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Economic Feasibility Analysis of Off-Grid PV Systems for Remote Settlements in Bhutan

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ABSTRACT

Through rigorous rural electrification projects, over 99.97% of Bhutan's households now have access to electricity, which is predominantly generated from run-of-the-river hydropower plants. Despite this achievement, around 5% of the rural households still do not have access to electricity to meet their cooking load demands and, therefore, they extensively rely on firewood, LPG, and kerosene for cooking purposes. Apart from hydropower, penetration of other renewable sources such as solar and wind power in the country is negligible. Thus, an attempt was made to determine the investment costs of installing PV systems for off-grid households in remote settlements by studying their economic feasibility. The study shows that the initial cost of investment for an off-grid Solar Home System for a rural household is US$1.42 per Wp using polycrystalline PV modules and US$1.55 per Wp using monocrystalline PV modules. The average cost of installing SHS is determined to be US$ 2342.67 per household. The results of analyses indicate that standalone SHS for remote rural households is not financially viable with the current price of electricity supply in Bhutan. However, SHS provides a more cost-effective option than a grid-line extension, which is estimated to cost about US$ 6700 per household for the remaining off-grid settlements.

Keywords: Rural Electrification, Off-grid, Solar home system, PV System, Economic Analysis
JEL Classifications: C8, G0, Q4

1. INTRODUCTION

Bhutan greenhouse gas emission rate is 0.8 metric tons per capita (World Bank GHG data 2012) As per data collected by the National Energy Commission Secretariat (NECS) the country's carbon dioxide emission of 2.2 million tons per year can be totally sequestered or captured by the country's forests. At the 15th UNFCCC Conference of Parties (COP15), the country re-emphasized its commitment to remain carbon neutral. With the carbon sequestration capacity estimated to be 6.3 million tons of CO2 per year, Bhutan is really even a carbon sink economy. This assured by the Kingdom's constitution that the mandates the government to maintain the country's present 60% minimum forest cover (BP p.l.c., 2018; International Energy Agency, 2017; Ministry of Economic Affairs, 2018b; REN21, 2017, 2018).

Bhutan energy consumption is dominated by heating or thermal energy. Heating or thermal energy is mostly used by the building sector. Cooking and space heating are the dominant thermal energy use in rural areas and thus, in the country as whole. They mostly use biomass fuels that include firewood, briquettes, and biogas.

The fuel supply mix for thermal energy consumption consist of petroleum at 21%, coal and its derivatives (from industries) at 15%, and biomass at 36%. The remaining 28% of energy consumption is fueled by electricity.

However, energy consumption for industries and transport, which are both thermal and non-thermal energy uses are also increasing. (Ministry of Economic Affairs, 2018a, 2018b).

Bhutan is a major producer of hydropower for local use and for export. From 2005 to 2014, the sale of hydroelectricity has become a major source of domestic and export revenue for Bhutan. It has become a very significant major share in 2016 (IRENA, 2019).

Lighting is the main energy use in the household sector. In rural households, 1.2% use solar energy while 1.2% use kerosene.

Even if the country has already achieved electricity access to all, more than 30% of rural population continues to depend on firewood for cooking and heating. In the country as a whole (including both rural and urban areas), 95.2% of households use electricity and 69.0% use of LPG for cooking (National Statistics Bureau of Bhutan, 2017). Renewable Energy plays a crucial role in the transition of the sustainable energy system.

The literature review done by the researchers indicated that majority of the economic viability studies, and the feasibility and assessment evaluations were focused on small systems of capacities between 40-120 Wp, on to micro-grid systems that serve densely populated settlements or villages found in different parts of the world. Most the studies and assessment were done for systems that have already been built or installed. However, there are only a few techno-economic studies for stand-alone SHS (solar home systems) that were designed to meet lighting and cooking loads. Therefore, this research aimed to study the potential of solar energy, and to do an economic evaluation of stand-alone PV systems, for remote off-grid areas of Bhutan.

The objectives of this research were to determine the investment costs for stand-alone solar home systems (SHS) for electrification of rural off-grid households, and to conduct economic assessment and analysis comparing such households electrified through standalone SHS, or PV microgrid or connection to the national grid.

One of the first steps in conducting this research was the collection of secondary data on the off-grid villages/settlements.

There were 163001 regular households in the country in 2017, out of which 62.2% were rural households (National Statistics Bureau of Bhutan, 2017). Grid electricity is the main source for lighting in 96.6% of Bhutanese households. It is also the main source of energy for cooking in 95.2% of households (Table 1).

The data pertaining to off-grid households and villages as of 2018 were obtained from the Rural Electrification division under bhutan power corporation limited (BPC), the electricity utility company in the country. The list is not a comprehensive one as there most likely be information missing for a few settlements missing, as there had been continous addition or deletion in the number of households. There seems to be a disparity in the definition of a household by 2017 of population and housing census of bhutan (PHCB) (National Statistics Bureau of Bhutan, 2017) and BPC; hence the number of rural households differs.

Bhutan is administratively divided into 20 districts called Dzongkhags, which are further divided into 205 blocks or Gewogs. Each block has several sub-blocks called Chiwogs, which then administer a group of nearby villages (Figure 1).

As per the BPC data, more than 1800 rural households spread across the country in over 200 remote villages and settlements do not have access to grid electricity. The number of households in the off-grid settlements ranges from a single household to a maximum of 54 per village/settlement. These households which are not connected to the grid are predominantly far-flung remote villages located in difficult terrains with sparse population density. With rural developmental activities taking place, a few of these villages have now become accessible from village feeder roads within a few hours' treks. However, there are still other villages which can only be reached after three to nine days of the trek from the nearest road head.

There are 1272 households in the cooler/colder central and northern areas and 588 households in the hot and humid southern region, which are off-grid. The average population density per household in Bhutan, as found by the PHCB 2017 survey, was 3.9, i.e., four persons per household.

This study was divided into two parts: Technical assessment of solar resource in Bhutan; and the economic assessment and analysis.

2. ANALYSIS PROCESS

2.1. Technical Assessment of Solar Resource in Bhutan

The solar resource data show that the annual average values of global horizontal solar radiation in Bhutan range from 4.0 to 5.5 kWh/m^2- day (4.0 to 5.5 peak sun hours per day) (Figure 2) and the annual average values of Direct Normal Solar Radiation

Table 1: Distribution of households in bhutan by the main type of energy for lighting and cooking (National Statistics Bureau of Bhutan, 2017)

Area	Main source of energy for lighting (%)				
	Grid electricity	Solar	Kerosene	Personal generator	Others*
Urban	98.9	0.2	0.3	0.0	0.6
Rural	95.3	1.6	1.6	0.1	1.4
Both Areas	96.6	1.1	1.1	0.1	1.1

Area	Main source of energy for cooking (%)					
	Grid power	LPG	Kerosene	Firewood	Biogas	Others
Urban	98.2	91.9	0.3	1.0	0.7	0.4
Rural	93.5	55.6	1.3	36.7	2.6	0.3
Both Areas	95.2	69.0	0.9	23.5	1.9	0.3

*İncluding LPG, candle, and firewood

(DNI) range between 2.5 and 5.0 kWh/m^2-day (Paul et al., 2009). The annual average global solar radiation at latitude tilt by district range between 4.7 and 5.3 kWh/m^2-day, as shown in Table 2, (Paul et al., 2009). Based on these, the estimated potential total installed capacity or grid-connected PV systems in Bhutan is e 58,000 MWDC, corresponding to an annual generation of about 92 MU_{DC} and 82 MU_{AC} of electricity.

In the high altitude, cold alpine regions in the northern Himalayas, the solar insolation in the winter months are at the highest. The lifestyle of the rural population in Bhutan is considered to be substantially similar except concerning the climatic condition, those in the northern areas require room heating, while those in the warmer/hotter southern foothills require cooling in the summer months. As stated earlier, Bhutan has three distinct climatic zones, the central and northern regions have temperate and cold alpine climates, while the southern plains and foothills experience humid and subtropical climate. The households in the south face cooling needs during hot and humid summer months, while room heating is a necessity in the colder regions during the cold season. The rural population relies heavily on fuelwood for cooking as well as heating of their homes. Furthermore, in the high altitude cold areas, heating or boiling of water and cooking often consume a long time and, therefore, more energy compared to the low lying, warmer zones.

2.1.1. Peak load evaluation and computation of energy demand

Considering the climatic conditions, two cases with different loads (to cover lighting, cooking, and other basic electric requirements) are forecasted for (1) 588 off-grid rural households located in the warmer / hotter southern districts of Samdrup Jongkhar, Samtse and Sarpang, and (2) 1272 households in other parts of the country. Electric ceiling/stand fans were considered for the former case, and an appropriate increase in usage of cooking appliances was adopted for the latter, as given in the following Tables 3 and 4. A household with 4 to 5 rooms, including kitchen and bathroom, was considered for the calculations.

As indicated in Table 3, the peak load was calculated at 2.5 kW for lighting, cooking loads, and other necessary appliances such as TV, battery chargers, and fans for Case 1. The energy demand was 2.91 kWh/day for a representative rural household in that region. For Case 2, peak load was 2.4 kW and against that a daily energy demand of 3.13 kWh/day as tabulated in Table 4.

The energy demands computed above are approximately 3 kWh/day per household, which agree with the average daily energy billed for domestic rural customers in Bhutan, as indicated in Table 5.

2.1.2. Annual global solar insolation (E_{global}) in Bhutan

The average annual global solar radiation at latitude tilt for all districts in Bhutan range between 4.7 and 5.3 kWh/m^2-day. The minimum insolation of 4.7 kWh/m^2-day was considered for sizing the PV systems.

2.1.3. Peak power (P_{peak}) of PV arrays

The peak power (kW_p) of the PV arrays under standard test conditions (STC) was determined using the following formula:

$$P_{peak} = \frac{E_{el} * I_{STC}}{E_{global} * Q} \tag{1}$$

Where

E_{el} = Real electric output energy of the system (kWh/day)
I_{STC} = Incident solar radiation under STC (1 kWh/m^2-day)
E_{global} = Global solar radiation at the site (kWh/m^2-day)

Table 2: Average global solar resource of each district

District	Average insolation at tilt (kWh/m^2-day)	District	Average insolation at tilt (kWh/m^2-day)
Bumthang	5.2	Samdrup Jongkhar	4.7
Chukha	4.8	Samtse	4.7
Dagana	4.8	Sarpang	4.7
Gasa	5.3	Thimphu	5.3
Haa	5.0	Trashigang	4.9
Lhuentse	4.9	Trashiyangtse	4.9
Mongar	4.8	Trongsa	4.9
Paro	5.3	Tsirang	4.9
Pema Gatshel	5.0	Wangduephodrang	5.1
Punakha	5.0	Zhemgang	4.8

Table 3: Load evaluation and energy demand calculation for a typical rural HH in southern districts of Samtse, Samdrup Jongkhar, and Sarpang

S. No.	Appliance	Rated power (W)	Qty	Daily average usage (h)	Daily energy consumption (Wh/day)
1	LED lamps	5	6	3	90
2	Rice cooker - 1.5L	600	1	1	600
3	Induction cooker	1000	1	1.2	1200
4	Water boiler - 3L	700	1	0.75	525
5	Television set	16	1	3	48
6	Ceiling/Stand Fan	50	2	4	400
7	Chargers (for phones, emergency lamps)	10	5	1	50
	Total	2496			2913
	Peak load demand=2.5 kW			Peak energy demand=2.91 kWh/day	

Table 4: Load evaluation and energy demand calculation for a typical rural HH in temperate/alpine regions

S. No.	Appliance	Rated power (W)	Qty	Daily average usage (h)	Daily energy consumption (Wh/day)
1	LED lamps	5	6	3	90
2	Rice cooker - 1.5L	600	1	1	600
3	Induction cooker	1000	1	1.5	1500
4	Water boiler - 3L	700	1	1.2	840
5	Television set	16	1	3	48
6	Chargers (for phones emergency lamps, etc.)	10	5	1	50
	Total	2396			3128
	Peak load demand (kW)=2.4 kW			Peak energy demand=3.13 kWh/day	

Table 5: Energy sales to domestic customers between 2014 and 2018 (Bhutan Power Corporation Limited, 2018)

Particulars		2014	2015	2016	2017	2018
Energy sales in kWh to Domestic Customers (*1000)	Rural	83,862	94,953	103,054	108,610	118,058
	Urban	127,099	127,899	134,401	13,327	134,776
Number of customers	Rural	89,377	94,488	99,417	104,230	108,377
	Urban	43,536	45,044	47,378	48,618	49,917
Avg. daily energy consumption per customer (in kWh/day)	Rural	2.606	2.791	2.879	2.895	3.026
	Urban	8.109	7.887	7.880	0.761	7.500

Table 6: SHS sizing for Case 1

PV modules: polycrystalline		
Module size and efficiency	=	265 W and 16.3%
Module dimensions	=	1640×992×35 mm
Module weight	=	17.2 kg
SHS capacity	=	6×265 W
No. of PV modules and Capacity of PV required	=	3528 nos.; 934.92 kW
Charge controller		
40A MPPT solar charge controller 12/24V	=	1 no.
Battery storage (250Ah, 12V)		
No. of batteries for one SHS	=	6 nos.
Solar Inverter (1800W)		

Accessories: Cables, connectors, mounts, etc

Table 7: SHS sizing for Case 2

PV modules: Polycrystalline		
Module size and efficiency	=	280 W and 17.2%
Module dimensions	=	1640×992×35mm
Module weight	=	17.2 kg
SHS capacity	=	6×280 W
No. of PV modules and Capacity of PV required	=	7632 nos.; 2136.96 kW
Charge controller		
40A MPPT solar charge controller 12/24V	=	1 no.
Battery storage (250Ah, 12V)		
No. of batteries for one SHS	=	6 nos.
Solar ınverter (1800W)		

Accessories: Cables, connectors, mounts, etc

Q = Quality factor of the PV system. Values range between 0.1 - 0.4 for Stand-alone PV systems.

For Case 1

E_{el} = 2.91 kWh/m^2-day
Q = 0.4 (Considered)
Therefore, P_{peak} = 1549 W i.e. 1.549 kW.

For Case 2

E_{el} = 3.13 kWh/m^2-day
Q = 0.4 (Considered)
Therefore, P_{peak} = 1664 W i.e. 1.664 kW.

2.1.4. Sizing of PV modules and system components

The polycrystalline PV modules, charge controller, battery back-up, and inverters are sized as under Tables 6 and 7:

For typical rural households, SHS sizes of 1.59 kW_p for warmer regions and 1.68 kW_p for cooler / colder temperate and alpine regions were determined to meet their lighting, cooking, and other basic electricity needs. Based on these two capacities, the economic assessment was carried out.

2.2. Determination of Investment Cost of Stand-alone Solar Home Systems

The cost structure of any photovoltaic (PV) system involves two main components: (1) the PV modules and (2) the balance of system (BOS) costs, which represent the cost of everything else required for the system to function. The BOS costs include costs of inverters, back-up batteries, controller, cabling, mounting structures, bolts and connectors, installation, labor, permits or approvals, land acquisition, and site preparation (Elshurafa et al., 2018). However, for solar home systems, costs related to land acquisition and site preparations are absent.

There are no local manufacturers of PV technology in Bhutan, and all materials and PV system components have to be imported. As the country is land-locked, the majority of goods from third countries are shipped via India and the nearest seaport is the Kolkata Port in West Bengal, India. As the off-grid sites are scattered all over the country in more than 200 locations, separate transportation costs for every settlement could not be determined, and therefore, 30% of the materials cost was considered to allow as transportation and handling costs. The costs of the PV systems were derived using prices and rates of PV panels and other system components and accessories obtained from data available online. Sales tax and customs duty are exempt from the purchase of spare parts for RE projects in Bhutan. Over the prices of PV modules and other components in Indian or Chinese markets, the following costs were considered to derive the required investment:

1. Transportation and handling costs @ 30% on prices in India
2. Assembling and installation costs @ 10%
3. Project Administration and Management costs @ 10%
4. Contingencies @ 5%.

The details of the calculations are given in Tables 8 and 9.

The initial cost of investment for SHS using monocrystalline PV modules is 9.3% higher than polycrystalline PV modules, and thus for further analysis, only the PV systems with polycrystalline modules were considered. The following economic parameters were assessed for the study:

2.3. Cost-benefit Analysis (CBA)

CBA is a tool for resource distribution/policy determination/ criteria of the government for the most efficient resource use. The government evaluates the cost and benefit of the project from the standpoint of social welfare. The project evaluation for cost and benefit is done for public resources without reference to the market price.

Table 8: Calculation of investment costs of SHS using polycrystalline PV modules for all the off-grid households

		US$
I	System component costs	US$
	PV Modules (Polycrystalline)	890,845.20
	Inverters	435,240.00
	Batteries	1,887,418.26
	Charge controllers	106,392.00
	Subtotal	3,319,895.46
	Cost of other system components (viz. cables, mounts and accessories) (adding 5% of sub-total)	165,994.77
	Total cost of components for 1860 SHS	3,485,890.23
II	Assembling and installation costs @ 10%	348,589.02
III	Project Administration and Management costs @10%	348,589.02
IV	Contingencies @ 5%	174,294.51
Total PV system capital cost of investment		4,357,362.79
Cost per kW_p		1418.47

Table 9: Calculation of ınvestment cost of SHS using monocrystalline PV modules for all the off-grid households

I.	System component costs	US$
	PV modules (monocrystalline)	1,198,033.20
	Inverters	435,240.00
	Batteries	1,887,418.26
	Charge controllers	106,392.00
	Subtotal	3,627,083.46
	Cost of other system components (viz. cables, mounts) and accessories (adding 5% of sub-total)	181,354.17
	Total cost of components for 1860 SHS	3,808,437.63
II	Assembling and installation costs @ 10%	380,843.76
III	Project Administration and Management costs @10%	380,843.76
IV	Contingencies @ 5%	190,421.88
Total PV system capital cost of investment		4,760,547.04
Cost per kW_p		1549.72

There are three factors present as criteria for Cost-Benefit Analysis:

2.3.1. Net present value (NPV)

The net present value (NPV) method for evaluating the desirability of investments can be defined as follows:

$$NPV = \frac{B_1}{(1+i)} + \frac{B_2}{(1+i)^2} + \ \ldots\ldots \ + \frac{B_n}{(1+i)^n} - TIC - \sum_{n=1}^{N} \frac{C_n}{(1+i)^n} \quad (2)$$

Or

$$NPV = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = PVB - PVC \quad (3)$$

B_n = Expected benefit at the end of year "n"
TIC = Total initial cost (investment)
C_n = Expected cost at the end of year "n"
I = Discount rate i.e. the required minimum annual rate on new investment
n = Project's duration in years
N = Project's period
PVB = Present value benefit
PVC = Present value cost.

2.3.2. Benefit-to-cost ratio (BCR)

This criterion, sometimes, is used in large power and water projects by the ratios of the present worth values of revenues to the present worth values of costs. This ratio gives a measure of the discounted benefits per dollar of discounted costs.

An objection of BCR occurs for the reason that presenting the size of competing projects (in terms of costs and benefits) are not revealed in the resultant ratios.

$$BCR = \frac{PVB}{PBC} \quad (4)$$

Where,
PVB = Present value benefit
PVC = Present value cost.

2.3.3. Internal rate of return (IRR)

The internal rate of return (IRR) is another time - discounted measure of investment worth. The IRR is defined as that rate of discount, which equates the present value of the stream of net receipt with the initial investment outlay:

$$NPV = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} \quad (5)$$

$$= \text{PVB} - \text{PVC} \quad (6)$$

Where, "r" denotes the internal rate of return (IRR).

An alternative and equivalent definition of the IRR is the rate of discount which equates the NPV of the cash flow to zero:

$$NPV = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = 0 \quad (7)$$

2.4. Electricity Tariff and Cost of Supply in Bhutan

The existing electricity tariffs in Bhutan for the Low Voltage customers are given in Table 10. The Rural LV Block I category, which includes the rural domestic households, rural cooperatives, community temples, and monasteries, and micro trade activities receive 100 units of free electricity per month and any energy consumption above 100 units per month are charged at tariffs applicable for LV Blocks II and III.

The electricity tariffs approved up to June 2019 by the regulatory body, Bhutan Electricity Authority (BEA), for medium and low voltage customers are lower than the cost of supply of electricity in order to make electricity affordable to the users. The Royal Government of Bhutan, therefore, grants a subsidy to BPC, which is equal to the difference in the cost of supply and tariff for every unit of energy sale. The cost of supply includes the generation cost and the transmission/distribution network cost as presented in Table 11 (Bhutan Electricity Authority, 2019).

For the analyses, the unsubsidized tariff or the cost of electricity supply for low voltage customers @ US$ 0.083/kWh was considered to calculate the benefits.

3. RESULTS AND DISCUSSION

For an economically viable investment, the net present value (NPV), should be positive and the Benefit-Cost Ratio (BCR) greater than 1. The payback period should also be as short as possible so that the returns on investment are realized early on. However, this research showed that the economic indicators indicated that investment in the installation of standalone SHS in remote off-grid settlements in Bhutan was financially not viable with the existing (BAU) conditions. The NPV was (-) US$ 2,871,555.77, BCR was equal to 0.66, and returns on investment cannot be anticipated even at the end of the economic life of 25 years (Table 12).

Several scenarios were projected, as given in Table 13, and analyzed to determine the feasibility of each. Apart from the

Table 10: Current tariff structure of BPC for low voltage customers (Bhutan Power Corporation Limited, 2018)

Tariff structure	Unit	BTN	US$
LV Block - I (Rural) 0–100kWh	kWh	-	-
LV Block-I (Others) 0–100 kWh	kWh	1.28	0.02
LV Block-II (All) >100–300 kWh	kWh	2.68	0.04
LV Block III (All) >300 kWh	kWh	3.53	0.05
LV Bulk	kWh	4.02	0.06

BTN: Bhutanese ngultrum, 1 US$=70 BTN

Table 11: Cost of electricity supply in Bhutan from 2017 to 2019 (Bhutan Electricity Authority, 2019)

Type of voltage	Generation cost (US$/kWh)	Distribution network Cost (US$/kWh)	Total cost of supply (US$/kWh)
Low voltage	0.023	0.060	0.083
Medium voltage	0.023	0.054	0.077
High voltage	0.023	0.009	0.032

Figure 1 : Administrative map of Bhutan

Figure 2: Seasonal solar insolation at latitude tilt by district

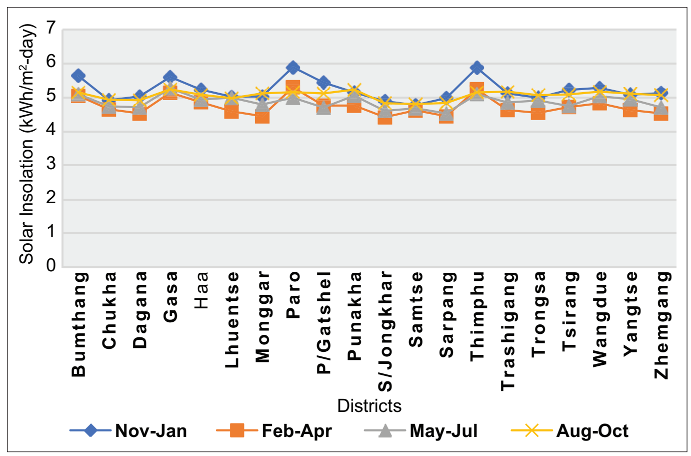

Table 12: Economic analysis for stand-alone SHS

(1860 SHS units)		
Installed capacity	3071.88	kW
Economic life	25	Years
Total Investment Cost	4,357,362.79	US$
Investment cost per unit	1,418.47	US$/kW
Battery replacement cost every 5 years	1,887,418.26	US$
Inverter replacement cost (on the 13th year)	435,240.00	US$
O and M @ 0.5% of ınvestment cost per annum	0.5%	
Annual yield	5269810	kWh
Supply price of electricity	0.083	US$/kWh
Discount rate	6%	
NPV	(2,871,555.77)	US$
BCR	0.66	
DPP	37.8	Years
LCC	8,462,922.14	US$
IRR	(9.56) %	
LCOE	0.064	US$/kWh

Table 13: Various scenarios and key assumptions

	Investment cost (US$)	Key assumptions of features
BAU	4,357,362.79	• 100% investment by the developer
Scenario 1	2,440,123.16	• 50% of A as grant from development banks (e.g. ADB, World Bank) or other donor agencies e.g., JICA, ADA • Remaining 50% of A+B + C=Developer's cost
Scenario 2	2,056,675.24	• 60% of A as grant • Remaining 40% of A+B + C=Developer's cost
Scenario 3	1,673,227.31	• 70% of A as grant • Remaining 30% of A+B + C=Developer's cost
Scenario 4	1,481,503.35	• 75% grant on the costs of components and installation • Remaining 25% of A+B + C=Developer's cost
Scenario 5	522,883.53	• 100% grant on the costs of components and installation • B+C = Developer's cost
The revised price of electricity		• A 5% increment on the existing cost of supply as tariff revision @ US$0.087 per kWh
Discount rates		• 6% (Interest rate on ADB loans for rural electrification projects in Bhutan) • 7.25% (National Bank's interest rate on fixed deposits by institutions and corporations) • 9.45% (National Bank's interest rate for loans for Renewable Energy projects) https://www.bob.bt/loans-interest-rates/
Benefit calculation		•Existing cost of grid electricity for LV customers @US$ 0.083 per kWh •Source: Electricity Tariff in Bhutan, 2017. Table 11

(a) Costs of system components, assembling and installation. (b) Project administration and management costs. (c) Contingencies

five scenarios, the analysis was carried out using three different discount rates of 6%, 7.25%, and 9.45% and also using a revised price of electricity supply. The results of the analyses are as shown in Tables 14-17.

The analyses showed that in the BAU operation, the LCC of 1860 standalone SHS with a total capacity of 3.07 MW was s US$ 8,462,922.14, US$ 7,944,940.48 and US$ 7,223,725.00 when discounted at 6%, 7.25%, and 9.45% respectively.

For the same situation, all the net present values were negative, indicating that costs exceeded the revenues at all the three discount rates that were considered, and the NPV was the lowest for the highest discount rate used. The IRRs also showed negative values for all three cases.

When different scenarios from 1 to 4 were considered as outlined in Table 13, there was a slight improvement in the economic indicators, but the investments were still not viable. The NPVs were still below zero, payback periods longer than the economic life of the systems, and the BCRs were also less than 1. However, in scenario 5 (100% grant on the costs of components and installation) the NPV of the investments was US$ 962,923.49, BCR was 1.21, and DPP was only 2 years, which was the most ideal situation for investment.

Analyses, after considering the revised electricity price of US$ 0.087/kWh and using 6% discount rate, showed negative results for BAU and Scenarios 1 and 2. For Scenarios 3 and 4, the NPVs became positive, and BCR was greater than one, which was desirable results. However, the payback periods were still found to be very long at 23rd and 24th years, respectively.

The average cost of installing a SHS to meet the lighting and cooking load demands of a rural household in a remote, off-grid village or settlement was calculated at US$ 2,342.67. The BPC

Table 14: Results of analyses using a discount rate of 6%

Parameters	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Investment (US$)	4,357,362.79	2,440,123.16	2,056,675.24	1,673,227.31	1,481,503.35	522,883.53
NPV (US$)	(2,871,555.77)	(954,316.14)	(570,868.22)	(187,420.29)	4,303.67	962,923.49
BCR	0.66	0.85	0.91	0.97	1	1.21
DPP (years)	>25	>25	>25	>25	25	2
LCC (US$)	8,462,922.14	6,545,682.51	6,162,234.59	5,778,786.66	5,587,062.70	4,628,442.89
LCOE (US$/kWh)	0.064	0.050	0.047	0.044	0.042	0.035
IRR	–9.6%	–5.8%	–4.3%	–1.9%	0.1%	58.0%

Table 15: Results of analyses using a discount rate of 7.25%

	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Investment (US$)	4,357,362.79	2,440,123.16	2,056,675.24	1,673,227.31	1,481,503.35	522,883.53
NPV (US$)	(2,960,498.78)	(1,043,259.15)	(659,811.22)	(276,363.30)	(86,639.34)	873,980.48
BCR	0.63	0.83	0.88	0.95	0.98	1.21
DPP (years)	>25	>25	>25	>25	25	2
LCC (US$)	7,944,940.48	6,027,700.85	5,644,252.92	5,260,805.00	5,069,081.03	4,110,461.22
LCOE (US$/kWh)	0.06	0.046	0.042	0.04	0.038	0.031
IRR	–10.6%	–6.9%	–5.4%	–3.0%	–1.1%	56.2%

Table 16: Results of analyses using discount rate of 9.45%

	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Investment (US$)	4,357,362.79	2,440,123.16	2,056,675.24	1,673,227.31	1,481,503.35	522,883.53
NPV (US$)	(3,079,440.23)	(1,162,200.61)	(778,752.68)	(395,304.75)	(203,580.79)	755,039.02
BCR	0.57	0.78	0.84	0.91	0.95	1.22
DPP (years)	>25	>25	>25	>25	>25	2
LCC (US$)	7,223,725.00	5,306,486.21	4,923,038.29	4,539,590.36	4,347,866.40	3,389,246.58
LCOE (US$/kWh)	0.055	0.040	0.037	0.034	0.033	0.026
IRR	–12.4%	–8.8%	–7.3%	–4.9%	–3.1%	53.0%

Table 17: Results of analyses using discount rate of 6% and revised price of electricity supply=US$ 0.087/kWh

Parameters	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Investment (US$)	4,357,362.79	2,440,123.16	2,056,675.24	1,673,227.31	1,481,503.35	522,883.53
NPV (US$)	(2,602,092.33)	(684,852.70)	(301,404.78)	82,043.15	273,767.11	1,232,386.93
BCR	0.69	0.90	0.95	1.01	1.05	1.27
DPP (years)	>25	>25	>25	25	24	2
LCC (US$)	8,462,922.14	6,545,682.51	6,162,234.59	5,778,786.66	5,587,062.70	4,628,442.89
LCOE (US$/kWh)	0.064	0.050	0.047	0.044	0.042	0.035
IRR	–8.4%	–4.0%	–2.2%	0.8%	3.2%	63.2%

Annual Report of 2017 revealed that 202 households in the very remote villages under Soe and Lingzhi sub-blocks were connected to the grid-electricity in 2017 with funding from Austrian Development Agency at a cost of approximately US$ 15,350 per household. A preliminary estimate with the Rural Electrification office in BPC showed that the cost of connecting the remaining off-grid households to the grid network would cost about US$ 6,700 per household.

4. CONCLUSION

From this study, it can be concluded that even though the world market prices of PV modules are falling sharply, the Balance of System costs, which comprise the major portion of the cost of PV system installation is still expensive, especially for remote off-grid locations. With the current scenario in Bhutan, where the cost of electricity generation from hydropower is quite low @ US$0.023/kWh, and there is no feed-in tariff framework designed and approved yet for solar or other renewable energy technology, developing and investing in solar PV systems for electricity generation is not found to be financially feasible or attractive to an investor.

On the other hand, the cost of connecting all the remaining remote households and villages to the electricity grid network is much higher than the cost of installing adequate standalone PV systems. Some of these off-grid households or settlements are located inside the protected areas, and therefore, environmental, and other relevant stakeholders often reject forestry clearances to string the distribution and transmission lines through the areas. In such cases, investing in distributed PV systems are seen as the best alternative to reach electricity to off-grid households.

The Alternative Renewable Energy Policy 2013 of Bhutan (Royal Government of Bhutan, 2013) had set out a preliminary minimum target of 20 MW by 2025 through a mix of renewable energy technologies, and within them, electricity generation target from solar resource was set to 5 MW. To meet this target and to attract interests from project developers and investors to participate in the development of solar and also in other RE technologies in the country, policy incentives from the government by designing and fixing appropriate tariffs may be required at the earliest to promote solar PV technology in Bhutan.

As this desktop study (Abanda et al., 2016; Akikur et al., 2013; Aravindh and Ganesh, 2016; Azimoh et al., 2016; Baurzhan and Jenkins, 2016; Bhutan Power Corporation Limited, 2018; Chaiporn et al., 2018; Chaurey and Kandpal, 2010; Erin, 2017; Farman et al., 2011; Ghafoor and Munir, 2015; Halder, 2016; Hamed, 2017; Hirsch et al., 2018; Khan et al., 2018; Kulworawanichpong and Mwambeleko, 2015; Lhazom and Thanarak, 2019; Oko et al., 2012; Ruud et al., 2015; Sam and NREL, 2017; Stojanovski et al., 2017; Sunfueltechnology, n.d.; Synergy Enviro Engineers, n.d.; The World Bank, 2017; Wichit et al., 2015; Zubi et al., 2016; Zubi et al., 2017) was carried out using secondary solar resources data only, site surveys and detailed assessment of meteorological and topographical data were outside the scope of this study. Therefore, ground measurements and site-specific surveys or data regarding topography, shading effects (obstructions, etc.) have not been considered, and only one common solar resource value of 4.7 kWh/m^2/day based on the lowest solar insolation at latitude tilt was applied in the calculations. Furthermore, 30% of the material, assembling, and installation costs were considered to derive the transportation cost of materials for all locations, which in practice would vary with each site depending on its accessibility from the nearest road, its topography, and its distance from the central and regional stores.

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