Are the off-grid customers ready to pay for electricity from the decentralized renewable hybrid mini-grids? A study of willingness to pay in rural Bangladesh

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Abstract:

Off-grid rural and remote area electrification through decentralized renewable hybrid mini-grids (HMG) has been prioritized in the recent national renewable energy policy of Bangladesh. Research was carried out to explore the actual customer willingness to pay (WTP) for the electricity to be supplied by such HMGs, while considering a wide spectrum of socioeconomic factors. Door to door household survey was conducted using structured questionnaire to collect respondent data in December 2015 from six off-grid villages under three different administrative districts. Wide variations in current cost of kerosene based lighting and expected load demand were observed among different income groups. Average monthly cost of lighting ranged between USD 3.0 to USD 9.24 and expected electricity usages as 3.60kWh and 33.76kWh. Families with higher income showed least mean satisfaction with kerosene lighting. However, strong mean willingness to switch HMG has been identified regardless of income status. The dichotomous choice contingent valuation method (CVM) was applied for this purpose. The maximum WPT value (USD 0.432/kWh) identified here indicates that a sustainable tariff model can be applied for attracting private investment in this sector.

Keywords: Off-grid electrifications, Hybrid mini-grids, Willingness to Pay, Contingent valuation method, Sustainable tariff

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Conflicts of Interest
The authors declare no conflict of interest.

1. Introduction

Moving from the ancient farm based economy to the modern industrialized society, human civilization has experienced a three thousand year of journey towards steam engine until the recent decades and the sophisticated steam turbine of today (Smil, 2004). Energy has been claimed as a major prerequisite for development. It is evident from the recent global history that countries lacking the basic energy availability and its applications are backtracked in the race of social and economic development. Despite remarkable achievements in many critical aspects of human development index (Human Development Report, 2014), around 1.2 billion people still have no access to basic electricity in the developing nations (IEA, 2016). Countries with low or limited electricity access also rank at the bottom of the HDI ranking list, suggesting a strong correlation between electricity access and human development. Moreover, lack of access to electricity restricts economic growth potential, thereby sustaining the vicious circle of poverty and poor welfare.

Bangladesh, one of the emerging countries in South Asia aims to attain the 'middle-income country' status by 2021 (Muzzini and Aparicio, 2013; BBS, 2015), and has already gained considerable success in ticking many human development indicators in the recent years. The country aims to supply reliable and affordable electricity for all by 2020 (Planning Commission, 2012; BPDB, 2015). Although country's electrification rate rose from 40% to 60% between 2003 and 2013, supply remains mostly urban oriented and still very unreliable (ADB, 2015). The huge gap between current generation status (8177MW) and government's ambitious generation target of 24,000MW by 2021 for universal access of electricity in a course of next five years is a serious challenge. The SDGs (Sustainable Development Goals) cannot be achieved by the 2030 without a rapid progress on the SDG7, which ensures affordable and secure access to sustainable energy for all. Only 50% electrification rate in rural Bangladesh against 90% in the urban areas raised the concern among the policy makers regarding the socio-economic development of the 80% of the total population of the country living in villages (World Bank, 2014). The BREB (Bangladesh Rural Electrification Board) a subsidiary of the Bangladesh Power Development Board (BPDB) was formed in 1972 to supply electricity to the rural areas. Since then BREB has achieved moderate success and grown in to 77 'Palli Bidyut Samitys' known as

PBS (operating co-operatives) across the country with a limited coverage and had positive socio-economic impact on rural lives (BREB, 2011). BREB partially covered 416 upazillas (sub-districts) out of 490 through the Palli Bidyut Samitys till March 2016 (BREB, 2016). However, because of insufficient grid extension, poor quality electricity, unreliable supplies, massive load shedding and organizational corruption this institution failed to achieve its strategic goal. As a result many areas of the country remain unelectrified. Under the current circumstances many rural consumers do not have any possibility of being connected to the national grid in the foreseeable future through the BREB.

To tackle the ever increasing supply and demand gap while considering own poor investment capability, limited natural resources, volatility of fossil fuel price and global environmental concerns, distributed electricity generation initiatives have been introduced in the 'final national energy policy 2008' as the Renewable Energy Policy of Bangladesh (2008). Policy driven and subsidy based Solar Home Systems (SHS) achieved the most remarkable success in this sector, which reached the installation milestone of 4.5 million units by March 2016 in rural Bangladesh (BREB, 2016). However, high initial investment (considering the rural economic conditions), very limited operating hours, poor quality of light, expensive repair and maintenance, lack of quality service standards and very high unit cost of electricity from the SHSs created a unique scope for the decentralized renewable mini-grids to serve this huge rural market (Mondal, et al., 2010). Benefits of such mini-grids over standalone SHSs are well evident in many literatures (Hazelton, et al., 2014; Bhattacharyya and Palit, 2016; Knuckles, 2016; Ulsrud, et al., 2011; Blum, et al., 2015; Chattopadhyay, et al., 2015; Yadoo and Cruickshank, 2012; Azimoth, et al., 2016; and Dada, 2014). As private investment is a necessity to get enhanced diffusion of renewable technologies in decentralized mode, several incentives and subsidies have been promoted in the recent years as major policy instruments for attracting investments in the renewable hybrid mini-grid sector. Unfortunately, Bangladesh has achieved no remarkable success in such approach of decentralized electrification as an alternative to grid extension in the off-grid rural and remote areas. According to the traditional investment theory, as the poor have no access to enough fund to spend they are not considered as a vital segment of the conventional market. The penetration approach for such markets by offering products or services in affordable small units has been proven successful in many developing economies. No research had been undertaken in Bangladesh so far to identify how much the off-grid customers' are willing to pay for decentralized electricity supply. This study therefore, explores the rural people's willingness to pay (WTP) for electricity from the renewable mini-grids.

Rest of this paper is organized as follows: section 2 presents the literature review followed by the methodology in section 3; section 4 outlines the results and discussions; finally conclusions are presented in section 5 with policy recommendations and scopes for further research.

2. Literature review

58% of rural households are energy poor and heavily dependent on kerosene for lighting purpose in Bangladesh (Barnes, et al., 2011). Mills (2003) reported that kerosene lantern's or lamp's measured energy consumption is around 53 litres per year for the simple wick types for an average of 3.5 hours a day operation. According to Iorkyaa et al., (2012) conventional kerosene lamps provide light output as low as 0.3 lumen per watt, which is very poor in comparison to standard LED light bulbs. Moreover, the health hazards and associated other risks of kerosene fuel use for lighting purposes are well documented in many literatures around the world (Chamania, et al. 2015; Gad and Pham, 2014; Pattle and Cillumbine, 1956; American Cancer Society, 2006; Mashreky, et al. 2008; Asuquo, et al. 2008 and Oludiram and Umebese, 2009). Mills (2012 & 2016) reported house fires, kerosene burns and contaminated indoor air quality associated with kerosene lighting in Bangladesh. The later (Mills, 2016) report highlighted that infants in Bangladesh incur about 40% of the fuel based lighting burns. Mashreky et al., (2008) specified that fuel based lighting cause 17,000 childhood burn injuries in Bangladesh.

Moving from liquid fuel based lighting to other available means of electricity is just not a simple choice but a matter of accessibility and financial affordability. Miah, et al., (2011) reported mean expenditure for energy usages in rural areas of Noakhali in Bangladesh to be USD 5.34 per month with a monthly mean income of USD 209.84, which is considered as a representative figure for other non-electrified areas of the country. Considering the price of kerosene Tk. 65 (USD 0.833) per litre (BPC, 2015), rural households energy expenditure remains the same or even less if electricity can be supplied at the standard rate of BREB through grid extension. In case of electricity to be supplied by decentralized mini-grids using renewable sources, customer affordability needs to be assessed, as unit cost of electricity would be higher in this case.

Pode (2013) concluded that improved lifestyle is the major factor for customer switching from kerosene to SHS. However, Komatsu, et al. (2013) reported that around 50% of households in rural Bangladesh continue to use kerosene at a monthly amount of 0.92L reduced from 3.932L for lighting purpose only even after installing SHSs. The main reasons behind this are inadequate load assessment and load management, insufficient energy storage, poor performance of the energy generating system, lack of proper service and maintenance and finally under size system due to less affordability (Asaduzzaman, et al., 2013). In Bangladesh 57.7% of the SHS users experience frequent unavoidable repair of batteries for an average cost of Tk. 228.41 (USD 2.93) per repair (Komatsu, et al. 2013). This phenomenon negatively affects the users satisfaction with their installed SHSs.

Researchers (Rahman, et al., 2013; Paul, 2011; ARE, 2008; Barnes, 2007 and Ziaur, 2012) expressed their concerns regarding the challenges of rural electrification related to institutional setup, financing and policy frameworks attributed to different geographical, economic and socio-political characteristics. Bangladesh is a unique example of these cases. The much-appreciated Bangladesh Rural Electrification Program (BREP) that gained huge attention among many other developing countries as being very successful (Taniguchi and Kaneko, 2009) had been facing the decline in its growth since 2006 (Rahman, et al., 2013). The exploratory work of Rahman, et al., 2013 identified the challenges and reasons for failure of rural electrification through conventional grid extension in Bangladesh. These are lack of investment, bad terrain, poor operation and maintenance, low number of connections per unit of extended grid and finally very low load demand per connection. Palit, et al., (2016) noted almost the same issues related to grid extension for rural electricity access in other South Asian nations.

Rural households pay higher unit cost for electricity generated from the SHSs in Bangladesh. The reason behind paying more in this case is not related to customer awareness or willingness toward renewable energy sources like the developed nations but as this being the only available option for rural electrification in the market. Consumers in the USA are willing to pay more for generic green energy (Borchers, et al., 2007). However, the nature of the rural Bangladesh's electricity market is different from that of the USA. Akhi and Islam (2014) reported the unit cost of electricity from SHS as TK 85.98/kW (USD 1.10 /kWh) in Gazipur, Bangladesh. If better quality energy can be supplied at a competitive price compared to SHSs, rural customers would be willing to join electricity supply from mini-grids. Gaudchau, et al., (2013) emphasized on the customer's willingness to pay to support such a tariff for the electricity from the mini-grid, which can make the system economically viable.

Energy consumption pattern and expenditure on energy usages in rural Bangladesh are different from developed economies. According to the Office for National Statistics (2014) on average, in 2012 British families spent around 5.1% of their income for energy usages, which was only 3.3% in 2002. Whereas a rural household with TK 10,000 (USD128) or more monthly income usually consume 54kWh/month electricity in Bangladesh and spend around 5 to 10% of their income on energy (Foysal, et al., 2012). Comparative expenditure on energy (considering electricity only) is higher in Bangladesh than many other countries. In general energy expenditure here is primarily dependent on household's income and as the income varies with seasons, so does the energy consumption. In rural Bangladesh during the seasonal famine earning drops by 50-60%, which results in a decrease in expenditure on food by 10-25% (Khandker, 2013). Energy consumption is affected as well due to seasonal reduction in income. However, energy consumption does not change considerably with a little increase in income level (Hassan, et al., 2014).

With increasing GDP growth, rural energy demand would shift to more electricity intensive usages in Bangladesh (Debnath, et al. 2015). However, still energy poverty (58%) is higher here than income poverty (45%) as the access to modern energy infrastructure is very limited (Groh, et al. 2016) and realistically people have low level of knowledge regarding possibilities and benefits of renewable energy (electricity) supply (Hassan, et al. 2014). Households would pay more for electricity supplied from renewable mini-grids than kerosene but eventually the unit cost of lighting, as cost per lumen-hour from such distributed generations will be much cheaper than lighting by kerosene.

Different studies reported ranges of electricity prices from renewable mini-grids across developing countries. Azimoh, et al., (2016) presented the levelized cost of electricity (LCOE) ranging between USD 0.08 to 0.41/kWh for rural South Africa, whereas, Kolhe (2012) reported cost of electricity as USD 0.30/kWh for a mini-grid in Sri Lanka. In case of Bangladesh Bhattacharyya (2015) found the LCOE varying from USD 0.465/kWh to USD 0.363/kWh while serving basic load and unconstrained load respectively. All of these studies indicated that LCOE from the renewable mini-grids are much higher than the costs of grid based electricity.

ARE (2012 & 2013) emphasized the 'willingness to pay' (WTP) of the customers as a major factor for the commercial success of the hybrid mini-grids. Sundt and Rehdanz (2015) applied meta-analysis on the existing literatures on households' willingness to pay in the developed economies and showed a general tendency of switching from conventional source of energy supply to renewable options. However, few studies reported customer willingness to pay for electricity from renewable sources in the developing countries. Abdullah and Jeanty (2011) reported the rural customer in Kenya are willing to spent around 5% of their monthly income for the electricity supplied by the solar PV. Twerefou (2014) studied consumer willingness to pay for improved electricity from renewable sources.

Different socio-economic elements (demography, income, population etc.) and value attributes of proposed renewable energy supply (quality, reliability, cost etc.) are closely related and act as key determinants in deciding factors for WTP. Rodgers (2001), applied socio-economic factors as hypothetical treatment and actual payment treatment cases of the dichotomous choice questions for such study. Longo, et al. (2008) and Henser, et al. (2014) used logit regression approach for analyzing influences of different dependent variables on a set of dichotomous and discrete variables while exploring WTP value. Whereas, Guo, et al. (2014) preferred multiple regression for identifying WTP toward renewable energy in Beijing. Most of these studies focused on customers who already have means of electricity supply. However, there are a very limited number of studies (Abdullah and Jeanty, 2011 and Voisenat-

Garces and Mukherjee, 2016) that investigated the customers' willingness to pay for electricity from renewable energy projects. Thus poor communities having no access to electricity are excluded from such studies to identify their willingness to pay for the electricity from the renewable mini-grids. Therefore, this research claims the novelty in carrying out rural customers' willingness to pay for electricity from decentralized hybrid mini-grids along with the study of actual load profile and other related factors in Bangladesh.

3. Methodology

Household energy requirements are directly related to the geographic, demographic and other socio-economic characteristics (Rao and Reddy, 2007; Miah, et al., 2010; Miah, et al., 2011). Urmee and Harries (2011) pointed that increasing demand of electricity in Bangladesh is the result of socio-economic growth. On the other hand Rahman and Ahmad (2013) argued that increased energy access is a necessary vehicle for rural development. This rural development can be either the very initial or further development stage to improve the quality of life. However, Customers' willingness to pay (WTP) is closely related to their socio-economic conditions that reflect their energy usages pattern, satisfaction with current means of lighting and expected electricity load demand. Therefore, this study covers a wide spectrum of the rural consumer market in Bangladesh.

Questionnaire based data collection is the most widely used technique in quantitative field data collection. For the rural electricity load assessment and willingness to pay study many researchers have used this technique. Blennow (2004) applied face to face survey method for rural electricity load assessment in Tanzania. Arega and Tadesee (2017) studied households' willingness to pay for electricity from renewable sources in urban and pre-urban areas of Ethiopia and collected the consumer data through face-to-face questionnaire based field survey. The same approach was applied by other researchers (Abdullah and Jeanty, 2011; Twerefou, 2014; Adaman, et al., 2011 and Gou, et al., 2014). To analyse the rural off-grid market in Bangladesh for determining the WTP for mini-grid based electricity this study followed the face-to-face data collection method. Collected data were further analysed applying different techniques, which are elaborated below.

Door to door household survey was conducted to collect respondent data in December 2015 from six off-grid villages under three different administrative districts (Figure 1). Two adjacent /nearby non-electrified villages were selected from each district. These are *Loharchara* and *Porir dip* in Cox's Bazar, *Pakuria* and *Ichharkandi* in Gazipur and *Betagi* and *Rasulpur* in Feni, which were termed as V1, V2 and V3 accordingly as the study segments. 100 households were randomly selected for interview from each segment.

3.1 Study Areas

Detailed village level socio-economic data are not available officially in Bangladesh; therefore upazilla (A sub-unit of a district and a smaller geographical region in Bangladesh used for administrative purposes) or union (a geographical sub-unit of upazilla) level data were used to describe the selected interview areas. Generally per capita income, seasonal income variations and socio-economic conditions of a specific village in Bangladesh are reflected by the characteristics of the upazilla or union it belongs to (Khandker, 2013).

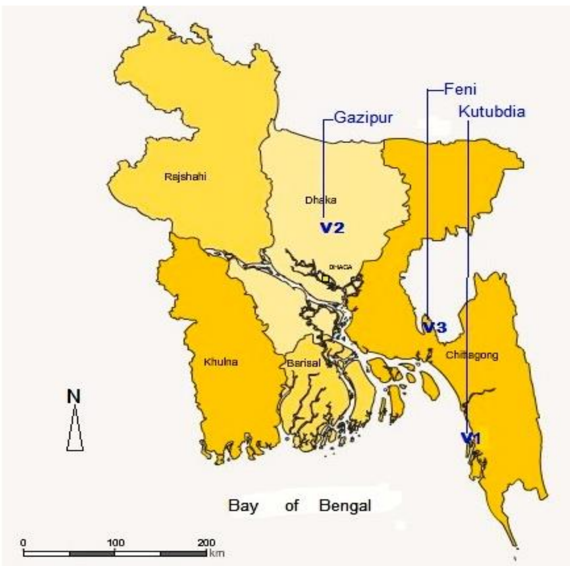

Figure 3.1: Map showing the study areas

Study segment V1 comprising of two nearby villages, *Loharchara* and *Porir dip* under the Kutubdia upazila in Cox's Bazar district represents the whole Island. Kutubdia is situated between 20°43′ and 21°50′ north latitude and between 91°50′ and 92°23′ east longitude. Secondary data regarding this study area was collected from

BBS (2011). The island has a total of 55 villages without any formal grid connectivity. A local grid from the wind turbines and a couple of diesel grids are the main source of electricity for some villages. Economy of the island is dominated by agriculture. However, marine fishing and dry fish production are the unique characteristics of the most of the villages. Average household size is 5.5 and the literacy rate is around 34%. Island's male-female sex ratio is 111 with majority of the women are not associated in economic activities.

Study segment V2 is in Gazipur district previously being a sub division of Dhaka district consisting 1114 villages of different sizes (BBS, 2014). It lies between 23°53′ and 24°21′ north latitude and between 90°09′ and 92°39′ east longitude. The two sample villages *Pakuria* and *Ichharkandi* are in Gaccha union. Male-female sex ratio here is 106, average household size is 4 and literacy rate is 48%. Agricultural activities dominate the economic activities in this union. *Pakuria* has an electrification rate of 3.3% whereas *Ichharkandi* has no electrification at all.

Study segment V3 is situated in Feni district, the former sub division of greater Noakhali. Feni lies between 22°44′ and 23°17′ north latitude and between 91°15′ and 91°35′ east longitude. It has 553 villages with around 27% of the population having no electricity (BBS, 2015). The sample villages *Betagi* and *Rasulpur* are under the Sonagazi upazila, which has a population of 2,35,000. Rural household size is 5.17, male-female sex ratio is 93 and literacy rate is 47% in this upazila. Economy is heavily based on agriculture and a good percentage of adult male population work in other districts of the country as seasonal labourers.

3.2 Survey Questionnaire

The initial survey instrument was prepared based on the secondary data available in different literatures and Bangladesh government's official publications. To increase the scope and efficiency of the initial instrument several discussion meetings were conducted in first few days of the field visit with the people involved in decentralized mini-grid or micro-generation business and professionals working in this sector in Bangladesh. Among them, the site manager of the Purobi Green Energy Limited (PGEL), Sandwip Island; the director of Sustainable Energy & Agro-resources Ltd (SEAL), Gazipur; Manager, Navana Renewable Energy Ltd., Dhaka and resident engineer of Feni Wind Power Plant, Feni were the most resourceful ones. The initial survey instrument was revised according to field experience gained through the discussion meetings. Two volunteers were included in all the discussion meetings, who subsequently participated in the filed data collection process. Involvement of two volunteers in the whole process enhanced the uniformity of the valuable primary data collection.

The survey was conducted with maximum care to collect accurate data regarding respondents' demographic information, income level and frequency, detailed electricity or kerosene consumption, energy consumption pattern, level of satisfaction with current means of energy supply, intended energy usages, willingness to switch to proposed micro-grid and finally their willingness to pay for the renewable energy supply.

To obtain the above-mentioned data through the field survey the target-oriented questionnaire was finalized considering the socio-economic conditions of the non-electrified rural areas of Bangladesh. This final questionnaire contained six specific steps to serve the purpose. These are:

Step 1: To ease the whole interview process at first the scope and objectives of the study were briefly explained to the respondents. Once respondents were ready to answer the questions, data regarding their age group, gender, income and access to electricity noted at the beginning of the interview.

Step 2: Based on the electrification status of the households, respondents were asked different sets of questions at this stage. Respondents having electricity supply either through Solar Home Systems (SHS) or diesel generator grouped as electrified households. On the other hand respondents using *kerosene, pre-charged battery or solar lamp etc.* were classed as non-electrified households. Through specific target questions at this stage, households (both electrified and non-electrified) energy usages and monthly costs were estimated.

Step 3: At this stage of the interview, all the respondents were asked to express their level of satisfaction with the current means of energy supply and if they wanted to switch to electricity supply from renewable sources. Household with SHSs or diesel generators were asked if they wanted to switch to decentralized hybrid mini-grid (HMG) based electricity. On the other hand, non-electrified households were asked to express their level of preferences to switch to both SHS and HMG based energy supply.

Step 4: At this point of the interview process all the respondents were asked detailed questions to explore their electricity load demand and consumption pattern. Standard wattage of equipment was considered throughout this process and seasonal variations were carefully applied to calculate estimated load requirements.

Step 5: At this crucial stage of the interview respondents were asked specific questions to find out their willingness to pay (WTP) for the proposed electricity supply. While offering different bid prices (i.e. USD 0.40/kWh, USD 0.45kWh, USD 0.50/kWh) to the respondents, the total amount of expected electricity cost based on the estimated load demand of a particular household was mentioned along with the unit price of energy. Further analysis of WTP was based on the monthly estimated cost of electricity corresponding to unit bid values. This approach offered the respondents to have more informed decision regarding their expected expenditure for the proposed electricity to avoid any bias in deciding maximum WTP.

Step 6: Finally every respondent was asked if they were ready to pay a connection fee for the proposed electricity supply. Respondents, who answered yes, were further investigated if they were ready to pay the cost as one off or in instalment.

Acknowledgement card was issued at the end of every interview expressing thanks for their valuable time and cooperation, which contains interview date, interview serial number, village name and contact details of the researcher. The counterpart of each card was kept for record. This approach offers the opportunity to track back the respondent if any clarification of the collected data is required at a later date.

3.4 Sampling of Respondents

Most of the households in rural Bangladesh are in cluster of two to five or six houses under a specific title for the families (i.e. Choudhuri Bari, Mia Bari etc.) and do not bear any door number. Although individual households of a cluster may have different financial conditions they bear the same family title. Some single households have more than one families living under one roof and have separate cooking facilities or arrangements. Each of these families was considered as separate household for the purpose of this study.

Samples were drawn randomly using the 'Random Number Generator' application (an iOS app to be accessed as free) on the mobile device. This app has the feature to select a range of houses in a cluster from one to hundred. House number one was assumed the first right hand side one of the cluster. A maximum of two to three houses were interviewed from each cluster. In case of individual or separate houses, the same technique was applied assuming house number one was the first house on the right hand side of a village road and number two the first one on the other side of the road.

3.5 Cost of Energy

To calculate the cost of electricity used by the few respondents included in this study who already have electricity supply through the SHS or diesel generator all the related data, i.e., capacity of the power generating equipment, initial investment, running cost, repayment if any, repair cost, equipment's expected life and energy consumption were collected.

As SHS's performance depends on the available sunlight and storage devices, average output of solar panel in Bangladesh has been estimated as 25% of the rated output (Khan and Khan, 2002). Therefore, the following equations were used to calculate the energy output of the system and actual energy consumed by the household.

Total energy output E_t = Peak kW x % average output x estimated sunny hours per year x System's life span

Total energy consumed E_c = Individual appliances x working hours (kWh)

In theory, COE is derived by applying the total energy produced by the system. However, as the current study revealed that households with SHS mostly use the energy only in the evening time through the battery backup, therefore the actual amount of energy used was taken into account to calculate the COE. The same principle was followed to determine the COE from the diesel generators as well. The following equation was applied for this purpose.

$$\text{COE (USD/kWh)} = \left(\frac{\text{Total cost (Cost of the system + Maintenance + Repair)}}{\text{Total amount of energy (kWh) consumed (Ec)}}\right)$$

Total cost in the above equation refers to the lifecycle cost of the system. To calculate the amount of energy produced by the system, actual amount of energy consumed by the respondent and the COE during the interview specific formulae were set in Microsoft Excel to expedite the process during the field data collection.

Cost of kerosene used by individual household was estimated by identifying the monthly consumption only for lighting purpose. It is important to mention that electrified households in rural Bangladesh use light bulbs and other equipment with a wide range of capacities. Therefore, actual capacity of each equipment was collected to estimate the amount of energy consumed and hence the cost of electricity.

3.6 Level of Satisfaction and Willingness to Pay

Respondents were asked specific questions to express their level of satisfaction with the existing means of lighting, their willingness to switch to distributed mini-grid based renewable energy supply and finally their willingness to pay for the estimated usages of electricity. At the same time all non-electrified households were asked about their willingness to switch to SHS to explore their preferential choice between SHS and RMG (Renewable Mini-Grid).

To identify respondent’s satisfaction level with the existing mode of energy supply for lighting and other equipment (if any) and willingness to switch to better quality electricity supply (SHS or RMG) a five point Likert scale (‘1’ as very satisfied or very much interested to ‘5’ as very dissatisfied or not interested at all) was applied. similar approach was followed by Komatsu et al. (2013) to identify user satisfaction with the

SHS in Bangladesh and by Li, et al., (2013) to explore rural Chinese farmers' willingness to convert their conventional homes to solar homes. Using the Likert scale in this instance offers the advantage of allowing the respondents to express their degrees of opinion instead of just answering yes or no. However, the major associated risk in this approach is that respondents may incline themselves in a positive light.

Before introducing questions related to willingness to pay (WTP) a brief idea was given to the respondents regarding the health and environmental issues of using conventional liquid fuel for lighting, general price comparison among kerosene based lighting, diesel generator, grid energy supply by Polli Bidyut Samity (PBS) and electricity supply from the proposed mini-grid. This information helped the respondents to make informed choice of responses, which in turn helps to avoid any bias. Respondents were informed of the approximate price of electricity from the renewable mini grids to be supplied at a rate of USD 0.40/kWh and the price of grid electricity dedicated to the village areas at a rate of UDS 0.13/kWh (PBS, 2012). Although study (Alam and Bhattacharyya, 2016) shows that electricity price from the proposed hybrid renewable mini-grids can be supplied as low as USD 0.29 to USD 0.31/kWh, an initial bid (I_Bid) price of USD 0.40/kWh was offered to the respondents. The basis for offering USD 0.40/kWh was the unit price of electricity offered by one of the most successfully running decentralized solar-diesel hybrid mini-grid project in Sandwip Island, Bangladesh (Khan, et al., 2016).

To explore willingness to pay (WTP) the dichotomous choice contingent valuation method (CVM) was applied as this technique better captures use and non-use variables. CVM is a valuation technique based on market/customer survey where respondents have the opportunity to make an informed decision on the pricing of a good or service. Rahmatian (2005) described this method as the most suitable one for willingness to pay study as it captures the pricing options even in case of uncertainties and value a service or product that is not currently available. On the other hand, Venkatachalam (2004) criticized CVM for the probable disparity between willingness to pay and willingness to accept or ability to pay. However, the field data collection technique applied in this research tried to minimize the possible bias by associating customers' financial status and their estimated consumption.

CVM approach was applied by Anjum (2013) to determine household's intention to switch to better domestic waste management services and their willingness to pay for such initiatives in the city of Islamabad, Pakistan. Gunatilake, et al., (2012) also applied the same approach in Madhya Pradesh, India to explore consumer willingness to pay for better quality electricity supply. Many other researchers (Arega and Tadesee, 2017; Guo, et al., 2014; Twerefou, 2014 and Adaman, et al., 2011) also applied the CVM approach while studying customers' willingness to pay for electricity from renewable resources.

Four major determinants were tested towards respondent's intention to pay for proposed electricity supply from the mini-grids in this study. These are:

1. Better quality and more stable energy supply (compared to existing means)
2. Clean energy posing no health hazard
3. More income potential for family welfare
4. Cost saving in the long run

As different socio-economic and demographic factors (age, gender, income, frequency of income, size of household, electrification status, expected load) are related to respondent's willingness to pay, the mean willingness to pay for the proposed electricity supply was calculated by estimating the parametric model allowing inclusion of attributes of renewable electricity as major determinants into the WTP function. These are the four major determinants (reliable supply, no health hazard, income potential, cost saving) mentioned above. Validity and reliability of the CVM results are more justified by inclusion of these factors and thus achieve more acceptances.

Interative choice discrete type question was asked in the first instance if the respondents were willing to pay USD 0.40/kWh for the proposed energy supply. Respondents who accepted the first bid (USD 0.40/kWh) were asked if they were willing to pay more than the value of the first bid. Respondents refused the first bid were offered a lower bid. Eventually an open-ended question was asked using a five different bid sets. However, it was made clear that choosing lowest bid may not be realistic, as the mini-grid operator may not make enough profit to make the project viable for long run and selecting a higher bid might be beyond their financial capability. Finally the responses to the discrete choice questions were analysed by logit regression and open-ended maximum willingness to pay responses by multiple regression analysis using the SPSS software. Despite many advantages of the CVM approach, it is often criticized for different biases. To eliminate the starting bid point bias the pre-determined (as mentioned earlier) value of 0.40 was applied. To deal with the strategic bias the government supported private or public-private partnership of the proposed hybrid mini-grid projects were mentioned and finally to overcome the hypothetical bias respondents were assured about the better quality service to be provided under the new renewable energy policy of Bangladesh Government.

3.7 Logit and Multiple Regression Models

The logit regression function for determining WTP has widely been used by many researchers (Lal and Takua, 2006; Arene and Mbata, 2008 and Urpelainen and Yoon, 2015). Logit regression analysis approach was formulated as below assuming willingness to pay (WTP) as a dependent variable while others as independent variables.

$$\text{WTP} = f\,(I\_Bids + Age\_Gr + G\_MF + Income\_Gr + Income\_Freq + HH\_Size + HH\_EleStat + Load\_Expec)$$

Where, WTP the willingness to pay refers to respondents' dichotomous choice of yes or no corresponding to value '1' or '0' respectively. The independent variables of this model include initial bid (*I_Bids*) value as 40 and other bid values offered are 30, 45, 50 and 60. As a common market rule bigger values should have a negative relation with WTP. Age group (*Age_Gr*) assumed to have inverse relation with the WTP, as younger respondents in rural Bangladesh are more educated and are more open to accepting new technologies and services compare to their seniors. The entries for gender (*G_MF*) were made by coding '1' for male and '0' for female. Respondent's income level (*Income_Gr*) expected to have positive relation with WTP, as households with higher income tend to pay more for the service offered. However, income frequencies (*Income_Freq*) were grouped under two categories for this analysis. Respondents having both monthly and seasonal income were considered under the monthly income group, as these households are somewhat comfortable to pay monthly fees for the proposed electricity supply. Coding was applied as '1' for monthly income and '0' for seasonal income group. It is assumed that monthly income group are more likely to accept more WTP. Size of the household (*HH_Size*) is an important variable, which should have a negative relation with WTP. Electrification status (*HH_EleStat*) was classed as electrified households (SHS and Generator) and un-electrified households (kerosene, solar lamp, battery) and coded as '1' and '0' accordingly. Electrified households were expected to be less willing to pay for new electricity supply as they already have invested in energy generating equipment. Finally, the expected load demand (*Load_Expec*) of household has a complex relation with the WTP as because it is related to their income level as well.

$$WTP = \frac{1}{1+e^{\ln zi}}$$

Where, $\ln zi = \alpha + \beta_0 I\_Bids + \beta_1 Age\_Gr + \beta_2\, G\_MF + \beta_3\, Income\_Gr + \beta_4\, Income\_Freq + \beta_5\, HH\_Size + \beta_6\, HH\_EleStat + \beta_7\, Load\_Expec + \mu i$

Maximum willingness to pay (WTPmax) value expressed by the respondents was specified as the multiple regression function related to different socio-economic characteristics. Therefore, WTPmax represents the maximum amount respondents willing to pay.

$$\text{WTPmax} = \alpha + \beta_1 Age\_Gr + \beta_2\, G\_MF + \beta_3\, Income\_Gr + \beta_4\, Income\_Freq + \beta_5\, HH\_Size + \beta_6\, HH\_EleStat + \beta_7\, Load\_Expec + \mu i$$

Where, μi is the disturbance term also referred as the random error term. Unobservable influence or effect related to a specific variable can be captured while calculating the WTP value

4 Results and Discussions

The demographic data collected during the fieldwork represent the decision-making individuals (or persons assigned to act on behalf of the decision makers) of the households. It is clear from this survey (Table 1) that important household decision making is dominated by the male (91.33%) and mature young age group (31-40 year old) represents the highest (50%) number followed by the 41-50 year age group (30.33%). Monthly earning of Tk. 6001-8000 group dominates (40%) income distribution across all the three study segments (Table 2 & Figure 2). Most of the households (47.33%) have only seasonal income and 32% have monthly income. However, the total of monthly (32%) and the both type (monthly and seasonal) income (20.67%) group constitute 52.67% of the respondents (Table 2). 39% of the households in the study segments are characterised by 5-6 members in families and 29.33% households have 3-4 members in their families (Table 3). Demographic, income distribution and family size patterns across all the three study segments are same.

	Gender		Age distributions						Total
	Male	Female	25-30	31-40	41-50	51-60	61-70	70+	
V1	91	9	6	48	31	14	1	0	100
V2	96	4	5	59	26	7	2	1	100
V3	87	13	9	43	34	11	3	0	100
Total	274	26	20	150	91	32	6	1	300
%	91.33	8.67	6.67	50%	30.33	10.67	2	0.33	100

Table 1: Gender and age distribution at different study segments

	Number of households and corresponding monthly income (Tk)								Total
	<4000	4000 to 6000	6001 to 8000	8001 to 10000	>10000	Monthly Income only	Seasonal income only	Both type Income	
V 1	16	27	35	12	10	21	54	25	100
V 2	23	21	39	13	4	39	41	20	100
V 3	13	19	46	13	9	36	47	17	100
Total	52	67	120	38	23	96	142	62	300
%	*17.33*	*22.33*	*40*	*12.67*	*7.67*	32	47.33	20.67	100

Table 2: Household monthly income distribution and income frequency

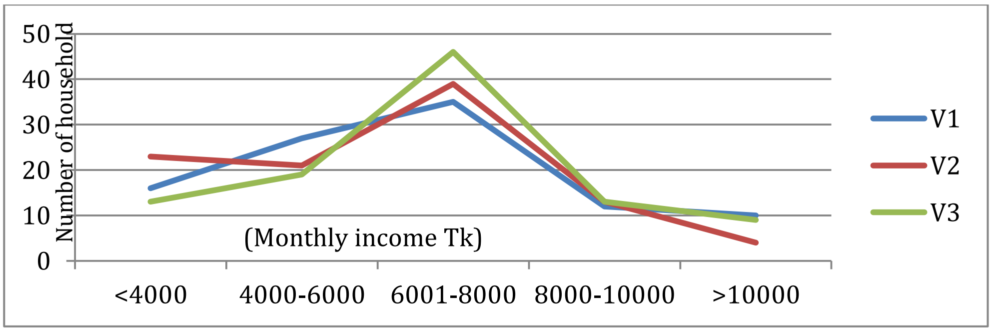

Figure 2: Household income distribution in three different study segments

	Number and size of households						Total
	2 People	3-4 People	5-6 People	6-7 People	7-8 People	> 8 People	
V1	2	33	28	25	9	3	100
V2	0	26	54	9	6	5	100
V3	3	29	35	22	7	4	100
Total	5	88	117	56	22	12	300
%	1.67	29.33	39	18.67	7.33	4	100

Table 3: Respondents' household size

Only thirteen households were found to be electrified in all study areas and the highest level of electrification was observed among the income group of Tk. 6001-8000 per month (Table 4). Wide difference in monthly consumption of electricity across different income group was recorded. The average lowest consumption was 3.60kWh and highest 33.76kWh per month for households with monthly income less than Tk. 4000 and more than Tk. 10,000 respectively (Table 5). While electricity prices varied among SHSs and diesel generators for individual installations, unit costs ranged between USD 0.77/kWh and USD 0.97/kWh for SHSs and between USD 0.82/kWh and USD 0.93/kWh for diesel generators. Notably, it was observed that electrical appliances (light bulb, fan, television etc.) used by the electrified households are not energy efficient. However, as the number of electrified households is comparatively small (13 households out of 300 samples) further research is required to make any conclusive remark in this regard.

	Electrified households					Total
	<Tk. 4000	Tk. 4000 – 6000	Tk. 6001 – 8000	Tk. 8001 - 10000	> Tk. 10000	
V 1	1	1	2	1	0	5
V 2	0	2	2	1	1	6
V 3	0	0	1	0	1	2
Total	1	3	5	2	2	13

Table 4: Electrified households across different study segments

Income level (BDT) monthly	SL	Family size (Number of people)	Source of energy	Equipment used	Average daily duration (Hours)	Average monthly Usages (kWh)	Unit cost (USD/kWh)	Average monthly Cost (USD)
< 4000	1	3	Gen*	2LB	3	3.60	0.87	3.13
4000 - 6000	1	5	SHS	2LB, 1Aud	4	5.25	0.90	4.73
	2	6	SHS	2LB, 1TV	5	13.20	0.85	11.22
	3	6	Gen	2LB, 1Audio, 1TV, 1MC	6	18.96	0.82	15.55
6001 - 8000	1	4	SHS	2LB, 1TV, 1Fan, 1MC	6	21.36	0.97	20.72
	2	7	SHS	2LB, 1TV, 1Fan, 1Aud, 1MC	5	18.72	0.83	15.54
	3	5	SHS	2LB, 1TV, 1Fan, 1MC	7	24.92	0.88	21.93
	4	6	SHS	2LB, 1TV, 2Fan, 1MC	6	20.60	0.87	17.92
	5	7	Gen	3LB, 1TV, 2Fan, 1Aud, 1MC	7	30.36	0.92	27.93
8001 - 10000	1	5	SHS	2LB, 1TV, 2Fan, 1Aud, 1MC	8	26.40	0.77	20.33
	2	7	Gen	3LB, 1TV, 2Fan, 1Aud, 2MC	7	32.96	0.88	29.00
>10000	1	6	Gen	2LB, 1TV, 2Fan, 1MC	8	25.60	0.91	23.30
	2	8	Gen	4LB, 1TV, 2Fan, 1Aud, 2MC	7	33.76	0.93	31.40

* Connection from the neighbour's diesel generator

(Gen: Diesel Generator, SHS: PV Solar Home System, LB: Light Bulb 20–40Wt; TV: Television 80-120Wt; Aud: Audio Device 20–40Wt; Fan: Electric Fan 60–80Wt; MC: Mobile Phone Charger 8–10Wt)

Table 5: Detailed electricity consumption pattern, usages and cost for individual electrified households

Dominance of kerosene (90.25%) as the main source of lighting is well evident among the non-electrified households in this study (Table 6). Only few families use solar lamp (3.48%) and batteries (6.27%). Energy consumption and number of lighting units increase with the higher income groups. Cost of kerosene lighting remains the lowest (USD 5.00/month) for the poorest (<Tk4000/month) and it reaches the highest (USD 12.95/month) for the affluent group having income of Tk8000-10000/month (Figure 3). Average highest duration of usages (3.64 hours a day) was observed among the second top income group (Table 6 & Figure 3). It is clear from Figure-4 that electrified households in the study areas use energy for lighting and other purposes for longer hours compared to the non-electrified ones. Regarding monthly energy expenditure families fitted with SHSs and diesel generators spend more than the families without electricity.

Income Level (Tk/month)	Source of lighting and Number of households			Average Usages		Average monthly cost (USD)		
	Kerosene	Solar Lamp	Battery	Lighting Units	Daily Duration	Kerosene	Solar Lamp	Battery
<4000	49	1	1	3.20	2.14	5.00	5.65	6.24
4000 - 6000	60	1	3	3.82	2.56	7.16	7.32	7.86
6001 - 8000	107	3	5	4.19	3.13	9.59	9.04	10.23
8001 -10000	28	3	5	4.34	3.64	12.95	11.71	12.35
>10000	15	2	4	4.45	3.53	11.50	10.14	12.21
Total	**259**	**10**	**18**					
%	90.25	3.48	6.27					

Table 6: Lighting usages and relative costs in non-electrified households

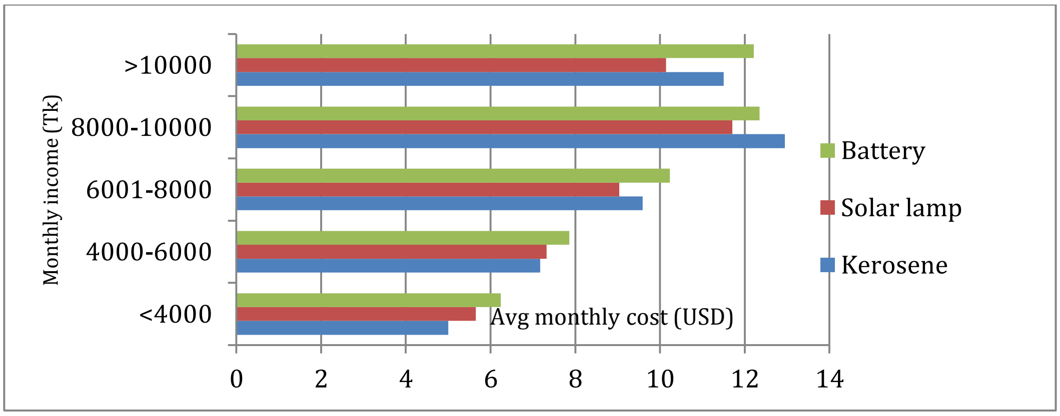

Figure 3: Average cost (USD/ month) of lighting in non-electrified households

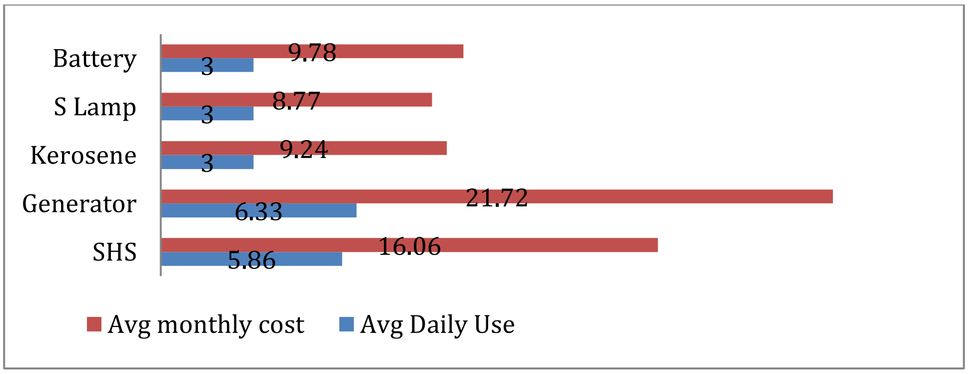

Figure 4: General energy usages trend (hours/day) and corresponding monthly costs (USD)

Non-electrified households using kerosene only for lighting purpose were asked to express their level of satisfaction and at the same time they were tested for their willingness to switch (WTS) to both SHS and RMG. Although the detail study of customer WTS to SHS is out of the scope of this research, it was briefly studied to compare it with the WTS value of RMG. The key reasons for their preferences were noted to justify the demand for the RMG. The highest mean satisfaction (3.51) with kerosene fuel for lighting was observed among the lowest income group (<Tk4,000/month) and the level of satisfaction level decreased with the increase in household income (Table 7 & Figure 5). Lowest mean satisfaction (1.63) was found with the highest income group (>Tk10,000/month). Figure 5 indicates customer's inclination of switching toward RMG. The linear mean WTS to RMG indicates a steady rise with increased household income (Figure 5). Respondents expressed their clear interest to get electricity from RMG rather than SHS as the mean value of WTS ranges from 3.67 to 4.86 for RMG across all income groups. The WTS to SHS had maximum and minimum mean value of 3.41 to 2.33, which do not represent a strong customer intension toward this technology.

Income level (Tk)	Total user Number	Mean satisfaction level	Willingness to switch to SHS (Mean)	Willingness to switch to RMG (Mean)
<4000	49	3.51	2.33	3.67
4000 - 6000	60	3.12	2.75	3.89
6001 - 8000	107	2.76	3.11	4.58
8001 - 10000	28	2.53	3.41	4.86
>10000	15	1.63	3.32	4.86

Table 7: Level of satisfaction with kerosene lighting in non-electrified households and willingness to switch to SHS and RMG

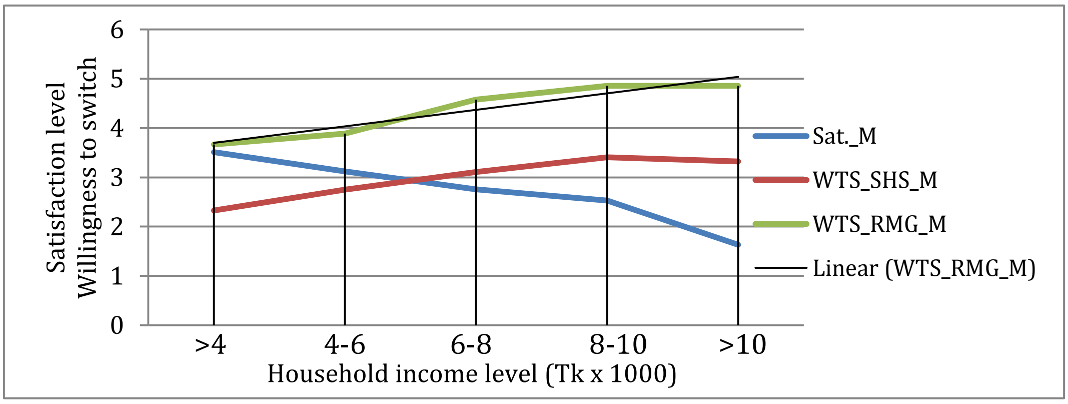

Figure 5: Mean customer (using kerosene only) satisfaction level and willingness to switch (*Sat_M; Mean Satisfaction level; WTS_SHS_M: Mean Willingness to switch to Solar Home System; WTS_RMG_M: Mean Willingness to Switch to Renewable Mini-Grid*)

Table 8 shows that households using SHS are more satisfied (mean satisfaction 3.73) with their systems than those using diesel generators (mean satisfaction 2.82) and on the other hand the battery users had higher mean satisfaction (3.64) than the solar lamp users (mean satisfaction 3.23). Lower mean satisfaction levels with current means of lighting correspond to higher MWS to RMG (Table 8 & Figure 6). The linear mean WTS indicates strong customer switching intention to RMG from diesel generator (mean WTS 3.95), solar lamp (mean WTS 4.73) and battery (mean WTS 4.82). However, the mean value of 2.35 representing customer WTS from SHS to RMG indicates poor intention level of switching.

Type of household	Mean satisfaction level	Mean willingness to switch to RMG	Sample (n)
SHS	3.73	2.35	7
Diesel gen	2.82	3.95	6
Solar lamp	3.23	4.73	10
Battery	3.64	4.82	18

Table 8: Mean customer (solar lamp, SHS, diesel generator and battery) satisfaction and willingness to switch to renewable hybrid mini-grid

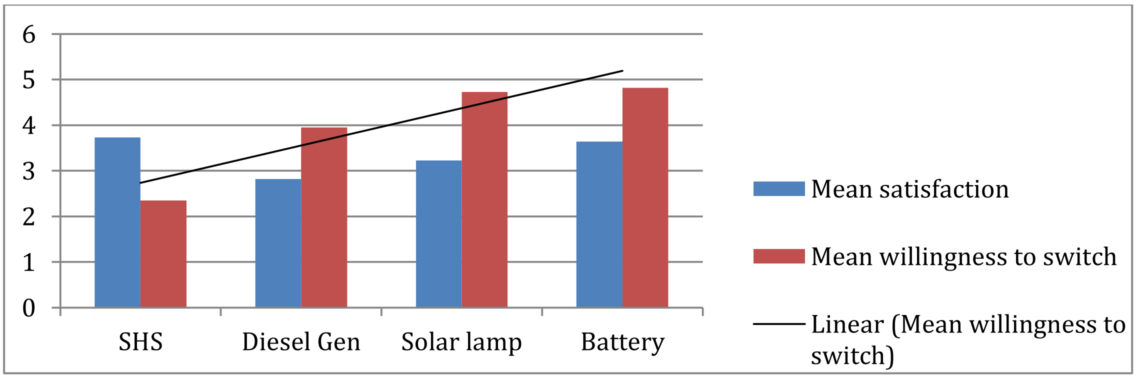

Figure 6: Customer (solar lamp, SHS, diesel generator and battery) mean satisfaction and willingness to switch to renewable hybrid mini-grid

Respondents were given opportunity to make informed decision regarding their expected electricity load demand to be supplied by the proposed hybrid mini-grid. Daily maximum and minimum estimated load for day and evening usages were calculated carefully. Households showed comparatively very low demand during the day (Table 3.9). Daytime monthly minimum load ranged from zero to 2.92kWh and maximum load ranged between zero and 3.46kWh. The lowest income group (<Tk4000/month) expressed no intention to use electricity during the daytime. However, households tend to use most of the expected load during the evening. The maximum monthly load requirement for evening time ranged between 5.04kWh and 24.38kWh and minimum load demand varied from 3.72kWh to 19.94kWh. Increased electricity demand was observed with the higher income groups. The mean expected demand of electricity from the mini-grid was estimated to be 18.863kWh/month/household (Table 9).

The existing monthly load consumption by the electrified households (calculated from table 5) has been compared to the maximum expected load demand by all households in figure 7. Bottom two income groups (<Tk4000 and Tk4000 - 6000 per month) showed slightly higher expected load demand than the current consumption by the electrified households of the same income level. Whereas, top three income groups represent less expected consumption (between 22.8kWh and 27.84kWh/month) in comparison with the actual current consumption by the electrified households (between 23.2kWh and 29.68kWh/month).

It is clear from figure 8, that monthly expected cost of proposed electricity (to be supplied @ USD 0.40/kWh) remains low for all households than the current spending for energy by both the electrified and non-electrified households (calculated from table 5 & 6).

Income level	Monthly household average expected load demand (kWh/ household)						
	Minimum		Total	Maximum		Total	
	Day	Evening		Day	Evening		Mean demand
<4000	0	3.72	3.73	0	5.04	5.04	
4000 - 6000	0.48	5.64	6.12	1.14	12.3	13.44	
6001 - 8000	2.40	17.60	20.03	2.62	20.18	22.80	18.864
8001 - 10000	2.84	20.68	23.52	2.84	22.36	25.20	
>10000	2.92	19.94	22.86	3.46	24.38	27.84	

Table 9: Expected domestic load demand by the non-electrified households

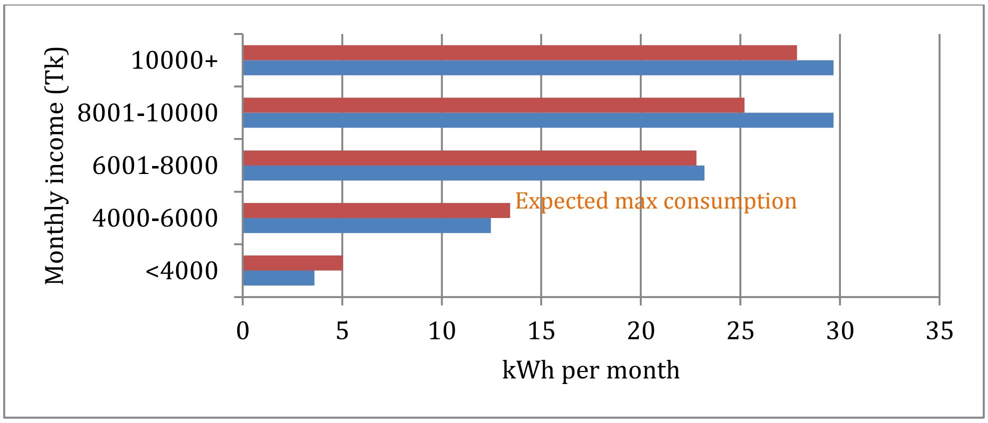

Figure 7: Monthly average calculated consumption (kWh) by the electrified households and average expected maximum consumption (kWh) by non-electrified households

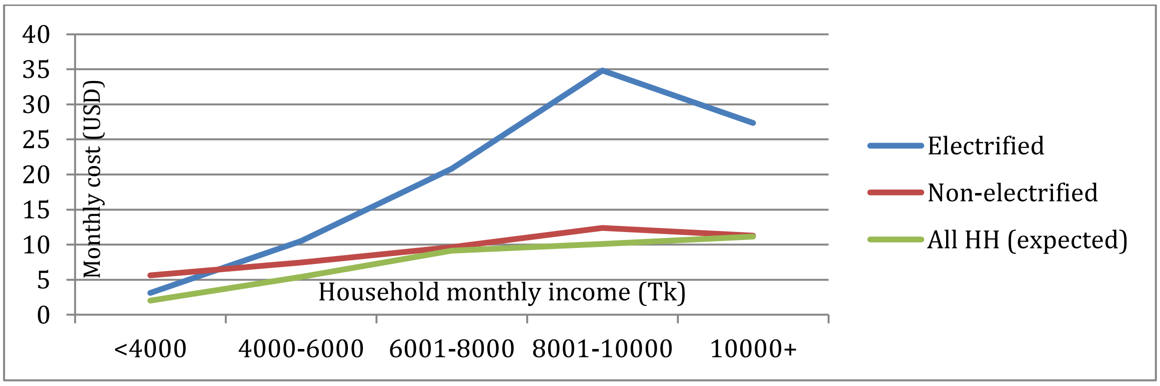

Figure 8: Current cost of energy used by the electrified (SHS, Diesel generator), non-electrified (Kerosene, Solar lamp, Battery) households and the expected cost electricity to be supplied to all households by the RMG at a cost of USD 0.40/kWh

Based on the consumer income level and expected electricity load requirement, connection types from the proposed mini-grids can be classed in five major categories (Table 10) as *Bottom user, Basic user, Medium user, Large user and Large plus user*.

User category	Income level (USD/month)*	Min & Max load demand (kWh/month)	Cost range (USD/month)	Cost as % of income
Bottom	< 50	3 - 5	1.2 - 2	2.5 - 4
Basic	51 - 77	5 - 13	2 – 5.2	4 – 6.76
Medium	78 - 103	13 - 20	5.2 - 8	6.76 – 7.78
Large	104 -128	20 - 25	8 - 10	7.78 – 7.81
Large plus	> 128	23 - 28	9.2 – 11.2	7.19 – 8.76

*Income in BDT converted to USD (1 USD = 78Tk)

Table 3.9b: Customer categories and their monthly cost of electricity against expected load

Regarding an initial payment as connection fee of Tk3000 (USD 38.6) per household respondents expressed different views (Table 11). The lowest income group (<Tk4000/ month) had the least willingness (24%) to pay the connection fee followed by (32%) the income group earning Tk4000-6000/month (Figure 9). Respondents with higher monthly income tend to have more acceptances to pay for the proposed connection fee. However, more respondents (mean 59.4) showed positive intention to pay the connection fee. Respondents who agreed to pay this fee, showed firm tendency (mean 82.80) to pay it by instalments. Only a small portion of respondents intended to pay the connection fee as one off payment, which represents a mean value of 15.52 (Table 11). Figure 10 shows that instalment payment is dominated as a choice over the one off payment across all the income groups.

Income level	Yes (%)						No	
		Mean	One off	Mean	Instalment	Mean		Mean
<4000	24		0		100		76	
4000-6000	32		6.25		93.75		68	
6001-8000	67	59.4	13.30	15.52	86.70	82.80	33	40.6
8001-10000	86		24		66		14	
10000+	88		32.45		67.55		12	

Table 11: Respondents willingness to pay connection fee for electricity supply form the proposed RMG

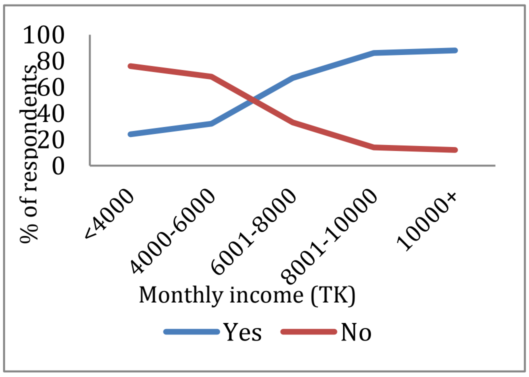

Figure 9: Respondents' willingness to pay for one off connection fee

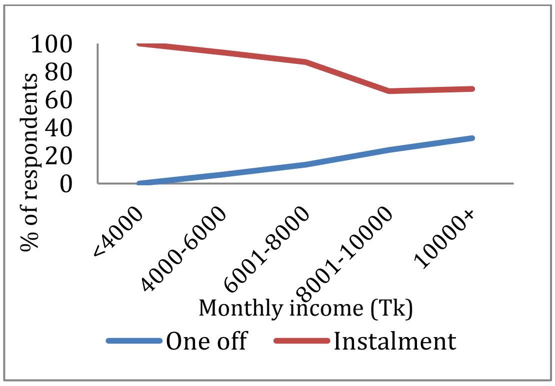

Figure 10: Respondents' preferred mode to pay for connection fee

Responses by the households related to some important variables have been presented in table 12 as overall percentage while studying customer WTP for this study. As household decision-making is dominated by the male (Table 1), the 87% WTP by the male respondents indicates a very positive attitude of villagers towards accepting the proposed unit price of electricity from the renewable mini-grid (Table 12). The dominant income (Tk 6001-8000/month) and age group (31-40 years) showed a very high interest (38.33% and 48.67% accordingly) in WTP for better quality energy through the RMG. Respondents currently using kerosene for lighting purpose are very keen (83.33%) to pay for electricity regardless of expected monthly household load demand.

Variables	Willingness to pay (%)	Un willingness to pay (%)
Gender and WTP		
Male	87.00	4.33
Female	08.00	0.67
Income level and WTP (in TK)		
<4000	14.44	3.34
4000-6000	20.00	2.33
6001-8000	38.33	1.67
8001-10000	12.00	0.67
>10000	07.33	0.33
Age group and WTP		
25-30	05.67	1.00
31-40	48.67	1.33
41-50	29.67	0.67
51-60	10.00	0.67
61-70	01.66	0.33
70+	00.33	0
Household lighting and WTP		
SHS	01.33	1.00
Diesel generator	01.33	0.67
Kerosene	83.33	3.00
Solar lamp	02.67	0.67
Batteries	05.67	0.33
Expected load demand and WTP (kWh/month)		
5 -10	14.00	2.67
> 10 - 15	23.00	1.33
> 15 - 20	34.33	1.00
> 20 – 25	13.67	1.00
> 25 – 30	08.33	0.67

Table 12: Willingness to pay related to different variables

Respondents were asked to express their level of willingness to pay for electricity from the proposed mini-grid based on four key determinants using the open ended bidding game (Table 13). In this process every respondent was given opportunity to choose their WTP value for all bid values against different determinants. Although high number of respondents (62% to 76%) expressed their willingness to pay the lowest bid (USD 0.30/kWh) considering all the determinants, more number of respondents intended to pay two relatively higher bids (bid 40 and bid 50). However, a steady decline in WTP was observed for the top two bids (bid 50 and bid 60) regardless of any key determinants (Figure 11). Cost saving and income potential were the most chosen determinants in the top ranked WTP as USD 0.40/kWh by the respondents (Figure 11).

Determinants Variables	WTP (%)	Bid 30	Bid 40	Bid 45	Bid 50	Bid 60
Better quality and	Yes	76	88	81	34	13
stable supply	No	24	12	19	66	87
Clean energy, no	Yes	65	86	77	41	21
health hazard	No	35	14	23	59	79
Income potential and	Yes	69	91	82	36	11
family welfare	No	31	9	18	64	89
Cost saving	Yes	62	94	76	43	19
	No	38	6	24	57	81

Table 13: WTP bidding game results based on four key determinants

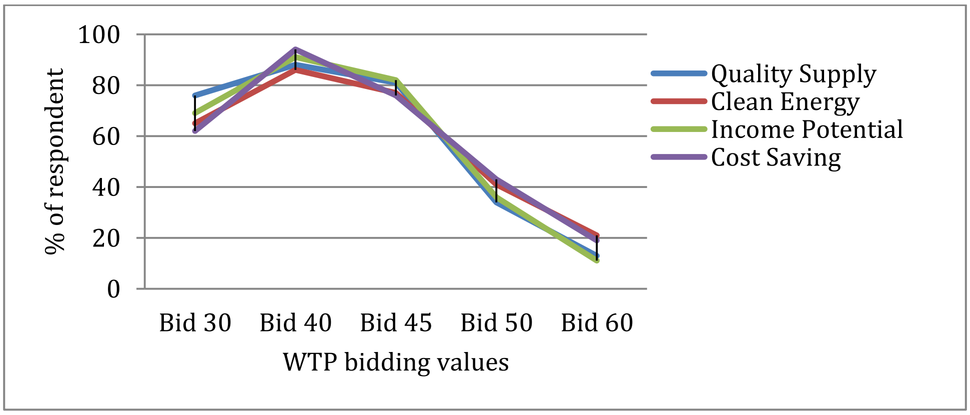

Figure 11: Key determinants and respondents WTP for different bid values

The logit regression and multiple regression values of different variables related to respondent’s willingness to pay are presented in table 14. Respondent’s age distribution shows negative relation with their willingness to pay values. The age group (Age_G) coefficient (-0.404623) suggests that unit increase in age (5years) tends to decrease the WTP by 0.405 units. This describes the phenomenon that if a group of respondent aged 30 years tend to pay USD 0.432/kWh, the WTP by the 35-year age group will be USD 0.426/kWh. It is clear that increase in age negatively affects the WTP but the magnitude is not very big. However, the odds interpretation of antilog coefficient 0.456 indicates that respondents are 0.456 times unwilling to pay for electricity from the mini-grid with an increase in age group. In the case of gender no significant relationship was observed between respondent's sex and their WTP.

Household income considered as a very important variable as the coefficient value of 0.003134 indicates positive relation with the WTP. In case of one unit increase in respondent's income the average maximum willingness to pay increases 0.0031 units. The effect of income as studied under different income groups (Income_G) is significant at 1%, 5% and 10% level of significance. The odds interpretation of antilog coefficient of 1.00162 suggests that respondents with higher income are more likely to pay for the electricity from the proposed mini-grid. It is interesting that income frequency (Income_Freq) shows no significant relation (coefficient value 0.512314) with the WTP.

The coefficient value of -5.714351 for the variable HH_Size (household size) indicates that unit increase in household size will have the respondent's average maximum willingness to pay (WTPmax) decreased by 5.71 units. For instance, a respondent with five members in family willing to pay USD 0.432/kWh, will reduce their willingness to pay to USD 0.373/kWh in case their family size increases to six. This negative relationship is significant at 1 percent and 5 percent level of significance. The odds interpretation antilog of coefficient 0.1243 suggests that if the size of household increases respondents become 0.124 times unwilling to pay for the electricity from the mini-grid.

The household electrification status (HH_EleStat) coefficient (-18.1024) represents a crucial negative relationship with respondent's WTP. If all other variables are maintained constant the households having electricity supply from SHSs or diesel generators are willing to pay 18.102 units less than the households with no electricity supply. However as mentioned earlier the number of electrified households in this study is too small to make a conclusive remark, further research is recommended in this aspect.

Variable	Logit regression			Multiple regression	
	Coefficient	Odds ratio	Prob.	Coefficient	Prob.
Age_Gr	-0.073842	0.456131	0.2434	-0.404623	0.6821

G_MF	1.573621	6.321524	0.0569	-1.627342	0.8172
Income_Gr	0.000132	1.000162	0.0006*	0.003134	0.0000*
Income_ Freq	0.512314	1.624315	0.4527	-7.726213	0.2737
HH_Size	-0.781523	0.124291	0.0037*	-5.714351	0.0067*
HH_EleStat	1.231426	0.214123	0.0721	-18.102461	0.2342
Load_Expec	1.812461	2.182421	0.0273*	2.125672	0.0049*
I_Bids	-0.031424	0.921426	0.0000	--	--
Logit mean dependent variable	*0.415200*	*Mean dependent variable*	*0.4321*	*R Squared*	*0.554324*

Table 14: Regression results for the different study variables related to willingness to pay

The regression analysed WTPmax indicated an average value of USD 0.4321/kWh for the electricity to be supplied from the proposed decentralized renewable hybrid mini-grids. However, maximum willingness to pay value not necessarily be the optimal ability to pay for the electricity in the case of rural Bangladesh. The estimated WTP value for a product or service should reflect the consumer's ability to pay (Russell, 1996). In some cases WTP may exceed the limit of the actual ability to pay. When consumers believe that acquiring a product or service is a necessity to uplift their social status, life style and economic condition, they are ready to pay more than their actual capacity. In such cases they have to squeeze expenditure on other items to maintain their commitment. Therefore, the relationship between WTP and ability to pay is a matter of debate and demands to clearly distinguish these two notions.

5 Conclusions and policy recommendations

The estimated average maximum willingness to pay value of USD 0.432/kWh for electricity supply from the proposed renewable hybrid mini-grid indicates that the tariff rural customers ready to pay would support a sustainable business model for good return on investment. The recent work of Alam and Bhattacharyya (2016) clearly indicates that such distributed hybrid mini-grids can supply electricity in rural Bangladesh at around USD 0.30/kWh while serving similar load profiles found in this study for 12 to 18 hours a day. Strong customer willingness to switch to mini-grid (mean value 3.67 to 4.86 across all income groups) counter-balances the relatively poor mean household monthly load demand (18.864kWh). However, the load management through efficient storage solution remains the main challenge as poor daytime domestic consumption has been identified through the current research.

Daytime agricultural and commercial load may offset the poor daytime domestic load. Further research is needed to explore the combined managed load, which requires consumer consultation and rewarding schemes to defer partial evening loads to the daytime and adding more electricity consumption (switching village diesel irrigation pumps, local businesses and cottage factories etc. to RE electricity) in the daytime.

Exploring rural households' willingness to switch to mini-grid based electricity and their willingness to pay for electricity while considering important socio-economic factors through this research builds a strong basis for cost effective mini-grid design with realistic load profile and selection of suitable business model for Bangladesh for attracting private investment. Customers' strong willingness to pay for both the tariff and connection fee indicates that achieving grid parity is not necessary for successful diffusion of renewable hybrid mini-grid based electrification in Bangladesh. However, with an increased diffusion trend of such electrification, hybrid mini-grids will attain economy of scale and thus it is expected that cost of electricity will decrease to a greater extent. The same approach may be applicable for other developing countries.

Contrary to the general belief that rural users may not pay for the services, this study finds that they are keen to pay for better quality energy. Their demand may not be high but as long as their demand can be reliably met, consumers are happy to pay for the service. This opens up the potential for providing the services through appropriate design and delivery options.

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