Electricity Access Improvement Using Renewable Energy and Energy Efficiency: A Case of Urban Poor Area of Dhaka, Bangladesh

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Abstract- Dhaka is one of the thickly populated cities in the world. The city is occupied by the influx of urban poor migrating to the city from rural areas in sufficient number annually. The slum dwellers are deprived by the government in terms of receiving access to authorized, reliable and affordable electricity services. The approach to provide legal electricity services as well as issues and challenges related to electricity access in the urban poor areas of Dhaka have not been well addressed yet. Moreover, there is no wide and effective policy specifically on electricity for low-income people as well as for the urban slum areas. Additionally, there are no effective steps for promoting renewable energy and energy efficiency. Therefore, renewable energy could be the promising choice to enhance the electricity access in slum areas of Dhaka. The goal of this research is to assess the present status of electricity access and identify the issues and challenges in an urban poor area of Dhaka. The research also evaluates the effectiveness of renewable energy and energy efficiency to improve electricity access. Based on a survey conducted in an urban poor area named Korail situated in Dhaka, the available resources like solar energy and solid waste are identified. The research shows that 17.2 MW power can be produced from solar PV against the demand of 2.6 MW. Besides, solid waste is capable of generating 1.44 MW and 1.14 MW by using the thermochemical and biochemical method respectively. Furthermore, 6.8 GWh electricity can be saved by replacing all the incandescent lamps with fluorescent lamps which will reduce the demand during the peak hours.

Keywords Energy access, solar energy, solid waste, energy efficiency, urban poor

1. Introduction

Electricity is one of the fundamental elements which is needed to decline poverty rate and boost the economic growth and social mobility of a country. A quarter of world's population is suffering from lack of access to clean and cost-effective energy services, such as efficient lighting and pollution free cooking facilities [1]. The absence of electricity hinders the development of society, country's health, education standard as well as the productive economic activities [2].

Dhaka, the capital city of Bangladesh, is one of the fastest rising cities in the world, accommodates 13 million people, including different service holders, workers and slum dwellers. The city is expected to shelter more than 20 million by 2025 [3]. There has been an excessive arrival of low-income people from the rural areas to urban areas since the independence of the country. Each year, about 300,000 to 400,000 people travel to Dhaka city from villages for earning money. They capture government lands, the edge of the roads as well as abandoned lands and buildings. There has been a dramatic increase in the population of Dhaka city from 6.5 million to 9.2 million during 2001-2005, while the aggregate amount of urban slums, has emerged from 3,007 to 4,966. The population in slum areas of Dhaka city has raised from 20% to 37% during the same period [4]. Some effective steps were initiated by the government of Bangladesh for urban slum people to improve their living condition by providing basic requirements. Several urban policies were proposed to support the urban poor concerning the development of slum infrastructure. Moreover, some initiatives were introduced to motivate them to return to their village. Furthermore, steps were taken to build a modern satellite city and provide them with low-cost housing. All the policies focus on developing the slum infrastructure and preserving the housing rights. However, there is no policy for delivering affordable, reliable electricity service to the urban poor people.

About 90% households in urban poor areas of Dhaka city are covered by electricity [4]. Nevertheless, the supply of electricity in the slum regions is very limited in terms of availability, reliability, affordability and authenticity. Though low-income people in the slum areas are covered by electricity, most of the cases it is being used illegally at very high prices. There is no effective inspection and energy auditing by utility companies [5]. Besides, the shortage of power has been affecting the Dhaka city severely. During the summer season, frequent load shedding is very general phenomena with the daily outage of electricity for around 2-3 hours in cities and 5-7 hours in rural areas. The government has raised the generation capacity to 15,351 MW; however, there has been a shortage of supply of around 1600 MW [6]. During the unavailability of electricity, the urban poor people use old traditional kerosene lamp called "kuppi" and "Hurrican" to meet their lighting needs. This kind of kerosene lamp is very inefficient and it produces a lot of smoke which is hazardous to human health. Besides, there is also a high risk of fire and burning skin. There are no effective rules to remove urban poverty as well as no energy policy for slum people. In addition, there is no central organization which will look after the electricity problems in the urban poor areas. Moreover, in the absence of authorized land and house ownership, urban poor people cannot get access to legal electricity services [7]. Even social organizations like NGO's face difficulties to work in slum areas because of unlawful locality of slums and intrusion of middlemen [8]. There is also no scope to learn about financial and health benefit as well as the use of cleaner fuel due to lack of awareness. In addition, lack of sufficient power generation and absence of competitive electricity market are also the key barriers to enhance electricity supply in urban poor areas [9].

Renewable energy could be one of the solutions to enhance electricity access in slum areas of Dhaka city [10]–[12]. The energy policy named "Draft Renewable Energy Policy" was presented in 2008 highlighting the renewable energy specifically solar energy and biogas [13]. There are various methods to transform energy using solar; however, generating power from solar is dominated by solar photovoltaic (PV) in Bangladesh. The idea of installing solar home system (SHS) was initiated in 2003 with small scale power generation to 50,000 houses. Since then, the number of SHS has grown significantly to more than 3.9 million with 20,000 SHSs are being installed in each month [14]. Hoque et. al [15] evaluated the performance of 40 W_P, 50 W_P, 65 W_P and 75 W_P SHS system which could supply 10546 MJ, 12303 MJ, 15818 MJ and 19773 MJ energy respectively in 20 years. There are various social, private and public organizations such as Infrastructure Development Company Limited (IDCOL), Bangladesh Rural Advancement Committee (BRAC), Grameen Shakti (GS), Rural Electrification Board (REB), Bangladesh Power Development Board (BPDB) and Local Government Engineering Department (LGED) in Bangladesh who are in charge to make awareness among general people regarding the benefits of using SHSs. The total number of SHS is installed by IDCOL is 1.4 million, which save 100,000 tons of fuel in a year as well as provide a better livelihood for 70,000 people [16]. According to a survey relating to the installation of the SHS, it has created about US$ 200 million markets in Bangladesh through a productive financing system by adjusting it easier for low-income people to reimburse the credit in installation over 3 years with interest [17].

The objective of this study is to assess the present status of electricity access and identify the challenges to electricity access in an urban poor area of Dhaka. The research also proposes renewable energy and energy efficiency to deliver clean, affordable and more sustainable electricity services. Two potential renewable energy sources; solar and biomass are chosen for this study. For energy efficiency, a life cycle comparison is performed between an incandescent lamp and a fluorescent lamp to demonstrate how energy-efficient appliances can save a significant amount of energy.

The paper is set out as follows. Section 2 delivers a brief explanation of solar energy potential, energy recovery potential from solid waste in Bangladesh, while section 3 highlights energy efficiency program in Bangladesh. The detailed methodology is presented in section 5 which covers study area, data collection method, steps and procedures of generating electriciy from solar PV, biomass as well as saving energy using energy efficiency strategies. Section 6 narrates results and discusion which assesses the current electricity status, identifies issues, challaneges and evalautes the electricity generation potential from solar PV, biomass as well as energy converation through energy efficiency approach. Finally, the paper concludes with recommendations and significant contributions.

2. Improving Electricity Access by Renewable Energy

2.1 Solar energy potential

Solar energy has got massive attention in Bangladesh since it has infinite resource and delivers a pollution free green energy [18]–[20]. Bangladesh has a vast opportunity for the development of solar power applications with per day mean solar radiation of 4-6.5 kWh/m^2 [21], [22]. Because of the massive potential of solar PV, it is commonly used for supplying electricity to the domestic purpose and small businesses. The concept of SHS has got huge popularity and become attractive choices for electrifying houses in rural areas [23], [24]. The wide use SHSs of Bangladesh has already achieved international benchmark. The installation of SHS targets those areas where there is no access to grid connection such as remote areas and have very less possibility of connecting grid within the next 5 to 10 years [25]. However, the cost of installation SHS was exorbitant initially and the usage rate was very low. There has been a dramatic increase in the number of SHS from 2004 to 2010 because of the easy monthly payment system, less price of the product and the subsidiary policy of the government. Due to the attractive financial schemes, about 4.1 million SHSs is installed in Bangladesh up to 16 October 2016 [26].

Theoretically, Bangladesh receives 69,751 TWh energy every year with daily mean sunny hours of 6.5. Compared to the conventional electricity generation, this value is 3000 times less than that of solar energy [16]. Annually, solar radiation has average power density of 100-300 W/m^2. Thus, an average output of 100 MW electricity can be generated with an area of 3-10 km^2 and 10% efficiency panel [27]. A study concerning solar energy harvesting reveals that the per capita 3000 kWh electricity demand can be achieved in a year with 6.8% (10,000 km^2) of the land of Bangladesh [28]. Due to the shortage of land in the capital city, the government of Bangladesh highlights the necessity of installing rooftop solar PV system. Kabir et al. [29] found that the total available bright rooftops area in Dhaka city is 10.554 km^2 (7.86% of total land) which have the ability to produce 1000 MW of solar PV electricity with 75 W capacity of the solar module. The technical assumption of the suitable land area in Bangladesh is only 1.7% for generating electricity from solar PV considering the available presence of grid connection [30]. Mondol and Denich [31] estimated the capacity of solar PV operated in a grid-connected mode with 10% efficiency of solar PV system and 200 W/m^2 annual average value of solar radiation. The results show that the grid-connected PV system can produce about 50,174 MW grid electricity in the Bangladesh.

2.2 Energy recovery potential from solid waste

The rejected material (especially biological and chemical waste) from the urban community is called municipal solid waste which consists of a homogeneous and heterogeneous accumulation of agricultural, industrial and mining wastes. The solid waste mainly comes from agricultural product, commercial establishments, institutions and industries [32], [33]. Several studies have been conducted to analyze the methods of recycling, generation, as well as reliability, economic feasibility, policy, market incentives of using solid waste in Bangladesh [34]–[38]. The average generation of municipal solid waste per day in Dhaka city is 4000 tones. About 50% of waste is collected and the rest amount is deposited openly outside Dhaka city which is causing environmental pollution [39]. Alam and Bole [40] studied the potential of urban solid waste for the generation of electricity by analyzing its economic feasibility at Dhaka city. The reports show that about 72 MW electricity can be provided with the collection of 1.28 million tons of municipal wastes. Though it may not be financially attractive on behalf of only electricity generation, but the maximum favorable energy utilization and environmental significance should also be taken into consideration. Islam and Saifullah [41] did a survey to calculate the total amount of municipal waste and bagasse in Rajshahi city. The study estimated the total amount of energy production for power and cooking application. The proposed method is very effective in generating electricity amounting 544 MWh/day and 119.8 MWh/day respectively from bagasse and waste during the sugar cane harvesting season.

3. Improving Electricity Access by Energy Efficiency

There has been always a gap between the generation of electricity and current demand. Therefore, the government is trying to implement some plans to solve the electricity crisis by installing new power plants. However, installing new power plants is time-consuming and require a huge amount of investment. Therefore, one of the effective programs is initiated by the government is demand side management which means managing of power demand by consumers and distribution companies. The program is mainly proposed for reducing demand for electricity. Efficient use of electrical appliances such as efficient star rated television, refrigerator, fan and energy efficient light could be one of the effective ways to reduce demand for electricity. The goal of efficient lighting initiatives which literally means “save lamp schemes” is to replace inefficient incandescent bulbs in the household by the compact fluorescent lamps (CFLs). The project replaces almost 30 million incandescent bulbs with an equal number of CFLs, delivering the same lumen or higher lumen output. The reduction of energy bills, improved quality of lighting as well as reduction of energy consumption are the significant outcomes of the program [42]. Another study conducted by the Power Division revealed that 445 MW peak power demand could be saved by substituting all the incandescent bulbs with CFLs. Even only energy efficient lighting could save 100 MW peak demand in industrial and domestic sections.

4. Methodology

4.1. Study area

Korail slum is chosen as the study area for the purpose of carrying out the research and to attain the objective. This slum is purposely selected because it is the oldest slum in Dhaka with 90 acres of land. At present, Korail has an estimated population of 100,000 and each family consists of 5 people [4].

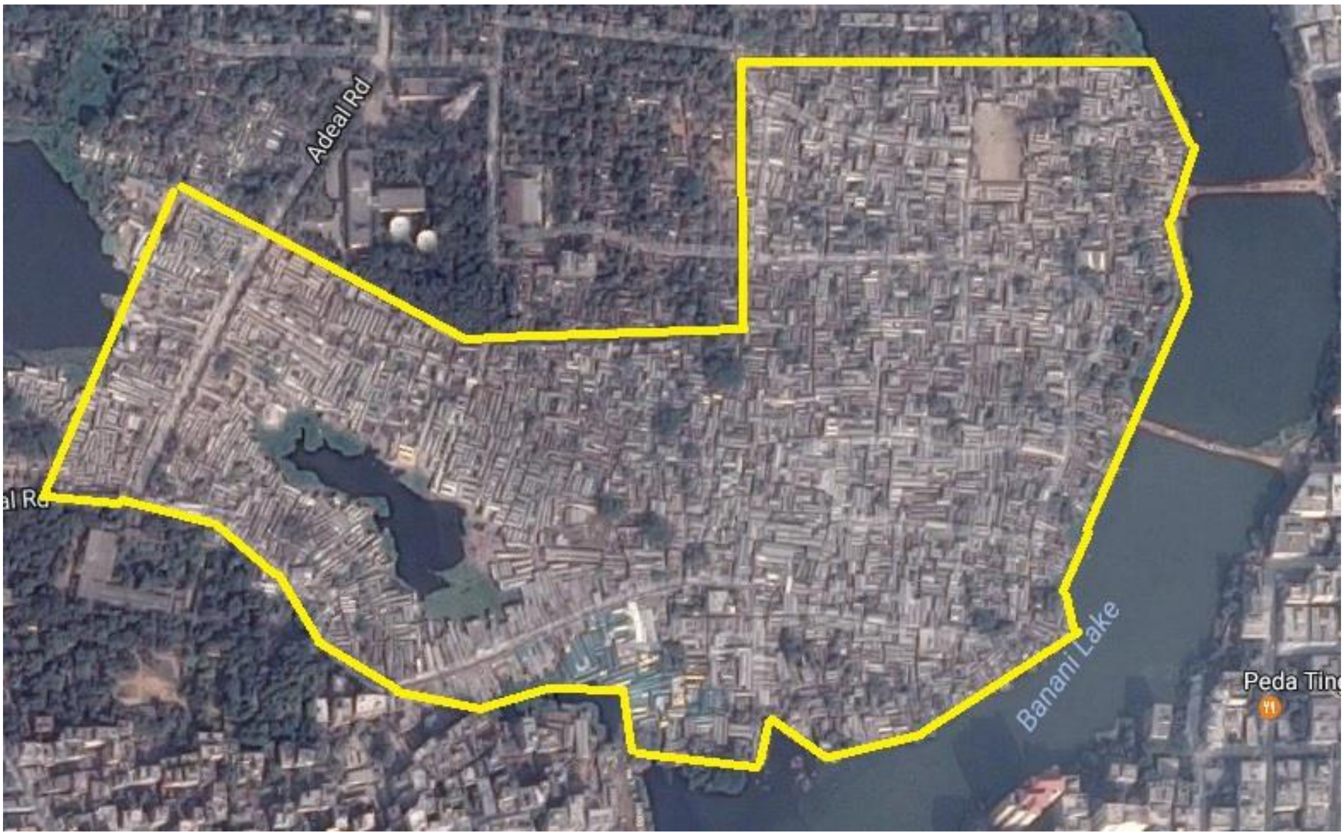

Fig. 1. Map of Korail Slum (collected from google map)

4.2. Data description and assumptions

The study was conducted in Korail slum based on a household survey. The sample size for the survey was estimated to be 100 considering 95% confidence level with 10% margin of error and 0.36 degree of variability [43]. In this study, the random sampling strategy was applied for the selection of each family in the slum to avoid any kind of bias.

The survey related to energy access was performed by using both primary and secondary data. The procedures for collecting primary data were achieved by observation as well as both formal and informal interviews. The survey also included meeting with key informants who were in charge to supply electricity service in the urban slum area as well as with NGOs, slum leaders, and different stakeholders. There were questions on electricity connection status for the households such as whether they are serviced by the utility company or from other sources and mode of payment to know whether they pay electricity bill by unit indicated in the meter or by other methods. There were also questions on user acceptance of electricity to know the reliability, availability, and safety of the supply. Some questions were also included to know the type of appliances used, their operating hours and amount of waste emitted in a day.

All essential information and secondary data were collected from various journals, thesis, authentic websites, previous annual reports, articles. Furthermore, the documents available in various agencies like BRAC, IDCOL, LGED, DPDC and DESCO and other concerned agencies were reviewed. For the clear understating of energy and poverty conditions of Bangladesh, article of UNDP and World Bank were also studied.

4.3 Electricity generation from roof-top solar PV system

By identifying the actual roof-top area, estimating demand of households and considering battery and converter efficiency, electrical power can be generated (MW) by using solar PV.

Actual roof top area is considered as half of the total area. It was noticed during the survey that all the house roof-top were not suitable to install roof-top solar PV since some slum houses are made of very poor quality materials (wood, C.I sheet). Bright roof top area is taken as half of the actual roof-top area due to shading effect. A total number of households in Korail slum is 20,000 considering each family has 5 members. The average demand in each house is 130 W or less. Each house is equipped with one light (60 W) and one ceiling fan (70 W). 75 Wp solar module is considered with an area of 0.8 m^2. Inverter efficiency and battery efficiency is taken as 60% and 80% respectively [29].

4.4 Energy recovery potential from household waste

Biodegradable, organic as well as non-biodegradable material play an important role in producing electricity from waste in the thermochemical conversion.

Table 1. Eqautions for electricity genetation estimation [44]–[46]

Methods	Equations	Equation No
Roof-top solar PV	$N_m = \frac{A_r}{A_m}$	(1)
	$E_{PV} = C_P \times GHI \times \eta_e \times \eta_b \times N_m$	(2)
Thermochemical process	$ERP = 1.16 \times NCV \times MSW_q$	(3)
	$PGP = \frac{0.048 \times NCV \times MSW_q \times \eta_{Th}}{1000}$	(4)
Biochemical process	$BG = TB_p \times \eta_d \times OBF \times VM \times MSW_q \times 1000$	(5)
	$ERP = \frac{BG \times NCV}{0.042}$	(6)
	$PGP = \frac{BG \times NCV \times \eta_B}{1008}$	(7)
Energy efficiency	$E_{cycle} = P \times T \times k$	(8)
	$E_{cost} = E_{cycle} \times C_E$	(9)
	$L_C = C_C + R_C + E_{cost}$	(10)

Where, $N_m =$ Number of modules to be installed; $A_r =$ Actual roof-top area for PV installation (m^2); $A_m =$ Area needed per module (m^2); $E_{PV} =$ Potential electricity generation (MW) from roof-top solar PV; $C_P =$ Capacity of module (Wp); GHI= Global Horizontal Irradiance of Dhaka; $\eta_e =$ Inverter efficiency; $\eta_b =$ battery efficiency; ERP=Energy recovery potential (kWh/tMSW); PGP=Power generation potenttial (MW/tMSW); NCV=Net calorific value (k-cal/kg for themochemical, kW /m^3 for biogas); MSWq=Municipal solid waste quantity (Tons/day); $\eta_{TH} =$ Thermochemical conversion efficiency; BG=Biogas generation (m^3/tMSW); $TB_P =$ Theoritical biogas potential (m^3 /kgVS); $\eta_d =$ Typical digestion efficiency; OBF=Organic biodegradable fraction; VM=Volatile matter (% on dry basis); $\eta_B =$ Biochemical conversion efficiency; $E_{cycle} =$ Total energy consumption during life cycle (kWh); P = Power rating (W); T= Hours of operation during lifetime (hr); k=Number of replacement; $E_{cost} =$ Total energy cost (BDT); $C_E =$ Cost of purchasing electricity (BDT/kWh); $L_c =$ Total life cycle cost (BDT); $C_c =$ Capital cost (BDT); $R_C =$ Replacement cost (BDT)

Each house emits 5 kg of solid waste per day. Each house emits both biodegradable and non-biodegradable waste. The calorific value of the organic matter, biodegradable material is taken as 1200 kcal/kg (typical) [47]. The calorific value of biogas is 0.242 kW/m^3 (typical) [47]. The theoritical biogas potential is 0.8 m^3/kg [48]. Typical digestion efficiency is 60% [49]. Organic biodegradable fraction is considered as 66%. A total organic/volatile matter (VM) is 50 % [44]. The conversion efficiency of thermochemical and biochemical is taken as 25% and 30% respectively [46].

4.5 Energy conservation and efficiency program

By replacing incandescent lamps with CFLs, energy consumption, as well as energy expenditure, can be saved. A comparison has been made between an incandescent lamp and fluorescent lamp to calculate energy savings (kWh), energy cost savings (BDT), payback period (years) for a house.

The mathematical expressions for electricity genetation estimation using different approaches is present in Table 01. All the parameters used in the equations are defiend below the table.

5. Results and discussion

5.1 Present status of electricity access

The surveyed area has 100% electricity access. The urban poor people in Korail slum are covered by electricity through a meter which is situated at the pole. The utility company (DESCO) provides electricity access to slum areas by taking a high amount of advance money (as security deposit). There is a slum leader/representative/area committee who makes the registration of the meter using his name. Various government organizations who are in charge of delivering electricity access in the slum areas do not have any direct link with slum dwellers [50]. The local goons take the responsibility to give electricity in the slum areas. They act as a primary contractor between the service provider and slum dwellers. The local goons take advantage from slum people by putting more charge on electricity bills. There are no electricity alternatives available for the slum dwellers and difficulty in meeting payments is met with violence and/or disconnection. The actual electricity supply is unreliable, limited by long outages and it is often unsafe.

The first cause of having this type of electricity access is because of the illegal status of slum dwellers. The urban poor people in slum areas do not have a specific set of legal papers which is required for a legal and authorized electricity connection. The second cause is the high price of electrical accessories and connection which include the installation cost, the cost of connection and the meter cost. Since slum dwellers are poor and hold a hardship life, they cannot afford the high upfront cost of electricity connection.

Slum dwellers pay the electricity bill either by equipment type or by agreed sum through negotiation. There is a different fee structure depending upon the use of appliances. Comparatively, the poor people pay more for consuming electricity than the legal users of either DESCO or DPDC. Slum residents pay more than 5 times higher for using incandescent lamp than normal tariff rate set by the Bangladesh Energy Regulatory Commission (BERC). For example, consider a typical slum house where a 60 W incandescent lamp is used for a monthly fee of 150 BDT. Considering five hours daily usage time and 30 days a month, a typical slum house consumes 9 kWh/month (60 W×5 h×30 day/1000). Therefore, the urban poor pay 16.67 BDT/kWh (150 BDT/month ÷ 9 kWh/month). However, the domestic tariff rate is 3.33 per unit (0-75 unit). In addition, due to the unplanned distribution of poor quality electric cables, the occurrence of short circuit is common phenomena which causes a fire hazard.

5.2 Issues and challenges

There are many issues and challenges which need to be discussed before proposing any approaches to improve electricity access in Korail slum of Dhaka city.

The most important challenges to access electricity in Korail slum are the illegal recognition and lack of financial capability of slum people. An authorized electricity connection requires legal tenure-ship and constitutional documents. Due to illegal nature, slum dwellers automatically left out from the valid electricity services. Barrett and Dunn [51] found that 30% of the city population hold 80% of the land while only 20% of the land is occupied by the remaining 70% people. The results demonstrate that there is a serious challenge for the government to accommodate land to all the city people. Since the majority of the urban poor migrate to Dhaka city for earning money and maintaining a decent livelihood, they do not have enough savings and assets. Therefore, they cannot afford to buy a legal land and house. Living in the residential areas of Dhaka city is very expensive since the land price has been rising dramatically. Therefore, urban poor people have no other choices but to move towards the city’s peripheries for searching cheap shelter [52].

The establishment of a legal settlement and affordable housing for the urban poor has become a huge challenge to get access to electricity. The National Housing Policy (NHP) was first introduced in 1993 in which the urban poor were given the advantages in receiving the housing rights with an offer of different housing prices as per their affordability. The strategic provisions of the NHP, 1993 has not been implemented in reality and no government has become successful in proposing effective plans, establishing housing rights and providing affordable housing needs of the urban poor [53]. A few promising plans were suggested to provide affordable housing to the urban poor. Rajdhani Unnayan Kartripakkha (RAJUK) started to prepare the Dhaka Metropolitan Development Plan (DMDP) in 1995. Firstly, Urban Area Plan (UAP) (1995-2005) was introduced which highlighted the shifting of the slum dwellers to healthy and safer places in Dhaka city. Nevertheless, the project was not attractive to the urban poor since they were transferred to surrounding areas outside the Dhaka city where they found difficulties in securing a job. Later, the strategy of Detailed Area Plan (DAP) (2005-2015) was introduced to upgrade the existing slums and develop low-cost housing. But the approach of slum up gradation was restricted to some areas such as Islambagh, Shahid Nagar and Jhilpar slum [54]. In conclusion, the high value of land, the limited availability of land and a massive number of urban poor people cause trouble for proper rehabilitation.

One of the main limitations of delivering electricity service to slum dwellers is slum eviction. There has always been a fear of eviction due to the illegitimate settlement of urban poor. Therefore, the government agencies, NGOs, and donors are not interested in investing capital in slum settlements assuming that they might lose the money any time due to slum eviction. Nazrul [55] stated that there are about 135 instances of slum evictions in Dhaka city occurred from 1975 to 2001. The largest slum eviction occurred in Agargaon where around 40,000 slum dwellers got affected. Moreover, there have been slum evictions from January 2004 to June 2005 which evicted 27,055 people in 17 incidents of which 13 incidents were conducted by the government and the rest 4 by private groups [56].

The absence of centralized institutions related to the development of energy services also becomes a challenge to deliver electricity access in slum areas. Slum development department was established by Dhaka City Co-operation (DCC) in the early 90s with a focus to enhance the infrastructure in the urban poor areas of Dhaka city. However, there was no connection between energy service providers and slum development department of DCC. Though the department installed street lighting in slum areas, the explicit plan to improve electricity services in terms of meter electricity connection, clean fuels was not proposed. The department was suffering from lack of financial aid which delayed the progress of any program. There are some other agencies who took responsibilities for the urban development; however, slum electrification program was not addressed. There is conflict on urban policy between DCC and other agencies due to dual metropolitan power and control. The power of DCC is controlled by the ministry of local government, therefore there is a lack of control and leadership of municipal government over municipal affairs. DCC relies on the support and acknowledgment from DPDC, DESCO and Petro-Bangla for the final execution of the plan relate to electricity supply. Due to the poor urban governance, DCC was incapable of implementing any plan and program to improve the electricity accessibility in the urban poor areas [57].

Another challenge to improve electricity access in slum areas is the lack of coordination among the energy sector institutions. UNDP [58] reported that energy sector institutions act separately and cooperate little among themselves. Therefore, their programs and policies do not collaborate and often contradict each other. For instance, sub-sectors such as energy and minerals do cooperate with the power sector independently; however, they do not cooperate their policies with each other. Hence, lack of communication among the institutions with several different policies not only create policy misperception in the energy sector but also weaken the governance monitor and control.

The last challenge is the lack of policies targeting the urban poor and urban poverty. UNDP also [47] reported that the approach concerning slum development is always being ignored from policy analysis. In addition, no policy has been introduced in relation to highlighting cleaner energy or energy efficiency. The government proposes policies which are more towards either increasing the capacity of a power plant or installing new power plants rather than being concentrated on demand side management or energy application [59].

There is a lack of awareness among slum dwellers regarding the benefits of using clean resources such as solar energy and biomass. Even they are not aware of the financial advantages of using efficient appliances. The reason is that most of them are illiterate and they are more concerned to meet the basic needs rather than to spend the time to gain knowledge about the benefits of using clean fuels.

5.3 Proposed suggestions for the improvement of electricity access

Improvement of electricity access in the urban slum areas needs long term effective plans, programs as well as support and cooperation from the government. Since the country has been suffering from a shortage of electricity supply for a long period time, therefore government is more concerned about fulfilling the demand of electricity in the residential, commercial and industrial purposes rather than focusing on the urban poor areas. In this circumstances, SHS or roof-top solar PV system may be extensively utilized for electrification purposes in the urban poor areas. Several private entrepreneurs along with a number of NGOs are providing solar PV to meet basic energy needs with microfinance scheme. A similar approach can also be promoted in the urban poor areas of Dhaka through attractive financing schemes like easy installment, subsidy. Besides, solid waste which remains unutilized and are thrown here and there can be used to produce electricity or can be combined with solar PV to make solar-solid waste hybrid system. Moreover, biogas produced from solid waste could be used for both lighting and cooking purposes. It is also evident that urban poor are unaware of the financial benefit of efficient appliances. Since the country has already been in the shortage of electricity supply, it is proposed to encourage the urban poor about the usefulness of using the energy efficient appliances which will reduce the demand of the city.

5.3.1 Assessment of electricity generation by rooftop solar PV

Potential of electricity generation from rooftop solar PV in the Korail slum area is estimated by using equation (1) and (2). Table 2 suggests that 17.2 MW electricity can be produced from 182108 m^2 bright roof top area. Total demand in the Korail slum is 2.6 MW considering a total number of houses of 20,000 and the demand of each house of 130 W. A typical slum house uses one incandescent lamp (60 W) and one ceiling fan (70 W) Therefore, 14.6 MW of can be saved which can be transmitted to the national grid. Thus, the solar energy program not only meets the local area demand but also it can add a significant amount of power to the national grid which is going to reduce the power blackout. As SHS has already been well accepted as promising alternative power source among the people due to its innovative financing mechanism, so it requires proper management by the government to disseminate the solar energy program in the urban poor areas.

5.3.2 Assessment of electricity generation by solid waste

The amount of electricity generated from the waste based on the thermochemical and biochemical conversion is estimated as 1.44 MW and 1.14 MW respectively using the equations from (3) to (7) and is presented in Table 3.

It is noticed that total demand of urban poor living in Korail slum cannot be fulfilled from the waste as total demand is calculated as 2.6 MW. However, the electricity from the solid waste can be utilized for lighting purposes. The estimated lighting load of Korail slum is 1.2 MW (60W × 20000 houses)

Another proposal could be to combine solid waste with solar PV to build a solar PV solid waste hybrid system. Furthermore, the biogas generated from the biochemical conversion can be used for cooking purposes since most of the slum dwellers use inefficient fuel for cooking burnt in traditional cook stove thus releasing very less amount useful energy. The main challenge of generating electricity from solid waste is the management of collecting waste. It requires strong teamwork as well as support from the urban poor to dispose the waste to a common place.

Table 2. Electricity generation from rooftop solar PV

Parameters	Unit	Amount
Total area	m^2	364217
Bright roof top area	m^2	182108
Actual roof top area	m^2	91054
GHI of Dhaka [25]	$kWh/m^2/day$	4.20
Capacity of Each module	W_P	75
Each module output	W	151
Area needed/module	m^2	0.8
Number of modules to be installed	No.	113818
Potential electricity generation	MW/day	17.2

Table 3. Electricity generation from solid waste using thermochemical and biochemical conversion

Conversion process	Parameter	Unit	Amount
Thermo-chemical conversion	Each house emits	kg/day	5
	Energy recovery potential	kcal	6,000
	Energy recovery potential	kWh	6.96
	Power generation potential	kW	0.072
	Net power generation potential considering 20,000 houses	MW	1.44
Bio-chemical conversion	Each house emits	kg/day	5
	Total biogas yield	m^3	0.792
	Energy recovery potential	kWh	4.56
	Power generation potential	kW	0.19
	Net power generation potential considering 20,000 houses	MW	1.14

Besides, the government together with NGO should come forward to raise awareness about the using of waste to generate electricity.

5.3.3 Energy conservation through energy efficiency

Slum dwellers are not aware of the energy conversation and energy efficiency practice. Most of the cases, they prefer appliances which have low cost. The low-cost appliances have very low efficiency.

Table 4. A comparative analysis between incandescent lamp and fluorescent lamp for Korail slum

Parameter	Unit	CFL	Incandescent Lamp
Power rating	Watt	26	60
Number of hours of operation during lifetime	Hour	10,000	1,000
Number of replacements	-		10
Energy consumption/per lamp during the life cycle	kWh	260	600
Total energy cost [60]	BDT	1394	5220
Capital cost per lamp [61]	BDT/ lamp	310	35
Replacement cost over lifetime	BDT		350
Total life cycle cost	BDT	1,704	5,605
Energy savings during life cycle	kWh	340	
Energy cost savings during life cycle	BDT	3,901	
Energy savings for Korail Slum	GWh	6.8	

For example, most of the urban poor use incandescent lamp due to its inexpensive cost compared to a fluorescent lamp. The inefficient appliance not only increases energy consumption but also has a higher energy cost. A comparative study is performed between an incandescent lamp (60W) and a CFL (26 W) for a slum house to estimate the energy savings and energy cost savings. The calculation is conducted considering the total lifetime using equations from (8) to (10). The same approach is also applicable to other efficient appliances (fan and television).

It is observed from Table 4 that a fluorescent lamp can save 340 kWh of electricity which can save 3,901 BDT. Considering all the houses (20,000) in the Korail slum, 6.8 GWh of electricity can be saved which will reduce the demand during the peak hours and subsequent load shedding.

6. Conclusion

The paper assesses the present condition of electricity access in Korail slum of Dhaka city with a comprehensive explanation of issues and challenges. The absence of strong governors, unplanned settlement of slum people as well as the lack of inspection and evaluation system causes more charge on electricity in slum areas. Furthermore, the failure of urban policy, poor governance, unlawful activities, the absence of a regulatory framework and the presence of political influence are also the key obstacles to supply cost-effective and legal electricity supply in urban poor areas. Therefore, introducing suitable plans, policies and proposing appropriate strategies to address the different challenges related to electricity access are very complex tasks. The government, as well as different private agencies, need to analyze the challenges closely, identify the cause of these problems and introduce policies to overcome the difficulties.

This study identifies the potential of solar power and solid waste to provide reliable and affordable electricity supply in Korail Slum of Dhaka. Besides, the study demonstrates the economic benefits of using efficient appliances. Replacing CFL with an incandescent lamp can save a substantial amount of energy as well as energy expenditure which not only provides better performance but also reduces electricity consumption during peak hours. It is significant to conclude that:

- Roof-top solar PV proves to be a promising approach to enhance the electricity access in Korail slum. The method can generate 17.2 MW electricity with 182108 m^2 bright roof top area. The demand of Korail slum is only 2.6 MW. Therefore, the surplus 14.6 MW electricity can be either stored or transferred to the national grid.
- Electricity generation from solid waste is another effective method to improve electricity access. Both thermochemical and biochemical conversion are proposed which can generate 1.44 MW and 1.14 MW electricity respectively.
- Replacement of incandescent lamp with CFL not only saves a significant amount of energy but also limits the energy cost. The energy saving during the lifecycle using a CFL is 340 kWh which saves 3,901 BDT.

List of abbreviations

AGECE	Advisory Group on Energy and Climate Change
BPDB	Bangladesh Power Development Board
BRAC	Bangladesh Rural Advancement committee
CFL	Compact Fluorescent Light
CUS	Center of Urban Studies
DAP	Detailed Area Plan
DCC	Dhaka City Co-operation
DESCO	Dhaka Electricity Supply Company Limited
DMDP	Dhaka Metropolitan Development Plan
DPDC	Dhaka power Distribution Company
GHI	Global Horizontal Irradiance
GNESD	Global Network on Energy for Sustainable Development
GOB	Government of Bangladesh
GS	Grameen Shakti
IDCOL	Infrastructure Development Company Limited
IEA	International Energy Agency
LGED	Local Government Engineering Department
NGO	Non-Governmental Organization
NHP	National Housing Policy
RAJUK	Rajdhani Unnayan Kartripakkha
REB	Rural Electrification Board
SHS	Solar Home System
UNDP	United Nation Development Programme
WAI	Weighted Average Index
WDI	World Development Indicator
WEC	World energy council
WHO	World Health Organization

References

[1] IEA, “Energy for All: Financing access for the poor,” 2011.

[2] AGECC, “Energy for a Sustainable Future. Summary Report and Recommendations,” 2010.

[3] UN Habitat, “Case Study: Dhaka’s extreme vulnerability to climate change,” *State of the World’s Cities 2008/2009*, 2009.

[4] N. Islam, A. Mahbub, N. Nazem, G. Angeles, and P. Lance, *Slums of Urban Bangladesh: Mapping and Census, 2005*. 2006.

[5] S. Rashid, “Strategies to reduce exclusion among populations living in urban slum settlements in Bangladesh.,” *J Health Popul Nutr*, vol. 27, no. 4, pp. 574–86, Aug. 2009.

[6] BPDB, “Key Statistics, Present Installed Generation Capacity (MW) as on 01 January, 2017,” 2017. [Online]. Available: http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=5&Itemid=6. [Accessed: 23-Jan-2017].

[7] UNDP, *Towards an “Energy Plus” Approach for the Poor: An Agenda for Action for Asia and the Pacific*. 2012.

[8] M. S. H. Lipu, P. Shrestha, and S. Kumar, “Energy poverty and access to modern energy of urban poor: a case of Dhaka, Bangladesh,” *Int J Energy Technol Policy*, vol. 12, no. 3, p. 270, 2016.

[9] World Bank, “Dhaka: Improving Living Conditions for the Urban Poor,” 2007.

[10] E. U. Khan and A. R. Martin, “Hybrid renewable energy with membrane distillation polygeneration for rural households in Bangladesh: Pani Para Village case study,” in *2014 International Conference on Renewable Energy Research and Application (ICRERA)*, 2014, pp. 365–368.

[11] N. Chellammal, R. C. Ilambirai, S. SekharDash, and K. V. Rahul, “Integration of renewable energy resources in off GRID system using three port zeta converter,” in *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, 2016, pp. 971–976.

[12] J. Arrinda, J. A. Barrena, M. A. Rodriguez, and A. Guerrero, “Analysis of massive integration of renewable power plants under new regulatory frameworks,” in *2014 International Conference on Renewable Energy Research and Application (ICRERA)*, 2014, pp. 462–467.

[13] Power Division, “Renewable Energy Policy of Bangladesh Power Division Ministry Of Power, Energy And Mineral Resources Government of The People’s Republic Of Bangladesh,” 2008.

[14] World bank, “Solar Program Brings Electricity to Off-the-Grid Rural Areas in Bangladesh,” 2016. [Online]. Available: http://www.worldbank.org/en/news/feature/2016/10/10/solar-program-brings-electricity-off-grid-rural-areas. [Accessed: 22-Jan-2017].

[15] S. M. N. Hoque, B. K. Das, and M. R. A. Beg, “Evaluation of Energy Payback and CO2 Emission of Solar Home Systems in Bangladesh,” *Procedia Eng*, vol. 90, pp. 675–679, 2014.

[16] M. S. H. Lipu, M. S. Uddin, and M. A. R. Miah, “A Feasibility Study of Solar-Wind-Diesel Hybrid System in Rural and Remote Areas of Bangladesh,” *Int J Renew Energy Res*, vol. 3, no. 4, pp. 892–900,

2013.

[17] NRSD, “Bangladesh, National Report on Sustainable Development,” *United Nation Conf Sustain Dev*, 2012.

[18] S. Mollik, M. M. Rashid, M. Hasanuzzaman, M. E. Karim, and M. Hosenuzzaman, “Prospects, progress, policies, and effects of rural electrification in Bangladesh,” *Renew Sustain Energy Rev*, vol. 65, pp. 553–567, 2016.

[19] M. Z. Rahman, “Multitude of progress and unmediated problems of solar PV in Bangladesh,” *Renew Sustain Energy Rev*, vol. 16, no. 1, pp. 466–473, 2012.

[20] M. S. H. Lipu, M. G. Hafiz, M. S. Ullah, A. Hossain, and F. Y. Munia, “Design Optimization and Sensitivity Analysis of Hybrid Renewable Energy Systems: A case of Saint Martin Island in Bangladesh,” *Int J Renew Energy Res*, vol. 7, no. 2, pp. 988–998, Jun. 2017.

[21] P. K. Halder, “Potential and economic feasibility of solar home systems implementation in Bangladesh,” *Renew Sustain Energy Rev*, vol. 65, pp. 568–576, 2016.

[22] M. S. H. Lipu and T. Jamal, “Techno-economic Analysis of Solar Concentrating Power (CSP) in Bangladesh,” *Int J Adv Renew Energy Res*, vol. 2, no. 5, pp. 750–762, 2013.

[23] S. M. Rahman and M. M. Ahmad, “Solar Home System (SHS) in rural Bangladesh: Ornamentation or fact of development?,” *Energy Policy*, vol. 63, pp. 348–354, 2013.

[24] M. F. Hossain, S. Hossain, and M. J. Uddin, “Renewable energy: Prospects and trends in Bangladesh,” *Renew Sustain Energy Rev*, vol. 70, pp. 44–49, 2017.

[25] S. A. Chowdhury and M. Mourshed, “Off-grid electrification with solar home systems: An appraisal of the quality of components,” *Renew Energy*, vol. 97, pp. 585–598, 2016.

[26] IDCOL, “Solar Home System Program,” 2016. [Online]. Available: http://idcol.org/home/solar. [Accessed: 22-Jan-2017].

[27] B. Van der Zwaan and A. Rabl, “Prospects for PV: a learning curve analysis,” *Sol Energy*, vol. 74, no. 1, pp. 19–31, 2003.

[28] S. Islam and A.-U. Huda, “Technical note Proper utilization of solar energy in Bangladesh: effect on the environment, food supply and the standard of living,” *Renew Energy*, vol. 17, no. 2, pp. 255–263, Jun. 1999.

[29] M. H. Kabir, W. Endlicher, and J. Jägermeyr, “Calculation of bright roof-tops for solar PV applications in Dhaka Megacity, Bangladesh,” *Renew Energy*, vol. 35, no. 8, pp. 1760–1764, 2010.

[30] B. Sørensen, “GIS management of solar resource data,” *Sol Energy Mater Sol Cells*, vol. 67, no. 1, pp. 503–509, 2001.

[31] M. A. H. Mondal and M. Denich, “Assessment of renewable energy resources potential for electricity generation in Bangladesh,” *Renew Sustain Energy Rev*, vol. 14, no. 8, pp. 2401–2413, 2010.

[32] Y. I. Tosun, “5MW hybrid power generation with agriculture and forestry biomass waste co-incineration in stoker and subsequent solar panel (CSP) ORC station,” in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, 2015, pp. 583–589.

[33] Y. I. Tosun, “The proposed design of co-combustion stoker for Şırnak agricultural biomass waste and Şırnak asphaltite in 35MW electricty production,” in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, 2015, pp. 358–363.

[34] H. M. Zakir Hossain, Q. Hasna Hossain, M. M. Uddin Monir, and M. T. Ahmed, “Municipal solid waste (MSW) as a source of renewable energy in Bangladesh: Revisited,” *Renew Sustain Energy Rev*, vol. 39, pp. 35–41, 2014.

[35] K. M. N. Islam and M. Jashimuddin, “Reliability and economic analysis of moving towards wastes to energy recovery based waste less sustainable society in Bangladesh: The case of commercial capital city Chittagong,” *Sustain Cities Soc*, vol. 29, pp. 118–129, 2017.

[36] A. Matter, M. Ahsan, M. Marbach, and C. Zurbrügg, “Impacts of policy and market incentives for solid waste recycling in Dhaka, Bangladesh,” *Waste Manag*, vol. 39, pp. 321–328, 2015.

[37] Q. Hamidul Bari, K. Mahbub Hassan, and M. Ehsanul Haque, “Solid waste recycling in Rajshahi city of Bangladesh,” *Waste Manag*, vol. 32, no. 11, pp. 2029–2036, 2012.

[38] M. Bishir and H. M. Raji, “Quantitative and Qualitative Analysis Of Biogas Produced From Three Organic Wastes,” *Int J Renew Energy Res*, vol. 6, no. 1, pp. 299–305, Mar. 2016.

[39] M. A. Sufian and B. K. Bala, “Modelling of electrical energy recovery from urban solid waste system: The case of Dhaka city,” *Renew Energy*, vol. 31, no. 10, pp. 1573–1580, Aug. 2006.

[40] J. Alam and W. Bole, “Energy recovery From Municipal Solid Waste in Bangladesh,” pp. 125–130, 2001.

[41] M. D. Islam and A. Z. A. Saifullah, “Solid Waste and Sugarcane Bagasse-A Renewable Source Of Energy In Rajshahi City, Bangladesh,” pp. 33–36, 2001.

[42] Power Division, “Vision Statement, Government of The People’s Republic of Bangladesh Vision Statement Power Division Ministry of Energy And Mineral Resources,” 2000.

[43] K. Jamil, A. Baqui, and N. Paljor, “Knowledge and practice of contraception in Dhaka urban slums: a baseline survey.” Dhaka Bangladesh International Centre for Diarrhoeal Disease Research Bangladesh [ICDDRB] 1993 May., 1993.

[44] M. S. Korai, R. B. Mahar, and M. A. Uqaili, “The feasibility of municipal solid waste for energy generation and its existing management practices in Pakistan,” *Renew Sustain Energy Rev*, vol. 72, no. December 2016, pp. 338–353, 2017.

[45] M. Chakraborty, C. Sharma, J. Pandey, and P. K. Gupta, “Assessment of energy generation potentials

of MSW in Delhi under different technological options," *Energy Convers Manag*, vol. 75, pp. 249–255, 2013.

[46] M. S. Korai, R. B. Mahar, and M. A. Uqaili, "Optimization of waste to energy routes through biochemical and thermochemical treatment options of municipal solid waste in Hyderabad, Pakistan," *Energy Convers Manag*, vol. 124, pp. 333–343, Sep. 2016.

[47] O. K. M. Ouda, S. A. Raza, R. Al-Waked, J. F. Al-Asad, and A.-S. Nizami, "Waste-to-energy potential in the Western Province of Saudi Arabia," *J King Saud Univ - Eng Sci*, Mar. 2015.

[48] A. Nielfa, R. Cano, and M. Fdz-Polanco, "Theoretical methane production generated by the co-digestion of organic fraction municipal solid waste and biological sludge," *Biotechnol Reports*, vol. 5, pp. 14–21, Mar. 2015.

[49] S. Saini, P. Rao, and Y. Patil, "City Based Analysis of MSW to Energy Generation in India, Calculation of State-Wise Potential and Tariff Comparison with EU," *Procedia - Soc Behav Sci*, vol. 37, pp. 407–416, 2012.

[50] N. Banks, "A tale of two wards: political participation and the urban poor in Dhaka city," *Environ Urban*, vol. 20, no. 2, pp. 361–376, Oct. 2008.

[51] A. Barrett and K. Dunn, "Reaching the MDGs in Urban Bangladesh Presentation at the World Bank Workshop. Towards a Strategy for Achieving MDG Outcomes in Bangladesh. Session 5: Challenges Facing the Urban Poor," 2006.

[52] S. Hossain, "Rapid Urban Growth and Poverty in Dhaka City," *Bangladesh e-Journal Sociol*, vol. 5, no. 1, 2008.

[53] M. Rahman, "Government and Housing for the Poor: Policy and Implementation in Bangladesh," 2010.

[54] RAJUK, "Government of the People's Republic of Bangladesh Ministry of Housing and Public Works Preparation of Detailed Area Plan (DAP) for DMDP Location-10 Final Plan Report," 2010.

[55] I. M. Nazrul, "Slum Eviction and Housing Rights in Dhaka City (1975-2001)," *Japanese J Hum Geogr*, vol. 55, no. 6, pp. 574–589, 2003.

[56] S. Mahmood, "Dhaka slum dwellers live under threat of eviction," 2012. [Online]. Available: https://www.theguardian.com/global-development/2012/apr/11/dhaka-bangladesh-slum-dwellers-eviction. [Accessed: 22-Jan-2017].

[57] M. S. H. Lipu and A. M. W. Bhuiyan, "Electricity access in urban slum households of Bangladesh: A case of Dhaka," *J Renew Sustain Energy*, vol. 6, no. 5, p. 53112, Sep. 2014.

[58] UNDP, "Energy and Poverty in Bangladesh," 2007. [Online]. Available: http://www.asia-pacific.undp.org/content/rbap/en/home/library/climate-and-disaster-resilience/energy-n-poverty/bangladesh.html. [Accessed: 22-Jan-2017].

[59] M. S. H. Lipu, T. Jamal, and A. R. Miah, "Barriers to Energy Access in the Urban Poor Areas of Dhaka, Bangladesh: Analysis of Present Situation and Recommendations," *Int J Energy Econ Policy*, vol. 3, no. 4, pp. 395–411, 2013.

[60] DESCO, "Tariff Rate," 2017. [Online]. Available: https://www.desco.org.bd/?page=tariff-rate. [Accessed: 23-Mar-2017].

[61] CFL bulbs, "Blaze CFL Energy Saving 26 Watt B22 White Light 807840," 2017. [Online]. Available: https://www.othoba.com/blaze-cfl-energy-saving-26-watt-b22-white-light-807840. [Accessed: 23-Mar-2017].