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ORIGINAL PAPER

Renewable and non-renewable energy consumption pattern among households around a protected area in Southeastern Bangladesh

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Abstract
This study explores renewable and non-renewable energy consumption patterns, expenses for fuels, and associated socioeconomic factors among households around a protected forest area (park) in Southeastern Bangladesh. Methods involve randomly surveying a total of 176 households with pre-tested questionnaires in three different categories: ≤ 1 km (nearby), 2–4 km (far), and ≥ 5 km (very far) from the park, respectively. A rural household consumes 12 times higher renewable fuels than non-renewables, with leading fuelwood (1182.73 kWh month^{-1}), primarily used for cooking. Households´ consumptions of fuelwood and leaves are higher nearby the park, however; the consumptions of crop residues and sawdust are significantly higher at the households far away from the park. For sourcing fuelwood, most of the households nearby the park depend on private forests, and those living away rely on the market and sawmills. For renewables, a household spends 42% of the total energy expenses, while 58% on non-renewables. Households nearby the park spend 12% of their energy budget to buy kerosene, an inconvenient fuel, mostly for lighting, however; those away from the park only spend 5% of their energy budget for kerosene and 28–31% on cleaner energy such as liquefied petroleum gas and electricity. More affluent and educated households shift from kerosene and spend more on cleaner fuels. The rural households' current high dependence on renewable energy, their diminishing pressure on public and homestead forests for fuels, and the pattern of unequal energy access based on their distance from the park can contribute to achieving sustainable development goal (SDG 7) to ensure clean, affordable, and sustainable access to energy for all by 2030.

Keywords Biomass · Energy budget · Expense · Fuelwood · Renewable · Sustainable

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Introduction

Mostly in the developing world, 2.6 billion people depend on biomass fuels for their cooking and heating (IEA 2017). Similarly, in Bangladesh, about 80% of the total population relies on biomass energy directly or indirectly (Masud et al. 2020). Most people living in rural areas that account for 72% of the total population use various sources of bioenergy to meet their daily energy needs (BBS 2018). Traditional biomass fuels in the form of wood, bamboo, leaves, agricultural biomass, and animal dung are commonly used for domestic cooking and heating including some commercial uses such as rice parboiling (Md. Saydur Rahman 2013; Huda et al. 2014; Islam et al. 2014a). These biomass fuels represent over 92% contribution to the rural primary energy supply (Mainali et al. 2014; BBS 2018). Rural households that often lack modern energy facilities and reliable electricity networks end up depending on kerosene and candles for lighting (Mondal and Denich 2010; Islam et al. 2014b). Some of the households may have access to solar energy for lighting if there are provisions of technological and financial assistance at local and national levels. In contrast, rural households that have good electricity connections but no natural gas pipeline network rely mostly on the use of biomass for cooking and heating (Ahiduzzaman and Islam 2011; Halder et al. 2014). However, with a limited natural gas reserve that accounts for only 11.92 TCF as of 2018 (BPDB 2019), Bangladesh would likely experience a severe fuel crisis in the coming decades (Huda et al. 2014; Islam et al. 2014b). A small percentage of the financially affluent households consider using liquefied petroleum gas (LPG) for cooking, however; most rural people can hardly afford it. Currently, the Government of Bangladesh (GoB) aims to reach a target of 10% renewable-based electricity generation by 2041 (Power Division 2016), for which biomass and solar energy have the most prospects (Amin et al. 2016; Karim et al. 2019; Masud et al. 2020). Having a better understanding of what types of energy these rural households use along with their relevant expenses and influencing socioeconomic factors is, therefore, critical to providing them equal access to energy.

There were several exploratory investigations on household energy consumption in different rural areas of Bangladesh, however; and the results varied based on the study regions (Miah et al. 2010, 2011a; Foysal et al. 2012; Hassan et al. 2012). Previous studies in southern and central Bangladesh revealed traditional biomass fuels as substantial contributors to the rural household energy supply (Jashimuddin et al. 2006; Akther 2010; Nath et al. 2013). Moreover, Baul et al. (2018) studied in rural Chittagong and found biomass fuels as a heavily used primary energy source that accounts for households´ 87% monthly energy consumption. The authors also reported that two-thirds and 31% of the households' energy expenditure were for buying biomass fuels and non-renewable fuels, respectively, and emphasized promoting renewable energy production and consumption at an affordable rate to tackle the ongoing energy and climate change crisis in the country. However, there is an inadequate holistic analysis of rural energy consumption pattern integrating non-renewable and renewable fuels sources to end uses, relevant expenses, and other socioeconomic factors that influence the households' energy access in Bangladesh.

Justification and objectives of the study

Although several studies focused on household-level energy consumption patterns in Bangladesh, the locations of most of the previous studies were on households that were either very close to forest areas or urban areas. There is a gap of knowledge to better understand the household-level energy consumption pattern and related factors in the areas that are not rich in forests or lack modern non-renewable energy facilities such as LPG and natural gas (Miah et al. 2011a; Rahut et al. 2014; Jeslin Drusila Nesamalar et al. 2017; Verma et al. 2019). Socioeconomic conditions of the households appeared to be as determining factors in consumption and expenses of fuels (Reddy and Srinivas 2009; Behera et al. 2015; Rahut et al. 2017; Yousaf et al. 2021). To understand rural households' degree of dependence on forests for energy, our study was so far the first attempt to research the areas that were either relatively very close or very far from the protected forest areas. We also considered several parameters that included whether the households, with or without private hill forest and their access to renewable and non-renewable energy fuels.

Only a few studies focused on rural households' dependence pattern on forests or protected areas for both renewable and non-renewable energy fuels. To fill the research gap, this study explores renewable and non-renewable energy consumption patterns, expenses for fuels, and associated socioeconomic factors among households around a protected forest area (park) in Southeastern Bangladesh, with a specific focus on households with various distances from the park. Our goal is to provide quantitative and qualitative information from this study results that would help enhance relevant policy support to address rural energy access and deficit around a protected forest area. With a better understanding of the rural households' forest dependence pattern for fuels, this study would enable relevant organizations and agencies to ensure sustainable, affordable, and renewable energy supply for all in rural Bangladesh.

Materials and methods

Study site

The study was conducted at Hosnabad Union under Rangunia Upazila (subdistrict) in Chittagong district, Bangladesh (Fig. 1). The Rangunia Upazila occupies an area of 347.72 sq km, located between 22°18' and 22°370' N latitude and 91°58' and 92°08' E longitude (BBS 2018). According to Bangladesh population census 2011, it has a population of 340,000, with the male being 169,596 and female 170,404, and an average literacy of 70.75% (BBS 2018). The main livelihood is agriculture, followed by commerce, service, and off-farm activities. Rangunia Upazila consists of 15 Unions (smaller administrative unit) and Hosnabad is one of them covering an area of 2783.428 ha (Rangunia Upazila Office 2020).

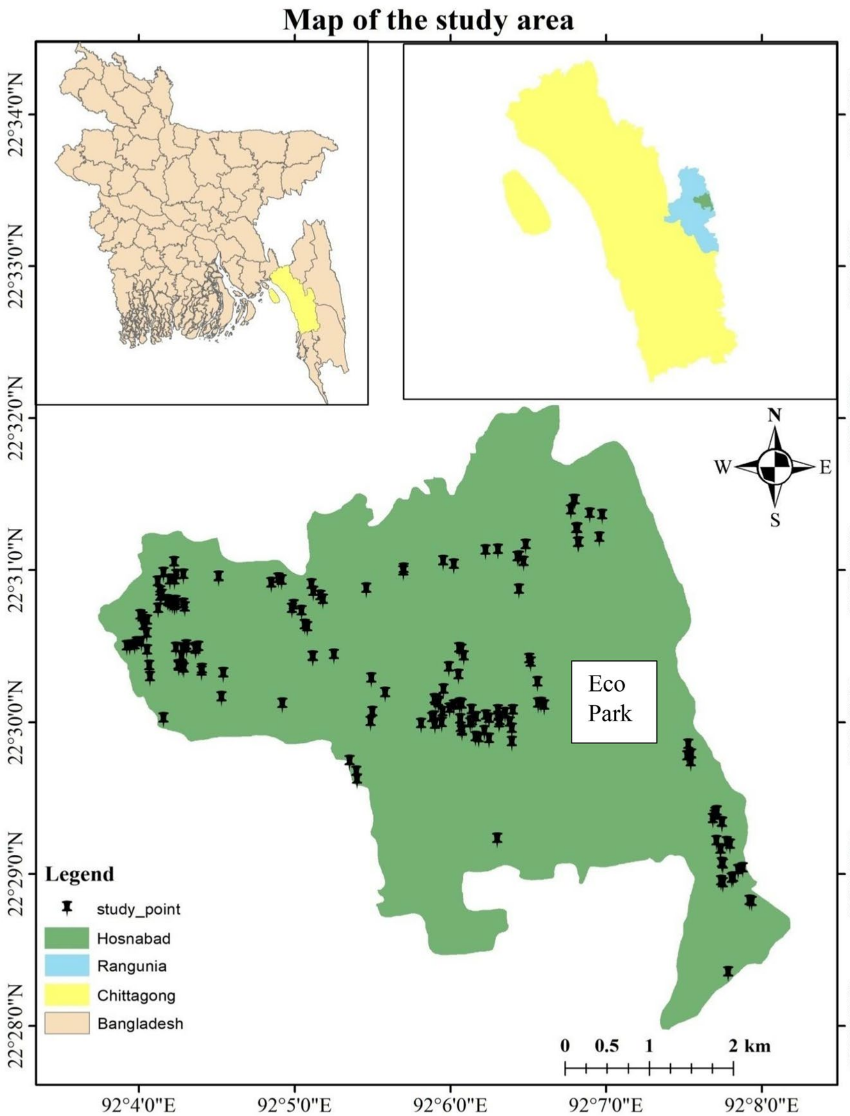

Fig. 1 Map of the study area with sampling points (Hosnabad Union, Rangunia Upazila, Chittagong district, Bangladesh)

There is 583.07 ha of public forest area under South Nishcintopur and Jungal South Nishcintopur mouza[1] in Hosnabad Union, occupying 42.56% of the total

[1] In Bangladesh, a type of administrative district, corresponding to a specific land area within which there may be one or more settlements.

Table 1 Selected wards and villages along with the households sampled by distances from Sheikh Russell aviary and eco-park (protected forest area)

Ward	Villages	Public forest area (ha)[a]	Distance from Sheikh Russel aviary and eco-park (km)*	Category[b]	No of households[b]	Households surveyed
1	Ghagra Khilmoghal	–	> 5 km West	Very far	261	14
2	Khilmogol	–	> 5 km West-north	Very far	470	24
3	Khilmogol	–	5 km North-west	Very far	312	16
4	East Khilmogol	–	4 km North-west	Far	292	15
5	Kanurkhil Khargola	–	3 km North-west	Far	253	13
6	South Nishcintopur	6.95	1.5 km North-west	Far	444	23
7	South Nishcintopur		1 km West	Near	487	26
8	Jungal South Nishcintopur	576.12	< 1 km North	Near	531	28
9	Jungal South Nishcintopur		< 1 km South-east	Near	478	26

[a](Kodola Forest Beat office 2019) [b](Hosnabad Union Parishad office 2019)

*Three categories of households were near: ≤ 1 km, far: 2–4 km, and very far: ≥ 5 km from the aviary and eco-park (Kodola Forest Beat office 2019; Hosnabad Union Parishad office 2019)

forest area under the management of Kodola forest beat.[2] This beat consists of both reserve and protected forests (Kodola Forest Beat office 2019). A part of the forest area has been announced as protected in 2010 under the Sheikh Russel Aviary & Eco-Park, located in South Nishcintopur, Hosnabad Union, Rangunia. This protected forest area was selected for the study because there are many inhabiting households surrounding the area who depend on the forests as a source of biomass fuels. In addition to identifying the households' dependence pattern on the forests for fuels, this study explores diverse renewable and non-renewable fuel sources used by the households in the area where a mixture of traditional and modern energy fuels is available.

Sampling procedure and data collection

A preliminary reconnaissance survey was conducted to draw an overview of the study area including the selection of Union, villages, location of a protected forest (Sheikh Russel Aviary and Eco-Park, we call "Park" hereafter). From Rangunia Upazila, we selected the Hosnabad Union which consists of six villages under nine Wards (the lowest unit of local administration in the governing system of Bangladesh). The nine Wards were divided into three categories, each consisting of three,

[2] the lowest administrative and management unit of Bangladesh Forest Department, BFD.

according to their distances from the Park. The categories were nearby, far, and very far corresponded to the distances of ≤ 1 km, 2–4 km, and ≥ 5 km from the park, respectively (Table 1). The information on distances of the Wards from the park and the total number of households with different socioeconomic scenarios was gathered from the Union Parishad office.

After collecting the preliminary information, we conducted interviews with key persons such as the Chairman of the Union, Members of the Wards, and elderly persons through which we informed them about the purpose and methods of the study, and verified the information on Wards and villages collected from the Union Parishad office. The questionnaire was also tested with some of the informants in addition to seven respondents from seven villages and the questions were validated with their clarity, comprehensiveness, and acceptability for the respondents, following Rea and Parker (1997). Their feedbacks enabled the questionnaire to be edited and restructured slightly according to the respondents´ convenience and suitability. We employed a snowballing approach (Narayan 1996) to identify the appropriate respondents for pre-testing and further information on the socioeconomic status of the villages.

Out of 3528 households of the Hosnabad Union, a total of 176 samples were selected and proportionately distributed in the seven villages according to the number of households (Table 1) with a sampling intensity of 5% (UNSD 2005). The required number of samples was selected randomly from the lists of the households of the villages supplied from the Union Parishad office. Subsequently, a respective local guide for each Ward guided and helped to identify the selected households. We physically interviewed mostly the female household members, who were primarily in charge of energy fuel use in the households. In several cases, we also interviewed households` heads who were primarily male household members. A female interviewer of our research team interviewed the female respondents and made the interview process smooth as, in most cases, only females are allowed to talk to the female household members in the rural setting. The survey was voluntary and took place from February to April 2019.

The questionnaire included both closed and open-ended questions, which were divided into three sections: sociodemographic data, consumption, and expenses of energy fuels. The sociodemographic data entailed landownership, size, earnings, and literacy of the households. The data included monthly fuels consumptions along with the sources of renewable and non-renewable energy. The amount of the major renewable biomass fuels, including fuelwood, leaves, was recorded in dry mass (kg) converting from reported local units (maund, auri, headload).[3] We tried to set one standard unit kilogram (kg) for collecting the biomass fuels data after verifying with the village heads. We also verified the respondents´ estimation of the renewable fuels by observation and spot measurement of the fuelwood and leaves whenever found in the yard. We collected data on amounts of non-renewables in a liter (l) for LPG and kerosene, kilogram (kg) for candles, and kilowatt-hour (kWh) for

[3] Maund equivalent to 37 kg, Auri equivalent to 8–10 kg, headload equivalent to 20–25 kg, depending on the type of fuels and carrying capacity of the means.

electricity. Finally, the data on the monthly expenses of various fuels were collected. The invoices for the monthly expenses of the electricity and LPG use were requested from the households in addition to asking about the size and quantity of candles with prices and quantity of kerosene with the price.

Data acquisition and analysis

Socioeconomic scenarios of the households

Mean values for the size, literacy (mean score), income (USD), and land ownership (ha) of the households were calculated and compared among three categories of the households: near, far, and very far from the aviary and eco-park. In calculating literacy, the score based on the duration of every education level in Bangladesh was put against the education achieved by each member of the household and subsequently, all the scores were summed and averaged by the total number of the household members. The scores 0, 5, 10, 12, 16, and 18 represented the illiterate, primary, secondary, higher secondary, graduate, and post-graduate levels of education, respectively. For example, a household consisting of three members who had primary (5), higher secondary (12), and graduate (16) levels of education received an ultimate literacy score of 11 indicating the household members receiving, on average, higher secondary education. In calculating the monthly income of each household, the incomes of all earners recorded in Bangladeshi Taka (BDT) during the survey were converted into US dollars (USD) by applying the exchange rate of USD 1 = BDT 84.5 (date of relevance: April 2019). Incomes of each household`s earning members were analyzed and the employment rate was expressed in percentage (%) of total employed people in the households sampled. Moreover, house types of households were expressed in percentage (%) of the total households.

Energy fuel consumptions and expenses

The collected data on the consumption of renewable fuels were in Kilogram (kg) that was converted into kWh by multiplying with the corresponding heating value (Biswas and Lucas 1997; Islam 1980) (Table A1). Fuelwood and cowdung were assumed to have a moisture content of 15–30% and 50%, respectively (Hossain 2003; Miah et al. 2009), which were also examined in the laboratory at the Institute of Forestry and Environment Sciences, University of Chittagong (IFESCU), Bangladesh. We assumed that the remaining renewable fuels are air-dried, which were randomly checked during the interview and examined in the laboratory. In the case of solar, the monthly consumption (watt-hour) for each household was calculated by Eq. (1) and then converted into kWh. All units used in non-renewable fuels in the survey were converted into a single uniform unit (kWh) sing the heating value of the corresponding fuels collected from the literature (IEA 2010a, b) (Table A1). For example, in the case of monthly use of candles per household, the size and amount, recorded during the survey, was converted into kg after verifying the masses of different sizes of candles available in the market. Afterward, monthly candles consumptions in kg per household were converted into kWh by multiplying with its heating value per unit (11.67 kWh kg^{-1}). Regarding household monthly income, the primary data on monthly energy expenses were recorded in Bangladeshi Taka (BDT) that were converted into US dollars (USD).

We calculated and compared mean values for monthly consumptions (kWh $month^{-1}$ $household^{-1}$) and expenses (USD $month^{-1}$ $household^{-1}$) of renewable and non-renewable energy fuels among the three categories of households. We also calculated the monthly expense ratio of each energy fuel in terms of percentage (%) concerning total fuel expenses and to the monthly income of a household (Eq. 2). For instance, the monthly expense ratio of LPG to total fuel expenses (renewable and non-renewable) and to the total income of the household was calculated and then expressed into a percentage (%). Ratios were calculated for both renewable and non-renewable fuels under three categories of households. The percentage (%) of the total households using different sources and purposes of each type of energy fuels were derived and reported (%) under the three categories of households–nearby, far, and very far from the park. In this case, a household had various energy fuels, sources, and purposes for the same type of fuel.

$$\text{Monthly solar energy consumption per household (watt} - \text{hour, Wh)} = \Sigma(P \times t \times 30 \text{ days}) \quad (1)$$

where P is the power of a bulb (Watt), and t is the duration (hour) of lighting in a day

$$Ratio\ (\%) = \frac{\text{Each fuel expense}}{\text{Household monthly total fuel expenses or total income}} \quad (2)$$

Statistical analyses

Descriptive statistics were used to understand various socioeconomic and resource status. One-way analysis of variance (ANOVA) determined the significant variation in mean values of consumptions and expenses of renewable and non-renewable energy fuels among the three categories of households. A post hoc test in the form of Tukey was performed to determine which category was significantly varied from the other categories of the households. The Pearson correlation was performed to understand the association of households' fuel consumption and expenses with land ownerships, income, literacy, and size of households. All these statistical analyses were performed using the package SPSS 26.0.

Table 2 Sociodemographic scenarios of the three categories of households sampled. Superscripts within a row (*a*, *b*, or *c*) indicate the significant differences at $p < 0.05$

Particulars	Near	Far	Very far	Mean of total
Mean age of respondents (years)	40.5 ± 0.81^{b}	47.8 ± 1.07^{a}	37.3 ± 0.73^{c}	41.6 ± 0.52
Mean household size (member household^{-1})	4.7 ± 0.08^{b}	5.0 ± 0.17^{a}	4.8 ± 0.09^{ab}	4.8 ± 0.63
Household literacy (mean score)	5.9 ± 0.13^{b}	5.7 ± 0.20^{b}	6.6 ± 0.22^{a}	6.1 ± 0.10
Mean household income (US$ month^{-1} household^{-1})	168.22 ± 3.97^{b}	185.37 ± 6.42^{b}	209.20 ± 9.80^{a}	185.12 ± 3.86
Household members principal employment (%)				Total %
Farmer	26	52	22	33
Daily labor	28	22	18	24
Service	30	13	42	28
Business	12	9	16	12
Wood business	4	4	2	3
House types (%)				
Kacha	75	86	70	77
Semi pucca	21	10	20	17
Pucca	4	4	9	6

Results

Socioeconomic status and land ownership of the households

Regardless of the categories of the households (near, far, and very far from the park), the age of the respondents ranged from 15 to 94 years, with a mean age of 42, and the household size ranged from 2 to 33, with a mean of household members of 5. The household members received an education, on average, just up to the beginning of the secondary level (score 6.1), with a significant difference between very far (class seven, score 6.6) and other two categories (class six, 5.7 and 5.9) of the households (Table 2). Across the three categories, considering all the employed members of the household, farming was the main employment, followed by the service and daily labor. All earning members of a household contributed to the monthly income, which was 185.12 USD. Mean monthly income significantly differed between the households located very far and those under the other two categories. Across the categories, the major houses (77%) were mud-walled with tin or grass shed (*kacha*), followed by *semi-pucca* (brick-walled with tin shed), and *pucca* (brick and concrete built house). With an increase in the distance of the households from the park, the proportion of *pucca* houses tended to be increasing (Table 2). The total land area of the households located nearby and far away from the park was significantly ($p < 0.05$) larger than those located very far away. The amount of hill area was significantly larger in the households nearby the park. On the other hand, the households under near and very far categories

Table 3 Households´ mean amount of various renewable and non-renewable fuels (kWh month^{-1} household^{-1}) consumptions with standard error of means by three categories

Renewables								
Household categories	Fuelwood	Leaves	Cowdung	Sawdust	Bamboo	Crop residues	Solar energy	Total mean
Nearby ($N=80$)	1216.35 $\pm 41.95^{a}$	147.52 $\pm 6.20^{a}$	10.50 $\pm 1.51^{a}$	0.40 $\pm 0.39^{b}$	23.98 $\pm 7.23^{a}$	10.97 $\pm 1.94^{b}$	0.14 $\pm 0.04^{b}$	1409.86 $\pm 43.37^{a}$
Far ($N=51$)	1193.15 $\pm 57.56^{a}$	137.49 $\pm 7.43^{a}$	10.34 $\pm 1.99^{a}$	7.69 $\pm 1.78^{a}$	30.72 $\pm 7.02^{a}$	8.98 $\pm 3.06^{b}$	0.67 $\pm 0.22^{a}$	1387.04 $\pm 59.24^{a}$
Veryfar ($N=54$)	1124.92 $\pm 55.25^{a}$	106.72 $\pm 5.51^{b}$	8.51 $\pm 1.34^{a}$	5.39 $\pm 1.40^{a}$	9.40 $\pm 3.26^{a}$	19.31 $\pm 2.56^{a}$	0.00 $\pm 0.00^{b}$	1274.25 $\pm 56.58^{a}$
Across three categories	1182.73 ± 29.00	132.60 ± 3.77	9.89 ± 0.93	3.87 ± 0.67	21.46 ± 3.78	12.92 ± 1.41	0.24 ± 0.06	1363.68 ± 29.89
Non-renewables								
	Electricity	LPG	Kerosene	Candle	Totalmean			
Nearby ($N=80$)	71.09 ± 1.77^{b}	13.47 ± 1.47^{c}	16.77 ± 0.67^{a}	0.49 ± 0.08^{a}	98.48 ± 2.30^{b}			
Far ($N=51$)	73.07 ± 2.11^{ab}	22.12 ± 2.06^{b}	9.99 ± 0.81^{b}	0.21 ± 0.05^{b}	99.97 ± 3.12^{b}			
Veryfar ($N=54$)	102.45 ± 4.45^{a}	35.49 ± 2.59^{a}	4.94 ± 0.46^{c}	0.12 ± 0.04^{b}	143.01 ± 6.18^{a}			
Across three categories	81.38 ± 1.75	22.40 ± 1.19	11.40 ± 0.43	0.30 ± 0.04	112.19 ± 2.37			

Different superscripts (*a*, *b*, or *c*) within a column indicate the significant differences at $p < 0.05$

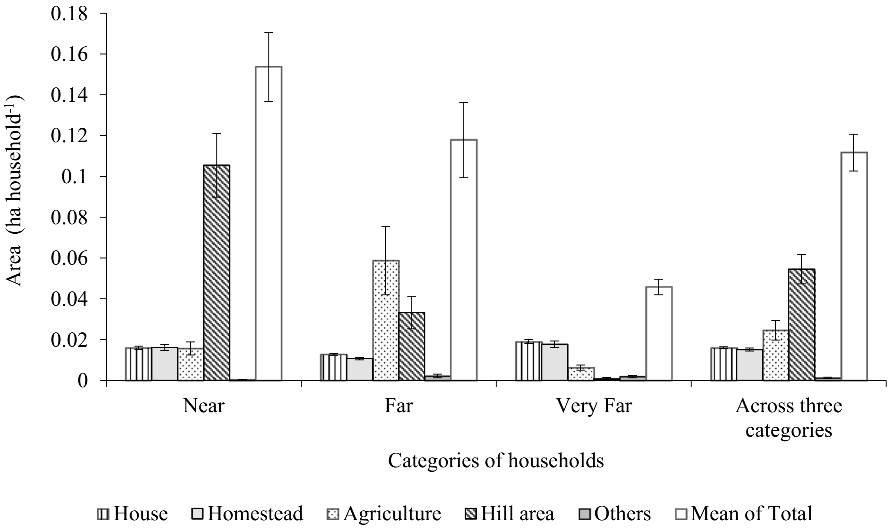

Fig. 2 Mean areas of the house, homestead, agriculture, hill, and total land ownership by three categories of the households. Bars represent the standard error of means

had a significantly ($p < 0.05$) larger amount of homestead, compared to the far category, and this pattern was opposite in case of agricultural land (Fig. 2).

Amounts of renewable and non-renewable fuels consumptions

In general, households´ mean energy consumptions amount in the study area was 1475.87 kWh month^{-1} household^{-1}, of which renewable fuels contributed 1363.68 kWh month^{-1} household^{-1}, with fuelwood being the highest and off-grid solar energy being the lowest (Table 3). Mean monthly consumptions of fuelwood, cowdung, and total renewable fuels were highest in the households near the park, with no significant differences between the categories. The consumptions of leaves were significantly ($p < 0.05$) higher in the households located nearby and far from the park compared to the other one. By contrast, the consumptions of sawdust were significantly ($p < 0.05$) higher in the households located far and very far away, compared to those nearby the park. The consumptions of bamboo and solar energy were highest in the households located far from the park, with no significant variation for bamboo between the categories, and for solar energy between nearby and very far from the park was found. The consumptions of crop residues were significantly ($p < 0.05$) higher in the households located very far from the park, compared to those in the other two categories (Table 3).

As discussed in the introduction, grid electricity found in this study area is generated mainly from the non-renewables including natural gas, furnace oil, diesel, and coal. In general, households´ mean consumptions of non-renewable fuels in the study area were 112.19 kWh month^{-1} household^{-1}, with the electricity being the highest and candles the lowest (Table 3). Households located very far from the park

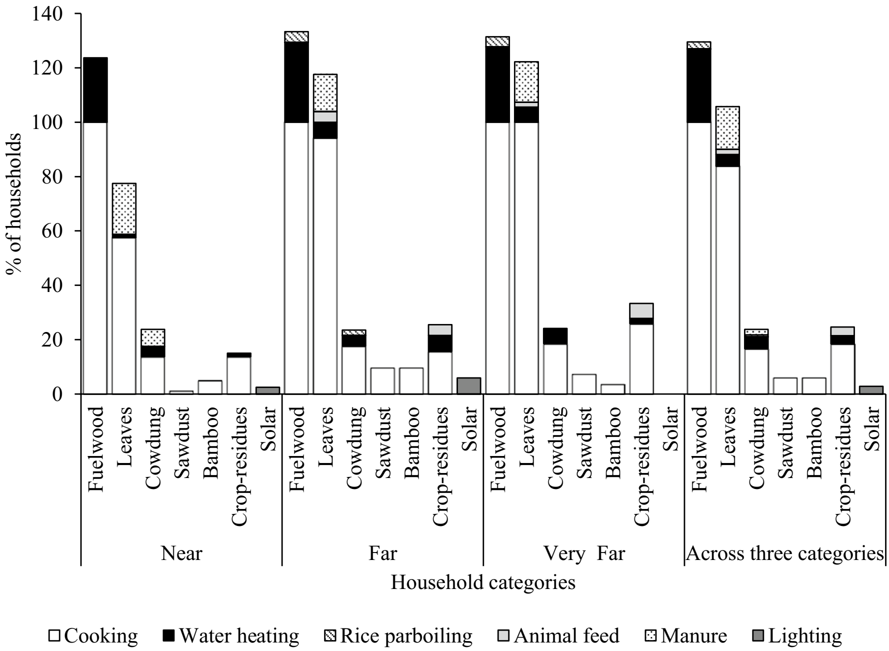

Fig. 3 The percentages of the households using renewables for various purposes by three categories. *A household used a single fuel for various purposes

consumed significantly ($p<0.05$) higher amounts of non-renewable fuels such as electricity and LPG compared to the other two categories, while no significant difference in consumption of electricity and the non-renewable fuel was found between the households nearby and far from the park. The consumptions of both kerosene and candles were highest in the households located nearby the park, with a significant ($p<0.05$) difference between the categories (Table 3).

Purposes and sources of renewable and non-renewable fuels

Most of the households, in general, used all types of renewable biomass mainly for cooking and water heating. Other major uses included using those as manure, animal feeds, and for rice parboiling. Solar is the only renewable energy that was used mostly for lighting in nearby and far households. Fuelwood was the dominant renewables used by all the households for cooking. The use of fuelwood for water heating was in 29% of households located far away, followed by those located very far and nearby the park, respectively (Fig. 3). Leaves were used for cooking by 94–100% of the households from far to very far away and 58% nearby the park and used as manure by 14–19% of the households across the categories. The uses of leaves and crop residues as animal feeds were found in the households located relatively far away from the park, and the number of households (together 10%) using crop residues as animal feeds was higher than those used for water heating. In addition to

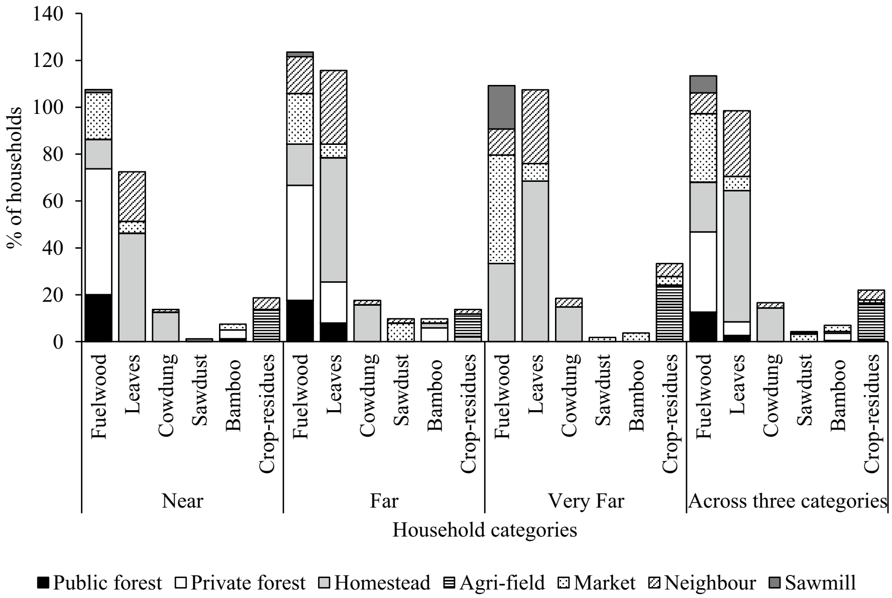

Fig. 4 The percentages of the households using various sources of renewables by three categories

cooking and water heating, cowdung was also used as manure by the households nearby and for rice parboiling by those located far from the park. Bamboo and sawdust were used only for cooking in three categories of households (Fig. 3).

Regardless of the categories, over 90% of the households depended on homestead forest areas mainly for fuelwood, leaves, and cowdung supply. Besides, all sorts of renewable fuels were sourced from neighborhood, market and private forest, agriculture field, and sawmill, respectively (Fig. 4). Households relatively close to the park (near and far) sourced renewable fuels (fuelwood, leaves, and bamboo) from public and private forests. The higher proportion of the households located very far from the park, compared to the other categories, sourced renewables from the homestead forests and market (fuelwood, leaves, bamboo, crop residues), sawmill (fuelwood), agriculture field (crop residues), and neighborhood (cowdung) (Fig. 4).

Expenses of renewable and non-renewable fuels

Households´ mean expenses for total renewable fuels in the study area was 7.24 ± 0.32 US\$ month^{-1} household^{-1}, of which, the expenses on fuelwood were the highest, the lowest on sawdust (Table 4). Households located far and very far away from the park spent monthly significantly ($p < 0.05$) higher amount on fuelwood, leaves, and subsequently on total renewable fuels, compared to those nearby the park. No significant difference was observed in renewable fuel expenses between the households located far and very far away from the park. However, a significant difference ($p < 0.05$) was observed in crop residues expenses between the households located far and very far

Table 4 Households´ mean expenses (USD $month^{-1}$ $household^{-1}$) for consumptions of renewable and non-renewable fuels with standard error of means by three categories

Renewables							
Household categories	Fuelwood	Leaves	Cowdung	Sawdust	Bamboo	Crop residues	Total mean
Near ($N=80$)	5.77 ± 0.46^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00	0.00 ± 0.01^{a}	0.17 ± 0.05^{a}	0.02 ± 0.01^{ab}	5.54 ± 0.46^{b}
Far ($N=51$)	8.47 ± 0.67^{a}	0.12 ± 0.30^{a}	0.00 ± 0.00	0.03 ± 0.01^{a}	0.13 ± 0.05^{a}	0.00 ± 0.00^{b}	8.75 ± 0.69^{a}
Very far ($N=54$)	7.98 ± 0.50^{a}	0.18 ± 0.05^{a}	0.00 ± 0.00	0.03 ± 0.02^{a}	0.07 ± 0.02^{a}	0.06 ± 0.02^{a}	8.32 ± 0.52^{a}
Mean across three categories	7.16 ± 0.31	0.09 ± 0.02	0.00 ± 0.00	0.02 ± 0.01	0.13 ± 0.03	0.03 ± 0.00	7.24 ± 0.32
Non-renewables							
	Electricity	LPG	Kerosene	Candle	Total mean		
Near ($N=80$)	3.91 ± 0.13^{b}	2.46 ± 0.26^{c}	1.62 ± 0.06^{a}	0.11 ± 0.02^{a}	8.11 ± 0.30^{b}		
Far ($N=51$)	3.91 ± 0.17^{b}	3.75 ± 0.34^{b}	0.97 ± 0.08^{b}	0.04 ± 0.01^{ab}	8.67 ± 0.38^{b}		
Very far ($N=54$)	6.71 ± 0.41^{a}	6.10 ± 0.44^{a}	0.49 ± 0.04^{c}	0.02 ± 0.01^{b}	13.32 ± 0.72^{a}		
Mean across three categories	4.75 ± 0.15	3.90 ± 0.20	1.10 ± 0.04	0.07 ± 0.01	9.82 ± 0.28		

Different superscripts (a, b, or c) within a column indicate the significant differences at $p < 0.05$

away were found. There were no significant differences between the categories for monthly expenses on sawdust and bamboo consumptions (Table 4). For solar, they invested, on average, 151.47 US$ as installation costs.

Households´ mean expenses for total non-renewable fuels were 9.82 ± 0.28 US$ month^{-1} household^{-1}, of which, the expenses for electricity were the highest and for candles the lowest (Table 4). Households located very far from the park, compared to the other two categories, spent monthly significantly ($p < 0.05$) the higher amount for electricity, LPG, and subsequently, total non-renewable fuels, while no significant difference was found in that expense between households nearby and far from the park. In contrast, the monthly expenses for both kerosene and candles were significantly higher in the households located nearby the park, compared to those in the other two categories, while no significant difference for expenses on candles between households located far and very far from the park (Table 4).

Ratio of households´ each fuel expense to the monthly total energy fuels expenses and income

Across the three categories, the expense ratio of the households for renewables was 42% of the total energy expenses, while the ratio for non-renewables was 58% (Table 5). Regarding renewables, the expense ratio to the households` total energy expenses was higher in the households located nearby the park compared to those that were very far away. By contrast, the expense ratio for non-renewables to the total energy expenses in the households located nearby and far away ranged from 59 to 62%, which was higher compared to those located far from the park. This trend was also followed in the ratio of expense for non-renewables to the household total income. The expense ratio to the total income for renewables increased with increasing the distances of households from the park, similar to that for total energy fuels. Households spent, on average, 9% of their income for total fuel expenses, with expenses of 5% and 4% for non-renewables and renewables, respectively (Table 5).

Factors affecting energy consumptions and expenses

We found a significant positive relationship ($p < 0.05$) between household income and expenses for total fuels, non-renewables, electricity, LPG, and bamboo, while being negatively associated with that for kerosene (Table 6). Similarly, energy expenses were positively affected by household literacy. The literacy of the households' members was significantly positively ($p < 0.05$) associated with the expenses for consumptions of total fuels, non-renewables, fuelwood, electricity, LPG, and renewables ($p < 0.01$), while being negative with sawdust ($p < 0.01$), and kerosene ($p < 0.05$). Moreover, with increasing household size, there is an increase in consumptions and expenses of fuelwood, renewables, non-renewables, and total fuels.

Table 5 The ratio of each fuel expense to monthly total fuel expenses and the total income of the households by three categories

Various energy fuels	Near		Far		Very far		Across three categories	
	% of total energy expenses	Expenses % of total income	% of total energy expenses	Expenses % of total income	% of total energy expenses	Expenses % of total income	% of total energy expenses	Expenses % of total income
Fuelwood	42.30	3.43	48.62	4.57	36.88	3.81	41.97	3.87
Leaves	0.00	0.00	0.69	0.06	0.83	0.09	0.53	0.05
Cowdung	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sawdust	0.00	0.00	0.17	0.02	0.14	0.01	0.12	0.01
Bamboo	1.25	0.10	0.75	0.07	0.32	0.03	0.76	0.07
Crop residues	0.15	0.01	0.00	0.00	0.28	0.03	0.18	0.02
All renewables	40.61	3.29	50.23	4.72	38.45	3.98	42.44	3.91
Electricity	28.70	2.33	22.47	2.11	31.02	3.21	27.85	2.57
LPG	18.02	1.46	21.52	2.02	28.17	2.91	22.84	2.10
Kerosene	11.88	0.96	5.54	0.52	2.25	0.23	6.47	0.60
Candles	0.82	0.07	0.24	0.02	0.11	0.01	0.39	0.04
All non-renewables	59.42	4.82	49.78	4.68	61.54	6.37	57.55	5.30
All total	100.00	8.11	100.00	9.40	100.00	10.34	100.00	9.22

Table 6 The correlation (Pearson *p*) of various fuels consumptions and expenses with land ownerships, income, literacy, and size of the households (HH)

Variables	HH literacy	HH size	HH income	Total land	Homestead	Agriculture	Hill
Fuels consumptions							
Total renewables	0.17[a]	0.27[a]	0.18[a]	0.04	0.16[a]	0.02	0.00
Total non-renewables	0.40[a]	0.30[a]	0.38[a]	– 0.03	0.14[a]	– 0.04	– 0.04
Total fuels	0.20[a]	0.29[a]	0.20[a]	0.03	0.17[a]	0.02	– 0.00
Fuels expenses							
Total renewables	0.09[b]	0.13[a]	0.02	– 0.21[a]	– 0.16[a]	– 0.11[a]	– 0.17[a]
Total non-renewables	0.42[a]	0.25[a]	0.41[a]	– 0.07[b]	0.18[a]	– 0.07	– 0.08[b]
Total fuels	0.32[a]	0.25[a]	0.28[a]	– 0.19[a]	0.00	– 0.12[a]	– 0.17[a]
Fuelwood	0.10[a]	0.11[a]	0.00	– 0.21[a]	– 0.17[a]	– 0.11[a]	– 0.17[a]
Leaves	0.01	0.19[a]	0.02	– 0.02	– 0.02	0.01	– 0.04
Bamboo	0.02	0.08[b]	0.14[a]	– 0.05	– 0.02	– 0.02	– 0.05
Crop residues	– 0.01	0.05	0.00	– 0.04	– 0.05	– 0.02	– 0.03
Sawdust	– 0.08[b]	0.02	– 0.03	0.00	– 0.06	– 0.02	0.03
Electricity	0.38[a]	0.28[a]	0.46[a]	0.02	0.18[a]	0.01	– 0.02
LPG	0.32[a]	0.15[a]	0.29[a]	– 0.16[a]	0.13[a]	– 0.11[a]	– 0.14[a]
Kerosene	– 0.10[a]	– 0.05	– 0.24[a]	0.15[a]	– 0.02	0.03	0.16[a]
Candle	0.07	0.03	– 0.01	0.24[a]	– 0.03	0.01	0.27[a]

[a]Significant at 0 .05 level

[b]Significant at 0.01 level

An increase in homestead area of the households had significantly positive ($p < 0.05$) effects on renewable fuel consumption, while decreasing the expenses for consumptions of renewables and fuelwood (Table 6).

Discussion

Purposes and consumptions of renewable and non-renewable fuels

The amount of households` total renewable fuel consumptions (1363.68 kWh month^{-1} household^{-1}) and fuelwood (1182.73 kWh month^{-1} household^{-1}) use for cooking, as a primary fuel, tended to be higher than the amount found (1087.79 and 693.27 kWh month^{-1} household^{-1}, respectively) by Baul et al. (2018) in Chittagong district of Bangladesh. Unlike our study findings, Akther et al. (2010) reported that tree leaves are the leading source of fuel for the households (654.5 kWh month^{-1} household^{-1}) in the central region of Bangladesh. The lower amount of leaves and cowdung consumption as fuels in our study sites results in leaving a larger amount of leaves on the forest floor that enables improving soil quality. Unlike other studies, our study shows that rural households' dependence on crop residues and sawdust for fuels increased with an increasing distance of the households from the park, and households primarily used these fuels for cooking. The off-grid solar energy was also used for lighting by some of the households in remote areas, where electrification and distribution were sparse with high costs for connection. With technological advancement and more affordability, use of solar energy as a source is becoming an increasing trend which was absent in the rural households of southern Chittagong (Miah et al. 2010). Islam et al. (2014b) and Mosaddek Hossen et al. (2017) also reported the variations in energy consumption amounts and availability of renewable and non-renewable fuels in different geographic locations.

An unevenness in electrification and distribution with high costs for connection made the lower consumptions of electricity used for lighting and cooling by the households located relatively nearby the park compared to those very far from the park. Conversely, households located very far from the park but nearby the Union Parishad Office had more even access to grid electricity connection and could afford the costs and, therefore, used a higher monthly amount of electricity due to their higher earnings compared to the other two categories. This evenness is unlikely to an area, where Miah et al. (2011a) conducted a study and found overall electricity consumption of 370 kWh month^{-1} household^{-1}, which was four times and a half higher than that we found (81.38 kWh month^{-1} household^{-1}). Since there was no national gas supply connection, LPG for cooking was used by 44% of the total households; however, due to the unavailability and high costs, the consumption of LPG increased with only an increase in the distance from the park. This energy consumption pattern is almost the opposite in terms of using kerosene and candles that were mainly used for lighting and to some extent, especially kerosene, for cooking. Additionally, the households with electricity connections used kerosene and candles for lighting in the case of power interruption. This is ascertained that the consumption of non-renewable fuels depended on the distance from the protected forest area and proximity to the Union Parishad Office.

Sources of renewable fuels

Generally, households` dependence for leaves and cowdung was mostly on homestead forests and neighborhoods, and for fuelwood, mostly on private forests and markets, in addition to homestead forests and sawmills. Households nearby the park (public forests), most of which also had their hill forest areas, collected fuelwood from those private forests in the hills. The pattern of using private forests and sawmills as sources for fuelwood had a positive role in diminishing pressure on public and homestead forests, dissimilar to earlier study findings (Hassan et al. 2012; Nath et al. 2013), in which, the rural households' fuelwood collection pattern was found to be heavily dependent on homestead forests.. Conversely, we also found that 37% of the households in our study area collected fuelwood from public forests, which was almost double (72%) in case of the poor households' dependency on Sal forest of Bangladesh (Islam and Sato 2012). This pattern was also influenced by the distance and households' affluence. For example, households located very far from the park and with financial solvency were reluctant to access public forests for fuelwood collection, in line with Ador et al. (2020). Those households, due to their buying ability, purchased fuelwood and sawdust mostly from the market and sawmills that replaced their need to collect fuelwood from the homestead and public forests.

Expenses for renewable and non-renewable fuels

The expenses (17 USD month^{-1} household^{-1}) for total fuel consumptions that we found were close to those found in different agro-ecological zones of Bangladesh (Foysal et al. 2012; Hassan et al. 2012). Our study results show that with an increase in the distance from the park, the monthly energy expenses of the households increased for both renewable and non-renewable fuels. People living away from the park tended to buy more fuelwood, leaves, and crop residues from the market. These households also tended to spend more on LPG and electricity due to their easy access to electrification networks, and modern utility facilities being close to the Union Parishad Office (i.e., semi-urban area). This expenditure pattern was also caused by their financial ability for which they spent more (28–31%) of their energy budget on clean and convenient fuels, such as electricity and LPG. Another study also reported similar results focusing on rural Vietnamese households and that household wealth was a driving force for using LPG (Vahlne 2017). By contrast, the households nearby the park spent less on buying fuelwood due to their high dependence on private and homestead forests for biomass. Across this area, the higher price of fuelwood contributed to expenses of renewable fuels to be 42% of total energy expenses of a household, which is similar to another study (Asaduzzaman et al. 2010), which reported this as 38%, but contrary to Baul et al. (2018) who reported this as 69% for biomass and 31% for non-renewables. This might be because the uses of electricity, LPG, and kerosene have become expensive over time, which contributed to expenses of non-renewable fuels to be 58% of total energy expenses of a household in this study. However, people living in remote areas with sparse utility connections had limited access to clean energy fuels and, therefore, had to spend relatively less on LPG and electricity, but more on kerosene (12% of their energy budget). Apart from the availability of the fuels in the area, higher prices of fuels contributed to the higher expenses for energy consumption of a household.

Factors affecting energy consumptions and expenses

We found that households´ income is an important determinant for investing in fuels such as non-renewables (expenses 5.3% of the total monthly income). Financially affluent households tended to consume and spend more on non-renewables, in particular, electricity, LPG, while showing low interest in kerosene as an inconvenient fuel. This finding is in line with the study findings by Behera et al. (2015) and Yousaf et al. (2021) conducted in Bangladesh, India, Nepal, and Pakistan. Conversely, in our study, a very weak and insignificant relationship of households´ income with the expenses for consumptions of renewables, fuelwood, and leaves reflects that the expenses for renewables rather depend on the availability and distances of resources around them and their land ownership. Households holding large land, hill, and homestead areas were not likely to spend more for renewables, in particular, fuelwood. Moreover, household size and literacy appeared to be among the key drivers for expenses of consuming fuels, as a household with increasing education level moves from dirty and inconvenient (sawdust and kerosene) to convenient fuels (fuelwood, electricity, and LPG). This is confirmed by Rahut et al. (2014, 2017) showing a tendency of moving to cleaner fuels from dirty fuels (kerosene and dung cake) with increasing education levels of Bhutanese households. Thus our study shows that income, literacy, size, and land ownership of the households had impacts on the expenses and selection of fuels, which is in line with the earlier studies in south Asia (e.g., Akther et al. 2010; Miah et al. 2010; Barnes et al. 2011; Behera et al. 2015).

Conclusion and policy implications

This study aimed to explore renewable and non-renewable energy consumption patterns, expenses for fuels, and associated socioeconomic factors among households around a protected forest area (park) in Southeastern Bangladesh, with a specific focus on households with various distances from the park. We found that all households in the study areas used renewable fuels in the form of fuelwood, leaves, cowdung, sawdust, bamboo, and crop residues mostly for cooking, heating, and using as manure. Remarkably, the solar energy was used for lighting mainly in the households nearby the park. The consumption of lower amounts of leaves as fuels while leaving larger amounts on the forest floor would improve soil and ecosystems. Private forests for those living nearby the park and market and sawmills for those living far away from the park were used as sourcing the fuelwood and sawdust while playing a positive role in diminishing pressure on public and homestead forests. For renewables consumption, households across the area spent 42% of their energy budget and 4% of their income, which for non-renewables, was 5% of their monthly income. In addition to differing access to rural electricity connections, with an increase in the distance from the park, households shift from inconvenient non-renewable fuels such as kerosene and candles to convenient fuels such as LPG and electricity, for which, they spent 28–31% of the total household energy budget. However, households` income, size, and literacy had a positive impact on the selection of convenient fuels, such as LPG, electricity, and fuelwood. Households with large homestead areas tended to spend less on biomass, fuelwood, for instance.

In this study, about 72% share of renewables to total fuels consumptions could be a great primary energy source for electricity generation and clean cooking through using improved technologies. This would help with Bangladesh's sustainable and renewable energy development authority plans to attain over 30% energy efficiency compared to 2013, majority solar and biomass base (SREDA 2021). Improved stoves and biogas plant installation through using fuelwood, leaves, and cowdung could be a clean energy source for lighting and cooking while increasing the efficiency of traditionally used cooking fuels. The scientific use of sawdust and agri-residues as briquette, an efficient and clean cooking fuel, could save fuel and time, with a greater share of renewables in the energy mix. The Renewable Energy policy 2008 of Bangladesh facilitates both public and private sector investment in renewable energy projects to substitute indigenous non-renewable energy supplies and scale up contributions of existing renewable energy-based electricity generations, for example, strengthening the potentials of solar energy and installing wood-based gasifiers at a local scale (Amin et al. 2016; Karim et al. 2019). These technologies with modern and efficient renewable energy sources can contribute to the clean development mechanism (CDM) and reducing emissions from deforestation and forest degradation and conservation of forest carbon stocks, sustainable management of forests (REDD+) mechanisms by substituting non-renewable gas and LPG for cooking. Moreover, the poor nearby the protected forest would reduce their dependence on fuelwood on public forests by engaging them in the REDD+ program while increasing carbon stocks and simultaneously generating livelihood options and biodiversity conservation (Miah et al. 2011b; Jashimuddin and Inoue 2012).

Our study also showed how different socioeconomic factors could influence energy consumption and expenditure patterns. Education, affordability, and other sociodemographic situations with modern facilities need to be improved as driving forces to play in the selection of clean and efficient fuels, solar energy, for instance. We did not consider the technology-based study, which still needs to be studied more in the operation. Our research will help the government to understand the site-specific potentials of renewables, persistent energy access deficit, and barriers to clean energy access while contributing to attaining SDG 7 (ensure clean, affordable, and equal access to energy system for all by 2030). The government and SREDA should work together with public and private investors, technical teams in conjunction with research organizations to overcome the barriers to sustainable and clean energy.

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Declarations

Conflict of interest Authors have no conflict of interests.

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