V., Chandra A., Bhattacharya M., 2009. Household energy consumption pattern and socio-cultural dimensions associated with it: A case study of rural Haryana, India. Biomass and Bioenergy 33 (11):1509-1512.
34. Parikh J. K., 1978. Energy use for subsistence and prospects for development. Energy 3:631- 639.
35. Bangladesh Energy Study (BES), 1976. Prepared for the Government of Bangladesh, administered by the Asian Development Bank. Vol. 1-8. Planning Commission, Dhaka, Government of the Peoples Republic of Bangladesh.
36. Tyers R., 1978. Optimum resources allocation in traditional agriculture: case studies in Bangladesh. Ph. D. thesis. Harvard University, USA.
37. Briscoe J., 1979. Energy use and social structure in a Bangladesh village. Population and Development Review 5 (4):615-641.
38. Islam N., 1980. Study of the problems and prospects of biogas technology as a mechanism for rural development. International Development Research Centre, Ottawa, Canada.
39. Quader A. K. M. A. and Omar K. I., 1986. Resources and energy potentials in rural Bangladesh. A case study of four villages. CSC Tech. Pub. Series No. 191. Commonwealth Science Council, London, UK.
40. Islam M. A., 1987. Energy planning for rural Bangladesh: comparative assessment of the energy situation in an electrified and a non-electrified village of Mymensingh district. Ph. D. thesis. Bangladesh Univ. Eng. And Tech. Dhaka.
41. Alam A. B. M. M., Hossain S. M. A., Bhuiya M. S. U. and Salam M. U., 1988. Biomass fuels situation in a haor village of Bangladesh (A special study). FSRDP Pub. No. 7. Farming Systems Research and Development Programme. Bangladesh Agricultural University, Mymensingh
42. Douglas J. J., 1981. Supply and demand of forest products and future development strategies: Consumption and supply of wood and bamboo in Bangladesh. Field Document 2. UNDP/FAO/Planning Commission Project. Government of the Peoples Republic of Bangladesh.
43. Kituyi E., Marufu L., Huber B., Wandiga S. O., Jumba I. O., Andreae M. O. Helas G., 2001. Biofuel consumption rates and pattern in Kenya. Biomass and Bioenergy 20:83-99.
44. Bhatt B. P., Sachan M. S., 2004b. Firewood consumption along an altitudinal gradient in mountain villages of India. Biomass and Bioenergy 27:69-75.
45. FAO, 1998. Woodfuel in Bangladesh: production and marketing. Regional Wood Energy Development Programme in Asia. RWEDP Reprot No. 38. Bangkok, Thailand.
46. Mondal M. A. H and Denich M., 2010. Assessment of renewable energy resources potential for electricity generation in Bangladesh. Renewable and Sustainable Energy Reviews 14:2401–2413.
47. World Health Organization (WHO), 2006. Household energy and health. Geneva.
48. Islam A. K. M., Islam M. Rahman T., 2005. Effective renewable energy activities in Bangladesh. Renewable Energy 31:677-688.
49. Islam M. R., Islam M. R., Beg M. R. A., 2006. Renewable energy resources and technologies practice in Bangladesh. Renewable & Sustainable Energy Reviews doi:10.1016/j.rser.2006.07.003.