Mini-grid based electrification in Bangladesh: Technical configuration and business analysis

Subhes C. Bhattacharyya*

Institute of Energy and Sustainable Development, De Montfort University, Leicester LE1 9BH, UK

A R T I C L E   I N F O

Article history:
Received 1 August 2013
Accepted 15 October 2014
Available online

Keywords:
Mini-grid
Off-grid electrification
Bangladesh

Abstract

This paper presents a local level study of a village off-grid system in Bangladesh. It applies an integrated methodology that identifies the demand in the off-grid village context using alternative scenarios. The techno-economic analysis of the optimal off-grid system architecture is then presented using HOMER software. Three energy resources are considered, namely solar energy, wind and diesel fuel. The optimal configuration suggested for the scenarios consists of diesel generators for the basic level of demand and PV-diesel hybrid for higher demand and reliable supply scenarios. The cost of electricity per kWh remains high for the basic level of supply and decreases as the system size increases. However, the capital and asset replacement costs increased considerably for bigger systems. The business case is then analysed for each scenario and it was found that it is practically impossible to reach grid price parity even with full capital cost subsidy, indicating significant amount of operating cost subsidy requirement that makes the larger systems financially unsustainable. Moreover, the small mini-grid system for the basic level of supply emerges as a cheaper option than providing the consumers with solar home systems. But the monthly electricity bill will become unaffordable for most consumers when demand restrictions are removed. Accordingly, the paper suggests a mini-grid based electricity supply to provide the basic level of provision alongside productive energy use during off-peak hours as the starting point. If the business develops and the demand improves, the system can be expanded subsequently using appropriate technology combinations.

© 2014 The Author. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/3.0/).

1. Introduction

Being at the forefront of Solar Home System (SHS) dissemination in the world, Bangladesh holds a special place in any discussion on off-grid electrification. In this densely populated, low-income country of 152 million people (in 2012), the overall rate of electrification is reported at 56% in 2011, thereby forcing about 40% of the population to rely on kerosene for lighting purposes[1]. However, there exists a significant variation between the rural and urban areas. 80% of the population resides in rural areas but only about 49% of the rural population is electrified whereas about 89% of the urban population is said to be electrified[1]. Although SHS has been successfully introduced in the country, particularly by Grameen Shakti, it has reached only 4% of the rural households and 0.5% of the urban households so far[1]. The Government aims to provide electricity to all by 2021 and although the strategy appears to consider both off-grid and grid extension options, the task looks increasingly challenging.

Although a lot of academic and other studies have analysed the case of Bangladesh, the literature focuses on two dimensions: the success of Bangladesh in introducing rural electrification through the rural electrification co-operatives (Palli Bidyut Samitis or PBS) (see Ref. [2] for example) and the success of Grameen Shakti in introducing SHS (see Refs. [3,9] and [11] for example). However, neither PBS nor SHS has succeeded in ensuring universal electrification of the country and in the case of SHS the use of electricity for productive purposes has remained insignificant. Moreover, a field-based appraisal of SHS in Bangladesh [9] reported various shortcomings including use of poor quality components, poor installation and an inadequate quality control mechanism. A few other studies (e.g. Refs. [4–6] and [10]), among others) have considered the case of hybrid off-grid systems for rural electricity supply but their analysis remains limited to just techno-economic analysis using a simulation tool, namely HOMER. Most of these studies are hypothetical in nature, rely on representative households consuming identical levels of energy for a given period of time, use generic technology/financial information and thus provide an
overall understanding of the hybrid option. Although these provide useful information, such techno-economic analysis does not really indicate whether the service can be provided as a viable business, whether costs can be recovered through affordable tariffs and whether the investment can be mobilized and if so, under what conditions.

The purpose of this paper is to argue for a transition to mini-grid based off-grid power supply in Bangladesh through a comprehensive analysis of the business case. The main aim is to understand the needs of the rural communities and identify the appropriate solutions based on local resource availability so that an affordable solution can be proposed that is financially viable and socially desirable. This work thus goes beyond the standard application of a simulation tool and adds value by bridging the above knowledge gap.

The paper is organized as follows: Section 2 presents the methodology used in this work; Section 3 presents the case study background information, Section 4 presents the techno-economic analysis of alternative scenarios using HOMER, and Section 5 presents the business case analysis. Finally some concluding remarks are provided in the concluding section.

2. Methodology

Unlike most studies that focus on techno-economic feasibility of a given solution or alternative solutions (e.g. see Refs. [13–16]), this study presents a multi-dimensional analysis covering the techno-economic, business and governance dimensions. Although techno-economic analysis still remains relevant, the work does not stop there. The outcome is further processed to consider the appropriate business delivery option and the conditions required to achieve such a delivery model. Moreover, given the diversity of local conditions that exist in reality, instead of using a stereotypical representative village or locality with fixed characteristics, this paper relies on scenarios of cases that capture different socio-economic conditions, stakeholder preferences, potential opportunities and alternative options. Thus this analysis aims to add value by expanding the knowledge frontier through a holistic analysis of off-grid systems.

The analysis starts with a detailed needs assessment which involves local information gathering to understand the socio-economic characteristics of the local population, their existing and potential livelihood, commercial and productive activities (agriculture and small-scale industries) as well as community-related needs. Instead of developing a single point energy demand estimate, alternative scenarios are developed considering different levels of energy service development (e.g. basic lighting needs, lighting and some livelihood/productive needs, service for a limited period of time, and reliable round-the-clock service, among others). It is also possible to consider multi-village systems for economics of scale.

The techno-economic analysis of appropriate electricity supply system for each scenario is then carried out using HOMER software package developed by NREL. Each case study considers alternative resource options taking local resource availability into consideration as well as alternative scenarios for electricity needs developed in the previous step. This also leads to a further level of iteration that provides a rich set of system configurations and their life-cycle costs corresponding to alternative development paths. Information has also been used to reflect the local cost of energy system components wherever possible.

Whereas other studies end here, this study takes a step further to analyse the results obtained from the techno-economic analysis to consider the practical electricity supply business issues such as viability, funding, tariff and cost recovery, as well as issues related to business environment such as regulatory governance. The flowchart of the framework is presented in Fig. 1. This work thus enhances the framework suggested in Ref. [12] and complements it.

In the following section, the above framework is implemented using a case study.

3. Case study of a village electricity system in Bangladesh

3.1. Village background

This paper considers a non-electrified village in Netrokona district of Dhaka division. Netrokona has the lowest level of electrification in the Dhaka division and is comparable to other poorly electrified districts of the country. Although Netrolona Palli Bidyut Samiti (PBS or village co-operative) exists and has electrified the urban areas, the villages remain non-electrified. The district is in the north of the country and its remoteness has resulted in poor level of electrification in many semi-urban and rural areas.

The chosen village, Mahishpur, comes under Atpara sub-district and is situated at 90°50'E and 24°48'N. Atpara is a remote sub-district, many parts of which are not well connected by road. The village under consideration holds 108 households with a total population of 546 people as per 2011 Census (of which 295 are male and 251 female). The average household size is 5.1 persons but the household size follows a bell-shaped curve with a minimum of 2 persons and a maximum of 8+ persons. The village is not electrified and does not have piped water supply. All households live in houses owned by them but more than 97% of the houses are “kutchas”. 47% of the population is less than 14 years old while about 5% is above 60 years of age. Of the working-age population, women largely take care of household activities and men work in agriculture for living. The village is connected through rural roads from Atpara and Banijjan, which are bigger villages nearby but part of it gets disconnected during the rainy season.

Being non-electrified, the local population relies on kerosene and candles for lighting purposes and fuel-wood, agricultural residues (e.g. jute sticks) and cow-dung cakes for cooking energy. The energy resources for cooking are collected or procured locally.

3.2. Needs assessment and scenarios

As an agricultural village, the local population is highly dependent on agricultural activities for living. The soil is fertile and generally multiple crops are produced. The main crops are paddy, wheat, jute, mustard seed and potato. The village also supplies various fruits, namely mango, jackfruit, banana, and papaya. The area receives more than 2400 ml of rainfall during the year but the monsoon brings most of the rain, thereby causing floods in the area on a regular basis. The area, being part of the freshwater wetland ecosystem, boasts of a number of large water bodies (ponds, lakes, etc.) and fishing is also an important activity. However, due to lack of electricity no processing of food or fish takes place locally and most of the produce is sold in raw form in the nearby markets. However, natural drying of food crops, fruit and cash crops like jute takes place in the village.

To analyse the possibility of electrification through off-grid systems, the scenario approach is used to develop alternative electrification options and pathways. Given the non-electrified nature of the village, the demand is unknown but through alternative scenarios, a range of demand possibilities is considered as follows:

a) Basic: Basic Service (residential demand) — In this scenario, it is assumed that the poor households only use electricity for lighting purposes, while the middle income and rich households use it for fans, TV and battery charging. There is no demand for productive use and the service is available for a limited period of time in the evening hours.
b) Basic+: Basic evening load along with day-time productive demand — This scenario extends the earlier scenario by adding demand for productive uses of electricity during any off-peak time. Such activities can include local artisanal activities and agro-based activities such as grinding, food-drying, rice milling, and similar small-scale activities or even agricultural water pumping at night.

c) Reliable: Reliable supply scenario — This scenario relaxes the time limited supply constraint by providing reliable supply to all consumers. In this scenario, demand from households at any time of the day and commercial/productive demand as they arise are considered.

d) Unconstrained: Full-flowered supply — This is similar to RS but here a higher demand is considered and 24/7 supply is envisaged.

Although more scenarios can be created, the above cases will provide a good understanding of local demand-supply conditions and the effect of them on the techno-economic performance of the system.

In the absence of income distribution information for the specific village, this work relies on the national income distribution profile for rural areas to capture the distribution of households by income categories. Income categories are classified into three groups as follows: households with less than 6000 taka/month income is classed as poor, household with income above 6000 taka/month but less than 15,000 taka/month are considered as medium income and any household with income above 15,000 taka/month are considered as rich. According to the above regrouping, 46% of the households are poor, 15% are rich while 39% of the households come under the middle income population. This results in 50 households in the poor category, 42 in the middle income category and 16 in the rich category. Based on the Household Income and Expenditure Survey 2010 [7], it is estimated that the poor are likely to spend 468 taka/month on lighting and fuel, while the middle income and rich households are likely to spend 572 taka and 768 taka per month respectively.

As the village is non-electrified, the consumption pattern is not available. However, past studies on Bangladesh provide a very standard pattern of consumption in off-grid areas: for example Roy [6] considers that rural households use 3 efficient lamps of 15 W each, 2 or 3 ceiling fans of 80 W each, a television of 80–120 W [4] also uses the same load assumptions. Lights are operated for 6–7 h a day, fans are operated 8–10 h per day during summer and a television is operated for 5–6 h a day. Ref. [5] on the other hand considers 3 lights of 15 W each, 2 fans of 40 W each and a TV of 40 W. The assumptions behind the needs assessment are indicated in Table 1. A number of alternative possibilities is considered. For example, initially the load may be limited to domestic use and the supply may be limited during evening hours only. This is captured in the Basic scenario. The possibility of developing limited commercial load in the evening and some productive load during the off-peak day hours is considered in Basic+ scenario.

As the table suggests, the demand pattern varies by the economic condition of the households and by season (summer and winter). The overall distribution of demand is obtained by summing the demand in each category of consumer in a given period.

3.3. Load profile for different scenarios

Given our scenarios discussed above, the load profiles are quite different in each case thereby allowing us to analyse a range of load situations.
Electricity demand constituents by households and scenarios.

| Items          | Poor HH                                                                 | Middle income HH                                                                 | Rich HH                                                                 | Commercial load | Productive load |
|----------------|------------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------|-----------------|-----------------|
| Basic          | 2 × 10W lighting for 5 h in the evening (5–10pm)                        | 3 × 10W lighting, 2 × 40W fans (summer time), 1 TV 80W for 5 h in the evening     | 4 × 10W lighting, 3 × 40W fans (summer time) and 1 TV 80W for 5 h in the evening | nil             | nil             |
| Basic+         | -do-                                                                   | -do-                                                                             | -do-                                                                   |                 |                 |
| Reliable       | 2 × 10 W lighting for 5 h in the evening (5–10pm) and 2 h in the morning| 3 × 10 W lighting for 2 h in the morning and 6 h in the evening, 2 × 40 W fans (summer time) operating for 18 h, 1 TV 80 W for 10 h. | 4 × 10 W lighting for 8 h per day, 3 × 40 W fans (summer time) for 18 h and 1 TV 80 W for 10 h in the day. | 500 W load for 5 h in the evening | Up to 10 kW off-peak load during day hours |
| Unconstrained  | Same as reliable                                                       | Same as reliable with an additional load of 80 W operating for 10 h              | Same as reliable but an additional load of 500 W operating for 24 h    |                 | Up to 10 kW load at any time |

a) Basic — basic load profile

As the demand is restricted only during evening hours, following the demand logic indicated in Table 2, the daily demand profile for the basic load is shown in Fig. 2 while the seasonal profile is shown in Fig. 3. The winter load is almost half of that in summer due to absence of fan load of middle and high income households. A 5% day-to-day random variation in load is assumed. The peak load of the system is 15.7 kW for 108 households and the average energy need is 53 kWh/day.

Clearly, the average to peak load is low in this case, thereby resulting in a low system load factor of 0.14.

b) Basic+ scenario (off-peak productive load and some commercial load added to Basic case)

In this case, it is considered that 10 kW of productive load is serviced during the day time (between 7 AM and 5 PM) during summer months while the load reduces to 5 kW during the winter months. The average load improves, resulting in a better system load factor of 0.34. The average daily energy need comes to 135 kWh. The peak load is 16.3 kW. The summer and winter daily load profiles are presented in Fig. 4 while the seasonal profile is indicated in Fig. 5.

c) The Reliable supply scenario focuses on reliable supply in rural areas both for residential needs as well as productive needs. This allows any load to operate at any time of the day. The load profile changes considerably here as some residential load at night (mainly for fans in summer) and up to 10 kW water pumping load for irrigation in summer has been considered. In winter, the demand for irrigation water reduces but a 5 kW load is considered at night. During the day time, up to 10 kW productive load in summer and up to 5 kW in winter have been considered. Here the system load factor further improves to 0.472 due to a better load distribution. The daily load profile and seasonal load profile are presented in Figs. 6 and 7 respectively. The peak load here is 28.5 kW and the daily energy demand is 323 kWh. Note that the winter base load is 5 kW whereas the summer base load is 10 kW in this case, which makes the system requirement quite different from the previous cases.

d) Unconstrained supply scenario

The scenario allows full demand potential development for the rich consumers and removes all supply restrictions. Consequently, the peak demand increases to 44 kW here and the overall load factor improves to 0.55. The average daily energy requirement increases to 589 kWh. The daily load profiles and seasonal profile are presented in Figs. 8 and 9 respectively.

Table 2 compares load profiles of different scenarios.

| Scenarios          | Peak load (kW) | Daily average energy (kWh/day) | Load factor |
|--------------------|----------------|--------------------------------|-------------|
| Basic              | 15.7           | 53                             | 0.14        |
| Basic+             | 16.3           | 134                            | 0.344       |
| Reliable supply    | 28.5           | 323                            | 0.472       |
| Unconstrained Supply | 44.4            | 589                           | 0.553       |

The solar energy availability in the case study village is obtained from HOMER. Based on the latitude — longitude information for the village location, HOMER estimated the annual average solar insolation of 4.58 kWh/m²/d. However, the insolation level increases between March and May and reduces during the monsoon season (July—September). The monthly pattern of radiation and the trend of cleanliness index are shown in Fig. 10.
The data for wind resources is not readily available for Bangladeshi villages. However, provides monthly average wind speed for a nearby location in the Dhaka Division. In the absence of any specific data for the village, this information has been used (see Fig. 11). It can be seen that wind blows all year round but the speed tends to be higher during the summer-monsoon months. The diurnal pattern strength of 0.0323 is used for the location and the wind speed peaks at 15 h.

For diesel generators, it has been assumed that the fuel is available from the national supply system and being incremental in nature, the village level demand will not affect the market conditions adversely. The prevailing local rates for diesel have been used, which may not reflect the true economic cost of the fuel.

### 3.5. Component details

Based on the above resource and demand considerations, the following components were considered: Solar PV, a generic 1 kW wind turbine, a generic 3 kW wind turbine, a diesel generator, batteries and converters. The specific details of each are provided below.

#### 3.5.1. Solar PV

The unit cost of solar PV systems has declined considerably in recent time. For this study, a 1 kW PV system is assumed to require $2800 and the replacement cost is $2000 per kW. A low operating and maintenance cost of $10/year/kW is considered. The cost is based on [8]. It is assumed that no tracking device is used. The life of solar panels is assumed to be 20 years. The simulation is carried out for various quantity—capacity combinations to facilitate optimal sizing of the system.

#### 3.5.2. Wind turbines

Two generic small wind turbines, namely of 1 kW capacity and 3 kW capacity suitable for rural application are included. According to [8], the civil construction and erection cost of wind turbines can be significant compared to the equipment cost, particularly in the small size range. Although the capital cost of 1 kW wind turbine can be close to $2500/kW, the overall cost of installation can be as high as $5000 to 6000. Accordingly, a capital cost of $4000/kW is used while the replacement cost is taken as $2500. The O&M cost is taken as $50/year for this turbine. It is assumed to have a life of 15 years and the hub height is 25 m. For the 3 kW wind turbine, the capital cost is taken as $10,000 whereas the replacement cost is taken as $8000, with $250/year considered towards O&M costs. Although [5] and others have used lower costs for Bangladesh, our cost assumptions are closer to the reality.

#### 3.5.3. Diesel generator

Diesel generators are widely used for electricity generation in rural areas and are widely available. There is minimal civil work
involved in this case and the generator cost captures the overall investment requirement. The capital cost of 1 kW of generator is considered to be $600 and the replacement cost is considered as $500. The operational and maintenance cost of the generator is taken as $0.5/hr for every 10 kW of generator size. It is assumed that the generator can be operated for 15,000 h in its lifetime and the minimum load it can take is 10% of its rated capacity. Diesel price is taken as $0.6/litre which is based on the local market price in Bangladesh.

3.5.4. Battery

For this analysis, Trojan L16P has been considered. This is a 6 V battery with a nominal capacity of 360 Ah and a normal life of 10 years. 4 batteries in a string are used so that a 24 V bus bar can be used. The cost of batteries varies widely depending on the make and source of supply. For this study, a cost of $150 for each battery is used while the replacement cost is taken as $100.

3.5.5. Inverter

The cost of converter is taken as $200/kW and the replacement cost is taken as $150/kW. It has a normal life of 15 years and is assumed to have an efficiency of 85%.

Other system costs: As HOMER does not include the cost of distribution network separately, a capital cost of $3000 towards the cost distribution network for 108 households is used and $200 per year towards fixed O&M costs.

The project life is taken as 15 years — this is done to match the project life with the debt repayment period. HOMER calculates any salvage value of the assets based on its remaining life and the replacement cost of the asset. Therefore, although components have different life periods, the project cost is fairly attributed for the project life. A real discount rate of 5.3% has been used in the analysis, based on the cost of capital in dollar terms.

Clearly, the economic parameters affect the overall results significantly. As mentioned earlier, some recent studies on Bangladesh have used quite different economic parameters (see Table 3 for some examples). Clearly, a lower capital and operating cost of any equipment makes it more desirable for the optimal solution and the cost of generation reduces. However, unrealistic costs reduce the relevance of the analysis and distort the optimal solution.

4. Results of the techno-economic analysis

For the techno-economic analysis, HOMER software package was used. The results for each scenario are presented below.

4.1. Basic supply scenario

Considering the demand, component cost characteristics and resource availability, a diesel generator of 20 kW emerges as the optimal architecture for this scenario. The capital cost comes to
$15,000 and the annualized operating cost comes to $7514/year (see Table 4 for cost summary). The levelised cost of electricity comes to $0.465/kWh. The diesel generator operates 1825 h/year and consumes 8209 L of diesel/year. As the life of the generator is limited to 15,000 h, a replacement is required after 8.2 years and an investment of $10,000 is required at this time. The generator produces 19,345 kWh in a year and there is no excess electricity production that goes waste in this case. The power generation profile is indicated in Fig. 12.

4.2. Scenario Basic+

The optimized system architecture for this scenario consists of a 10 kW PV system and a 10 kW diesel generator alongside 72 Trojan L16P batteries, and a 10 kW inverter — rectifier. The capital cost for this system comes to $49,800 and the net present cost (NPC) comes to $184,509, with a levelised cost of $0.368/kWh of electricity generated.

27% of electricity output comes from the PV system, whereas 73% comes from the diesel generator. Practically no excess electricity is produced in the process that goes unused. The monthly generation profile is indicated in Fig. 13 below.

The mean output of PV system is 40.3 kWh/day and the annual electricity generation amounts to 14,719 kWh. The PV system operates for 4378 h in a year and the levelised electricity cost from PV is $0.178/kWh. The monsoon months generally record reduced solar output (see Fig. 14). The capital cost of PV arrays comes to $28,000 and the PV system achieves a capacity utilisation of 16.8%.

The diesel generator runs for 4133 h per year, leading to a capacity utilisation of 44.5%. It produces 38,970 kWh/year and consumes 14,926 L of diesel. The diesel generator costs $6000 but adds another $16,253 for fuel costs over the project life time. Due to higher utilisation of the generator, its overall life reduces to 3.6 years and accordingly, four replacements are required during the project life. Each time, $5000 will be required to replace the generator. The power generation profile of the diesel generator is shown in Fig. 15.

The battery system has a nominal capacity of 156 kWh and provides an autonomy of 19 h. The annual throughput of the batteries is 10,261 kWh. The expected life of the batteries is 7.5 years and they have to be replaced once during the project lifetime requiring an investment of $7200. The capital cost for the battery system comes to $10,800 and the net present value of battery-related costs comes to $19,301.

The second best configuration consists of a 10 kW PV, 1 kW Generic wind turbine and a 10 kW diesel generator supported by a battery bank of 64 batteries and a 10 kW converter. The initial capital cost comes to $52,600 while the NPC comes to $188,049 and the levelised cost of electricity comes to $0.375/kWh. The renewable energy share improves to 30% in this case but the reduction in
and the levelised cost of supply. For the wind turbine, thereby increasing the capital requirement. Diesel use is more than offset by the increased investment required. The excess electricity generation is practically non-existent in this case and provides an autonomy of 18 h. The charging status of the batteries is shown in Fig. 19. The capital cost of batteries comes to $126,000 while the expected life of batteries is 5.9 years, thus requiring two replacements during the project life.

Table 4

| Component          | Capital cost ($) | Replacement cost ($) | O&M cost ($) | Fuel cost ($) | Salvage value ($) | Net present cost ($) |
|--------------------|------------------|----------------------|--------------|---------------|------------------|----------------------|
| Diesel             | 12,000           | 6541                 | 18,565       | 50,102        | 807              | 86,401               |
| Other              | 3000             | 0                    | 2034         | 0             | 500              | 5034                 |
| System             | 15,000           | 6541                 | 20,599       | 50,102        | 807              | 91,436               |

Table 3

Examples of cost assumption from literature.

| Cost parameter                | In Ref. [5]          | In Ref. [6]          |
|-------------------------------|-----------------------|-----------------------|
| Capital cost for PV           | 274 taka/W ($3.65/W)  | $270,950 for 100 kW PV arrays |
| Replacement cost of PV        | 206 taka/W ($2.75/W)  | $45,000 for 100 kW PV arrays |
| O&M cost                      | 50 taka/W/year ($0.67/W) | $500/year for 500 kW |
| Capital cost of a 3 kW wind turbine | 86,584 taka/kW ($1155/kW) | $455,000 for a 300 kW turbine |
| Replacement cost of a 3 kW wind turbine | 75,000 taka/kW ($1000/kW) | $65,000 for a 300 kW turbine |
| O&M cost of a 3 kW wind turbine | 10000 taka/year/turbine (or $13) | $1000/year for a 300 kW turbine |
| Capital cost of diesel generator | 10,000 taka/kW (or $133/kW) | $116,883 for a 500 kW generator |
| Diesel price                  | 45 taka/h (or $0.6/l) | $0.7/l |
| O&M cost of a diesel generator | 20 taka/h for 10 kW ($0.27/h); 30 taka/h for 20 kW ($0.4/h) | $5/h |

As shown in Fig. 16, PV arrays provide 34% of the electricity output while the remaining 66% comes from the diesel generator. The system also produces about 1% excess electricity that remains unused. The solar PV produces 121 kWh/day and operates for 4378 h per year producing 44,157 kWh of electricity per year (see Fig. 17). The levelised cost of solar electricity comes to $0.178/kWh and achieves a capacity factor of 16.8%. The capital cost of PV system comes to $84,000.

The diesel generator operates for 4939 h and produces 86,701 kWh/year. It consumes 33,550 L of diesel and achieves a capacity utilization rate of 49.5%. The capital cost required for the diesel generator is $12,000 but the fuel cost comes to $204,767 over the life of the project. Accordingly, the diesel system accounts for the highest share of the net present cost in this scenario. The power output is shown in Fig. 18. The expected life of the generator is about 3 years and consequently, 4 replacements are required during the project life, requiring $10,000 each time in investment.

The battery system has a nominal capacity of 346 kWh in this case and provides an autonomy of 18 h. The charging status of the batteries is shown in Fig. 19. The capital cost of batteries comes to $24,000 but the expected life of batteries is 5.9 years, thus requiring two replacements during the project life.

The second-best solution comes with a 30 kW PV system alongside a 1 kW wind turbine and a 20 kW diesel generator supported by a set of 160 batteries and a 15 kW converter. The capital cost comes to $130,000 but the net present cost comes to $436,792. The diesel generator requires 441 L of diesel less than the optimal case but this does not offset the capital cost of a wind turbine, making the option less attractive in terms of cost of electricity supply. However, it achieves 35% renewable energy share compared to 34% in the optimal case.

A 30 kW diesel generator could also meet the needs effectively and would require about $21,000 in capital investment but the operating cost makes this the least preferred solution in terms of
cost of supply. The levelised cost of electricity comes to $0.463/kWh. The diesel requirement also increases to 52,045 L in this case. In terms of levelised cost, this becomes the least preferred option, despite being the least capital intensive option. However, a 20 kW diesel generator along with 56 batteries and 1 10 kW converter turns out to be a better option than a diesel generator alone, as it can serve the load at a cost of $0.379/kWh. The capital cost increases to $25,400 but the fuel requirement reduces by more than 3600 L, thereby reducing the cost of supply substantially.

4.4. Unconstrained supply scenario

The optimal system architecture for this scenario requires 50 kW PV, and a 30 kW diesel plant supported by 200 Trojan L16P batteries and a 25 kW inverter-rectifier. The capital cost for this system is $196,000 while the NPC comes to $752,290. The levelised cost of electricity for the system is $0.344/kWh.

The electricity generation mix for this scenario is as follows: 31% of output comes from PV, and 69% from the diesel plant. Thus,
renewable energy penetration in the optimal system is 31%. Like other scenarios, excess electricity amounting to about 1% of the demand is produced which is not used. The electricity production mix is shown in Fig. 20.

The PV arrays produce 202 kWh/day and over the year produce 73,595 kWh. The monthly distribution of solar output is shown in Fig. 21. The capital cost for the PV system comes to $140,000.

The diesel generator operates 5889 h per year and produces 160,621 kWh (see Fig. 22). It consumes 61,835 L of diesel and has an expected life of 2.55 years. Thus, although the initial capital required for the diesel generator is $18,000, the present worth of the replacement cost comes to $51,424. The present value of the fuel-related cost, $377,407, is however the most important cost element for this scenario.

The second best solution consists of a 50 kW PV system, 1 kW wind turbine and a 30 kW diesel generator alongside 200 Trojan L16P batteries and a 25 kW converter. The capital cost of this system comes to $200,000 but the NPC comes to $753,517,

Fig. 16. Monthly electricity production profile corresponding to reliable supply scenario.

Fig. 17. PV power in reliable supply scenario.

Fig. 18. Diesel power output in reliable supply scenario.
making the levelised cost higher than the optimal solution ($0.345/kWh).

A 50 kW diesel generator can meet the demand with the least capital investment (of $33,000) but as before it emerges as a less preferred solution due to high operating cost. The diesel requirement increases to 92,845 L and the generator operates 8760 h per year.

The above scenarios provide alternative pathways of development of the off-grid electrification system. They also can be viewed as pathways to improve the system as the benefits of electrification lead to higher demand.

A comparison of the optimal solutions for four scenarios shows (see Table 5) the following:

- It appears that a diesel-based system is a preferable solution when the demand is limited and the supply is restricted. As the demand improves and the supply is provided round the clock, hybrid systems appear to be more appropriate.
- The initial investment cost is considerable for the hybrid systems. This happens due to intermittent nature of the renewable resources that require back-up capacities. Accordingly, all hybrid systems require a significant spare capacity, thereby reducing the overall system capacity factor. The reserve capacity in all these cases is high.  
- Depending on the size of excess capacity maintained in each scenario, the cost per kW of peak load serviced varies. But the initial investment cost of diesel-based systems tends to be comparatively low but the capacity replacement charges can be high for both diesel-based systems and hybrid systems. This is an important consideration for business viability analysis. While initial capital grants can help develop a system, unless there is adequate revenue generation to meet future costs, the long-term sustainability of a solution cannot be guaranteed. This aspect is hardly considered in the techno-economic analyses.  
- The cost of service remains quite high for all cases and considering the size of the poor population in the area, the cost can be unaffordable to many users.  

The electricity tariff approved by the Electricity Regulatory Commission for residential consumers is just $0.04/kWh for consumption up to 100 kWh. It is evident that in all scenarios the levelised cost of supply from off-grid sources is much higher. Therefore, the issue of business case for the investment needs to be considered separately, which is considered next.

5. Business and governance analysis of alternative scenarios

The techno-economic analysis considered above is useful in analysing the optimal technology combinations for a given energy demand. However, it does not perform any financial analysis of business investment. For example, the capital requirement is different for different optimal solutions and some sub-optimal solutions in a technical sense may even make more business sense, particularly when private investment is being looked into. Moreover, as the cost of supply turned out to be high, options for reducing the supply cost becomes important to make supply affordable to consumers. However, any such cost reduction mechanism has financial implications for the government, or the supply business or both. Therefore, a balance has to be achieved between affordable supply to consumers and business viability from the investors’ perspective. In this section a number of business-related questions is considered to see how the off-grid options considered in the previous scenarios can be delivered.

5.1. Financial cost-benefit analysis

The analysis presented here follows the principles of financial cost-benefit analysis. It is considered that a viable investment project (from the investors’ perspective) must generate positive net present benefits (i.e. the net present value of costs should be less than the net present value of benefits). In the case of our off-grid electricity supply project, the costs include initial investment, fuel-related costs, operating and maintenance related costs, and the cost of replacing assets. The benefits on the other hand come from sale of electricity and for the financial analysis, this only considers the revenue generated from sale of electricity.

For each type of stakeholder (namely investor, consumer and the government), different aspects are considered. For example, an investor while looking for adequate return on the investment has to ensure that the debt is repaid on time and the asset is replaced on schedule so that the business can be run effectively. This requires ensuring adequate funding for debt repayment and asset replacement. Similarly, consumers of different groups pay different tariffs for grid connected supply. A similar approach is used here as well.

### Table 5
Comparison of optimal solutions.

| Scenarios       | Architecture                  | Peak load (kW) | Capital cost ($) | Capital cost per kW of peak ($) | Levelised cost of electricity ($) | Installed capacity to peak load ratio | Diesel use (litres) | RE share |
|-----------------|-------------------------------|----------------|-----------------|---------------------------------|----------------------------------|-------------------------------------|---------------------|----------|
| Basic supply    | 20 kW diesel generator        | 15.7           | $15,000         | 955                             | 0.465                            | 1.27                                | 8209                | 0        |
| Basic+          | 10 kW PV, and a 10 kW diesel generator | 16.3     | $49,800         | 3055                            | 0.368                            | 1.23                                | 14,926              | 0.27     |
| Reliable supply | 30 kW PV, and a 20 kW diesel generator | 28.5     | $126,000        | 4421                            | 0.363                            | 1.77                                | 33,550              | 0.34     |
| Unconstrained supply | 50 kW PV, and a 30 kW diesel plant | 44.4     | $196,000        | 4414                            | 0.344                            | 1.80                                | 61,835              | 0.31     |

![Fig. 22. Diesel power output in unconstrained supply scenario.](image-url)
As the consumers are likely to compare the charges for off-grid service to the tariff charged for grid-based supply, this is considered in our analysis to see if grid price parity can be achieved. The effect of grid parity tariff on other stakeholders is also considered. Further, the rental charges paid for solar home systems is considered as an alternative and analyse the effects of such tariffs on the business. Finally, the burden on the government finances is also analysed.

5.2. Analysis of different scenarios

5.2.1. Basic supply scenario

Here, an initial investment of $15,000 is required, followed by an investment of $10,000 in the 9th year. In addition, $4925 per year is spent on fuel and $1825/year is spent on operating and maintenance costs. Accordingly, these recurring costs contribute significantly to the overall cost of electricity supply. In this scenario only residential demand exists and each household, whether rich or poor, consumes less than 40 kWh per month. All consumers use electricity when it is available and hence contribute to the peak load in proportion to their demand. The regulated tariff for residential consumers using up to 100 kWh per month is set at taka 3.05 ($0.04). Is it possible to achieve grid tariff parity for the off-grid supply in this scenario?

Out of the two major cost components, if the capital required for the assets is supported through a grant, the consumers would need to bear the operating costs only. Assuming that 100% of the asset replacement costs are borne through a grant, the cost of electricity comes to $0.387/kWh. This implies that even if $15,000 is provided to the project operator as a capital grant, the cost of electricity reduces slightly and the average electricity cost remains almost 10 times higher than the grid-based electricity. If the initial capital as well as the capital required for asset replacement is provided through a grant fund, thereby reducing the entire capital-related cost, the electricity charge per unit for the operating cost recovery comes to $0.359. Thus, just capital subsidy cannot ensure grid tariff-parity for this off-grid solution — some operating cost subsidy will also be required. In fact, if grid parity pricing is charged, the net present value of revenue comes to $7871 over the project life which will not recover even the operator’s cost and the distribution system fixed cost. Thus, it appears that aiming for a grid tariff parity for the off-grid system is a non-starter from any perspective. No business case can be made for such an option.

However, a more appropriate reference point could involve a comparison with the solar home systems (SHS). Given that solar home systems are popular in Bangladesh, it is legitimate to ask whether it makes economic sense to go for a diesel-based mini-grid instead of promoting SHS in such off-grid areas. Grameen Shakti, the leading SHS provider in Bangladesh, provides the equipment costs for various system capacities. A 10 W system costs $130, a 20 W system costs $170, a 50 W system costs $380, a 80 W system costs $560 and a 125 W system costs $970.1 In our scenario, a low income consumer is considered to use a 20 W load, while the medium and rich consumers use 190 W and 240 W respectively. As the systems are not directly comparable, it is assumed that the low income groups would go for a 10 W SHS, while the medium and high income groups would go for 50 W and 80 W systems respectively. Based on the household distribution used in our analysis, there are 50 poor households, 42 medium income households and 16 rich families. The total system cost for SHS for all these families comes to $31,420. Even considering a 4% discount offered for 100% down-payment, the capital requirement comes to $30,163 (i.e. two times the capital requirement for the mini-grid in Basic supply case). Clearly, from the capital cost perspective, the diesel mini-grid makes economic sense. As the batteries have to be replaced at least twice over the 15 year period and the electricity output will be much less than the diesel-based system, the cost of electricity delivered from the SHS would come to $0.715/kWh.2

Thus, from the life-cycle cost perspective, the SHS investment does not make economic sense compared to the diesel-based mini-grid considered in the Basic supply Scenario.

If consumers are buying SHS in Bangladesh, it is likely that consumers elsewhere will be willing to pay similar charges for electricity from a mini-grid. Grameen Shakti offers a number of financing options to SHS owners. The least demanding option requires them to pay 15% initially and the rest 85% in 36 equal monthly installments with a flat rate service charge of 8%. For our three chosen system sizes of 20 Wp, 50 Wp and 80 Wp, the initial payment comes to $20, $59, and $80 respectively while the monthly payment comes to a flat charge of $3.3, $10 and $14.3 respectively. Can these amounts be sufficient for the off-grid service suggested in BS Scenario?

In this scenario, our households consume more in summer than in winter due to fan loads for the medium and high income groups but for the low income group, the consumption pattern does not vary seasonally. Accordingly, the summer consumption is considered to find out their monthly expenditure at full levelised cost and with capital grant support. This is presented in Table 6.

As can be seen, the poor consumer groups would be paying about 50% of the cost they would be paying for a SHS while the middle income and high income groups would pay slightly more than that for a SHS in summer months. However, it needs to be kept in mind that the SHS would not provide the same level of electricity service as they get from the diesel-based mini-grid. But if they consume less, as is shown in the case of winter months, their payment will be reduced and can be lower than that of the SHS. Similarly, with 100% capital grant subsidy, the cost reduces but not very dramatically.

It can thus be concluded that for a limited level of supply over a fixed number of evening hours, a diesel-generator based mini-grid option can be a suitable option that requires about one-half of the capital cost of SHS based supply and provides a higher installed capacity. Poorer consumers with just fixed lighting loads can be charged a fixed monthly rate whereas other consumers can be charged based on their consumption level. The cost recovery is considered based on the costs payable for a SHS, this option can be suitable for implementation by socially-responsible private entities and by community-based organisations. Moreover, the technology in this case is widely available and can be operated using locally available skills. The option is however less environment friendly as it depends on a fossil fuel. It also faces the risk of fuel price fluctuations, but as a less capital intensive option, this offers a good starting point for building demand in off-grid areas. However, even for such a small-scale initiative, the investor has to secure more than a million taka, which may need financial and organizational support.

5.2.2. Basic+ scenario

In this scenario, a day-time productive load of 10 kW has been considered in addition to the evening residential-commercial loads.

---

1 Based on Grameen Shakti cost data as reported in http://www.gshakti.org/index.php?option=com_content&view=article&id=115&Itemid=124. 75 taka = 1 US dollar is used for conversion.

2 This assumes the capital cost of $30,163, battery replacement cost of $10,800 on the 6th year and 11th year; electricity output based on a 5 h use of the system at the system peak load, and a discount factor of 5.3% for a 15 year project life.
Thus, the productive load is serviced outside the evening peak. The system configuration changes in this case and a hybrid system emerges as the optimal choice. The capital cost required for this option is $49,800. In addition, the batteries require one replacement in the 8th year ($7200) and the diesel generator requires four replacements in the 4th, 8th, 11th and 15th years. The total capital requirement for asset replacement is $27,000 but its net present value comes to $17,671.

Following the economic pricing principle, if the off-peak consumption is charged to cover the operating cost only, the tariff for productive use comes to $0.242 (or about 18 taka per kWh). Although this is about 3 times the prevailing rate for this category of consumers of grid electricity, it is cheaper than the alternative supply from a diesel generator (which comes to $0.33/kWh for operating cost coverage and $0.423 for full cost coverage). For other peak load consumers, the economic principle requires the tariff to recover full costs including capital costs. The levelised cost for full cost recovery comes to $0.368, which is lower than that for Basic scenario. Consequently, residential consumers pay less on average compared to the previous scenario and they can expect to reduce their spending even compared to owning a SHS. However, as shown in Table 7, the revenue so generated is not sufficient to meet the revenue requirement of the electricity supplier. Thus, the strict economic cost recovery principle cannot be applied in this case.

One option could be to allocate the balancing cost to the productive users. This can be done in a number of ways but the most common options would be either to charge a fixed per kW/month charge in addition to the energy rate or to increase the energy rate without adding any fixed charge. The fixed charge has some merit as a part of the revenue will flow even if the user does not consume energy for any reason. Given the size of the productive load considered here, a monthly fixed charge per kW can be a logical choice.

It becomes clear that the addition of a productive load brings the average cost of supply down and improves the financial position of the supplier. This happens despite an increase in the capital requirement, although only small companies may become interested in this size of business. As the cost recovery is likely to be possible even without any government intervention, this can become a viable business opportunity in Bangladesh. However, it may be difficult to realise the full potential of productive load instantaneously. This highlights the importance of mapping local level opportunities and enlisting support of local stakeholders early in the development process. In addition, support for such ventures through some risk sharing arrangements can improve the attractiveness of the business.

Although this is a hybrid system, the diesel generator still plays an important role. Thus, this option can be viewed as an extension of the previous scenario where the operation starts with a diesel generator for a restricted period of supply and then expands to include off-peak productive load. However, the supplier is likely to continue with its diesel generator in such a case, which, as mentioned earlier, is not the least-cost option given the high fuel cost and asset replacement cost. However, such a gradual approach may make practical sense given the limited stress on initial capital requirement.

### 5.2.3 Reliable supply scenario

In this scenario, the supply reliability is considered, when 24 h of service is made available, allowing consumers to use electricity at night. This changes the demand situation considerably and the system configuration changes accordingly. All consumers now contribute to the peak demand, which increases the peak capacity requirement. Accordingly, all consumers should bear the responsibility for the peak load. In such a case, a time-differentiated tariff could be appropriate but given the small volume of consumption involved, the metering cost is likely to outweigh the benefits. Accordingly, a simple pricing system with flat rates for residential and commercial consumers and a fixed charge coupled with an energy charge for the productive uses could be appropriate.

The supply system for this scenario requires more PV arrays compared to Basic+ scenario. The capital cost increases to $122,000 while the diesel generator requires four replacements (at a non-discounted cost of $40,000) and the batteries require two replacements (at a non-discounted cost of $32,000). The levelised cost of electricity comes to $0.363/kWh, whereas the energy-related charge comes to $0.227/kWh. However, as before, sufficient revenue will not be recovered if productive users are charged only at the energy-related charge while others are charged at the full levelised cost. Moreover, in this case, there is no justification for the preferential treatment of the productive use, particularly when part of it coincides with the peak hours. Therefore, the tariff has to be carefully designed to avoid undesirable effects. An example is provided in Table 8 where an energy-related charge of $0.31 is used for productive uses supplemented by a fixed charge of $30/kW/month. Alternative tariff schemes can be developed to suit the specific requirements but a full-scale analysis of this aspect is beyond the scope of this paper.

Table 8 shows that the low income consumers will still pay less than that required for owning a SHS for a comparable service. However, a comparison with the SHS cost becomes somewhat less relevant for the middle and high income groups as they receive round-the-clock power from the mini-grid compared to a limited supply from the SHS. Although they are likely to spend more on

### Table 6

Consumer spending on electricity under different recovery considerations.

| Item                  | Unit | LI | MI | HI |
|-----------------------|------|----|----|----|
| Consumption in summer | kWh/mo/HH | 3  | 28.5 | 36 |
| Cost at full levelised | $     | 1.395 | 11.2525 | 16.74 |
| Consumption in winter | kWh/mo/HH | 3  | 16.5 | 18 |
| Cost at full levelised | $     | 1.395 | 7.6725 | 8.37 |
| Cost at 100% capital subsidy | $     | 1.17 | 11.115 | 14.04 |

### Table 7

Revenue generation using economic tariff.

| Item         | Unit  | LI     | MI    | HI    | Commercial | Productive | Total   |
|--------------|-------|--------|-------|-------|------------|------------|---------|
| Summer cons  | kWh/mo | 3      | 28.5  | 36    | 75         | 3000       | 3750    |
| Winter cons  | kWh/mo | 3      | 16.5  | 18    | 75         | 1500       | 2250    |
| Annual cons  | kWh/yr | 36     | 282   | 342   | 900        | 28500      | 31400   |
| Tariff       | $/kWh  | 0.368  | 0.368 | 0.368 | 0.368      | 0.242      | 0.242   |
| Revenue      | $      | 13.2   | 103.8 | 125.8 | 331.2      | 6897       | 7238    |
| Av monthly expense | $/mo | 1.1    | 8.6   | 10.5  | 27.6       | 574.7      | 602.3   |
| Income from all consumers | $/yr | 662.4  | 4358.592 | 2013.696 | 331.2 | 6897 | 14,262.9 |
| Revenue requirement | $/yr | 17,676.1 |

S.C. Bhattacharyya / Renewable Energy 75 (2015) 745–761
electricity cost for a reliable supply, the cost per unit of electricity is less. The average monthly bill between $20 and $27 for these categories is however much higher than these groups pay on fuel and electricity as per the Household Income Expenditure Survey. Moreover, the monthly bill for productive loads will be significant due to high consumption level and this can be a disincentive for promoting productive loads. A 100% capital grant would reduce the cost to $0.261/kWh but this could still make productive activities reluctant to consume significant quantities of electricity.

As the system size increases, the capital requirement increases as well. More importantly, the cost of asset replacement becomes important. Depending on the capital structure and repayment requirement, it is possible that the supplier faces some funding mismatch. This would require access to flexible funding arrangements and short term funding for working capital. However, unless the business is not organized around a bankable contractual arrangement, securing finance from traditional sources can be a challenge.

As indicated before, this option can also be considered as an extension of the earlier scenarios, particularly Basic Supply scenario. The advantage here is that the PV system along with the battery and converters can be appended to the diesel generator system suggested for Basic supply scenario. This gradual expansion of the system can work for rural areas where the demand is likely to develop once the benefits of electricity are realized by the population. Similarly, this also allows time for developing the productive load that can act as an anchor for the system.

5.2.4. Unconstrained supply scenario

This scenario removes supply restriction and allows for full demand development. Accordingly, the high income consumers can use electric appliances like refrigerators, while commercial consumers can use electricity at any time. Consequently, the consumption of middle income and high income households as well as commercial activities increases compared to reliable supply scenario. This scenario results in the least levelised cost of electricity of four scenarios.

As in Reliable supply scenario, all consumer categories contribute to peak demand and accordingly are required to bear the consequences by paying appropriate charges. Although the economically efficient tariff would have to distinguish between peak and off-peak periods, the time-of-use metering cost may be difficult to justify for such small consumers. Accordingly, energy-related tariff supplemented by fixed charges may be relevant. However, as the consumption of poor households does not change compared to reliable supply, they may be charged at a flat rate only. As shown in Table 9, if electricity is charged at the levelised cost of energy, the required revenue can be collected but the monthly bill for average high income households, commercial users and productive consumers becomes quite big, even by developed country standards, thereby suggesting limited attractiveness of such high level consumption for these categories of consumers. The operating cost component in the charge comes to $0.224/kWh, which is closely related to diesel fuel use in the system. The monthly bill will not change significantly even if the charge recovers only the operating costs. This perhaps shows the limitation of a diesel-based hybrid system.

Moreover, the capital cost of this system increases to $196,000 (or about 15 million taka), which may be attractive to medium sized firms. As before, the capital requirement for asset replacement also increases to $115,000 (non-discounted). Thus, financing the capital requirement becomes another constraint for this option.

Based on the above, analysis, it becomes clear that small-scale supply as indicated in the first three scenarios (Basic, Basic+ and reliable) can be developed into businesses for rural electricity delivery but as the system becomes bigger with higher demand, the monthly bill can be very high for high energy using consumers. The relatively high cost of supply may not be attractive for consumers and is unlikely to be sustainable. The capital constraint is another issue that can become difficult to overcome. Moreover, capital subsidy alone will not reduce the costs significantly as the operating costs remain high and providing capital and operating subsidy for village level supplies will not be sustainable in the long-run.

5.3. Remote area power supply system in Bangladesh

Bangladesh has set a target of providing universal electrification by 2020. The state-owned agencies like Bangladesh Power Development Board (BPDB), Rural Electricity Board (REB) and Palli Bidyut Samity (PBS) are involved in providing electricity in rural areas. In addition, Grameen Shakti, a non-profit organization, is also actively involved in promoting renewable energy solutions, mainly the SHS. However, recognizing the challenge faced by the country in reaching its target, the Government introduced a new initiative, called the Remote Area Power Supply System (RAPSS) in 2007. This allows the private sector to get involved in rural power supply and the guidelines for the RAPSS indicate that:

a) The Power Division of the Government will identify the potential RAPSS areas. These areas would cover the geographical area of two or more sub-districts.

b) The system can cover both off-grid and on-grid areas.

c) The operator will be selected through a competitive bidding process.

d) The operator will operate under a licence from the Bangladesh Electricity Regulatory Commission for a period up to 20 years.

e) A fund called RAPSS Fund will be created to support the rural electrification process and will receive funds from the government, donor agencies and other sources. The fund can be

---

Table 8
An example of tariff schemes for Reliable supply scenario.

| Item                  | Unit | LI  | MI  | HI  | Co | Prod | Total |
|-----------------------|------|-----|-----|-----|----|------|-------|
| Summer cons           | kWh/month | 4.2 | 75.9| 102 | 210| 7200 |
| Winter cons           | kWh/month | 4.2 | 30.3| 33.6| 210| 3600 |
| Annual cons           | kWh/year  | 50.4| 682.8| 882| 2520| 68,400|
| Tariff                | $/kWh   | 0.363| 0.363| 0.363| 0.363| 0.31  |
| Revenue               | $       | 18.3 | 247.9| 320.2| 914.8| 24,804|
| Av monthly expense    | $/month | 1.5 | 20.6| 26.7| 76.2| 2067 |
| Income from all consumers | $/year | 914.8| 10409.9| 5122.6| 914.8| 24,804|
| Revenue requirement   | $/year  | 41,516|

---

3 http://www.powerdivision.gov.bd/pdf/RAPSS.pdf.
used for providing capital grant support, to provide loans of 5–10 years duration, to subsidise connection charges and to offset duty, tax and VAT.

f) The retail supply tariff will be set initially through the bidding process but if the tariff is significantly higher than the tariff charged by the nearest PBS, then the government may decide to provide subsidy to close the gap, depending on the funding available from the RAPSS Fund.

g) The capital cost subsidy can be given up to a maximum limit of 60% and if the retail tariff still remains high, soft loan can be provided from the fund.

The RAPSS Guidelines provide a framework for private sector involvement in rural electricity supply but from our analysis it becomes clear that even if 100% capital cost subsidy is provided, the cost of supply will remain higher than the retail tariff approved by the regulatory commission for different categories of consumers. Table 9 shows the amount of capital subsidy required under different scenarios and the operating subsidy required to reach the grid price parity in rural areas under the optimal configurations considered in this study.

Clearly, it shows that trying to reach the grid price parity will impose significant financial burden on the government, particularly for reliable supply, and unconstrained supply scenarios. They are unlikely to be sustainable solutions. This happens even after providing significant capital support. The first two options could still be considered as the capital subsidy requirement is not too demanding and the price parity can be restricted to poor consumers while others may be charged the levelised cost. This will reduce the operating cost subsidy.

The case of sub-district level operation can provide the required scale economy and may ensure larger systems for local grids where higher technical efficiency of operation can also be expected. This can be an area for further research where an analysis using the terms and conditions offered by RAPSS guidelines can also be considered.

6. Conclusions

This paper has considered the village-level electrification in Bangladesh and analysed the viability and business case of a hybrid mini-grid system for a remote non-electrified village in Dhaka division. The analysis developed alternative demand scenarios, considered local resources for electricity generation, conducted techno-economic analyses of all scenarios using HOMER and performed business analysis. The demand scenarios captured alternative development pathways – starting from basic level supply for 5 h per day to unrestricted, reliable supply consisting of residential, commercial and productive loads. The techno-economic analysis suggested optimal configurations that consisted of diesel generators for the basic level of supply and hybrid PV-diesel solutions for more elaborate services. The renewable energy share in all configurations varies between 0% (in the basic cases) to 60% (in S5) and the cost of electricity per kWh decreases as the system size increases. However, the hybrid systems require significant excess capacity due to intermittent nature of solar energy and consequently, the initial investment requirement increases. Moreover, during the project life some assets (such as batteries and diesel generators) need to be replaced depending on their life and extent of use. This requires significant investment at regular intervals to keep the system going.

The analysis of business case of the investments revealed that the levelised cost of electricity from the off-grid options is much higher than the regulated tariff for various categories of consumers who receive grid electricity. However, the cost of off-grid supply is likely to be cheaper than the cost of owning a SHS. Low income consumers will pay almost one half of the cost of owning a SHS for a comparable level of energy use while the high income users may be paying somewhat more for the restricted level of supply, although the monthly bill will not be too burdensome for low level of supplies. However, the problem arises when demand restrictions are removed allowing consumers to use high volumes of energy. Their monthly bills will be burdensome, making higher consumption unattractive. This happens despite a reduction in cost of electricity per kWh due to high capacity-related costs and operating costs of the system.

It is also found that capital cost subsidy will not be sufficient to ensure grid price parity and significant amount of operating cost subsidy will be required. As the operating cost subsidy will impose a recurring burden on government’s finances, it is unlikely to be sustainable. This makes the energy access challenge significant. Our analysis suggests that the basic electricity supply provision through a mini grid is the most preferable business solution – it requires less capital, less subsidy volume and moderate monthly bills for...
consumers. Such a business can be organized by local entrepreneurs, private investors or local community organisations.

Bangladesh has been promoting Remote Area Power Supply System since 2007 where private investors can enter into rural electricity supply through a competitive bidding process for a maximum period of 20 years. This allows sub-district level geographical areas under the jurisdiction of the licensee. However, the objective of achieving grid-like pricing may be difficult to attain with capital subsidy and soft loans, unless the system has a low operating cost. This is an area for further investigation.

Acknowledgements

The work reported in this paper is funded by an EPSRC/DfID research grant (EP/G063826/2) from the RCUK Energy Programme. The Energy Programme is a RCUK cross-council initiative led by EPSRC and contributed to by ESRC, NERC, BBSRC and STFC. The author gratefully acknowledges the funding support. I also thank the anonymous reviewers for helpful comments. Usual disclaimers apply.

References

[1] BBS, 2012, Socio-economic and Demographic Report, Bangladesh Population and Housing Census 2011, Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People’s Republic of Bangladesh, Dhaka (see http://www.bbs.gov.bd/WebTestApplication/userfiles/Image/BBS/Socio_Economic.pdf, [accessed 05.03.13].

[2] Yadoo A, Cruickshank H. The value of cooperatives in rural electrification., Energy Policy 2010;38(6):2941–7.

[3] Sovacool BK, Drupady IM. Energy access, poverty and development: the governance of small-scale renewable energy in developing Asia, Chapter 3: Grameen Shakti in Bangladesh. Surrey, England: Ashgate Publishing; 2013.

[4] Nandi SK, Ghosh HR. A wind-PV-battery hybrid power system at Sitakunda in Bangladesh., Energy Policy 2009;37 (4):3659–64.

[5] Mondal AH, Denich M. Hybrid systems for distributed power generation in Bangladesh, Energy Sustain Dev 2010;14(1):48–55.

[6] Roy RB. Design and cost analysis of hybrid power system for off-grid rural areas of Bangladesh. Can J Electr Electron Eng 2012;3(7):413–23.

[7] BBS. Report of the household income and expenditure survey, 2010. Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka; 2011. see, http://www.bbs.gov.bd/PageWebMenuContent.aspx?MenuKey=320 [viewed on 23/6/2013].

[8] ESMAP. Technical and economic assessment of off-grid, mini-grid and grid-electrification technologies. ESMAP Technical Paper 121-07, The World Bank; 2007., http://siteresources.worldbank.org/EXTENERGY/Resources/336805-1157034157861/ElectrificationAssessmentRptSummaryFINAL17May07.pdf.

[9] Chowdhury Sharb, Mourshed M, Raiyan Kabir SM, Isam M, Morshed T, Khan MR, et al. Technical appraisal of solar home systems in Bangladesh: a field investigation., Renew Energy 2011;36(2):772–8.

[10] Mondal AH, Sadrul Islam AM. Potential and viability of grid-connected solar PV System in Bangladesh. Renew Energy 2011;36(6):1869–74.

[11] Urmee T, Harries D. Determinants of the success and sustainability of Bangladesh’s SHS Program. Renew Energy 2011;36(11):2822–30.

[12] Sen R, Bhattacharyya SC. Off-grid electricity generation with renewable energy technologies in India: an application of HOMER. Renew Energy 2011;36(2):388–98.

[13] Khan M, Iqbal M. Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renew Energy 2005;30(6):835–54.

[14] Hafez O, Bhattacharya K. Optimal planning and design of a renewable energy based supply system for microgrids. Renew Energy 2012;45:7–15.

[15] Lau KY, Yousof MF, Arshad SNM, Anwari M, Yatim AHM. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy 2010;35(3):3245–55.

[16] Bekele G, Palm B. Feasibility study for a sustainable solar-wind-based hybrid energy system for application in Ethiopia. Appl Energy 2010;87(2):487–95.