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SHORT COMMUNICATION

Analysis of Solar PV Energy Systems for Rural Villages of Nekemte Area, Oromiya Region, Ethiopia

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ABSTRACT

Currently, the main energy source used in rural areas of Ethiopia for cooking and heating is unprocessed biomass and fossil fuel such as kerosene, paraffin and petrol/diesel. These energy sources generate large volume of indoor air pollution that increases the risk of chronic diseases. Solar energy is the most practical and economical way of bringing power to poor and remote communities in the long-term and Ethiopia is strategically located in a maximum sun shines hours zone. This study assessed the potential of a solar PV power system to provide the required electricity for a rural community near Nekemte city in Oromiya regions of Ethiopia. The sunshine hour's data was obtained from the National Meteorological Service Agency (NMA). Results showed an abundant (average) solar energy potential of 5.52 KWh/m^2/day. Electric load for a single household, school and clinic was estimated at 313, 2064 and 2040 Wh/day respectively. The cost of energy from solar PV system was estimated at about \$1.2/kWh, \$0.92/kWh and \$0.87/KWh for household, school and clinic respectively. The findings encourage the use of the PV systems to electrify the remote sites of Ethiopia considering it long-term benefits and less cost of installation compared to national grid extension to the remote sites.

Keywords: Electric Load, Rural Electrification, Solar Energy, Solar PV, Nekemte, Ethiopia.

1 Introduction

Statistics shows that more than 2.5 billion of the world's populations rely on wood and charcoal for cooking [1],[2] [3]. The majority of them are living in rural areas of developing countries [4], [5]. A large portion of these individuals use open fires for cooking which corresponds to low thermal efficiency and high air pollution due to poor burning characteristic [1]. The indoor air pollution causes threats to health and even may lead to premature death [6]. Every year, about four million people die prematurely due to indoor air pollution from cooking [7].

Rural households in Ethiopia commonly use traditional open fires three-point solid biomass cook stoves, also called three- point stoves or simply open stoves with low thermal efficiency of 5-15% [8], [9]. Wood is a source of daily energy for over two billion people in developing countries [10], [11]. In Ethiopia, the household sector consumes 90% of total solid fuels [12] and cooking accounts 99.6% of the energy consumed in the sector [13]. Renewable energy resources (solar, wind, biomass and hydro) are the current international trend in rural electrification [14,15]. Among these, a solar PV energy system is thought to be an ideal solution for rural electrification due to its non-polluting, availability and reliable nature [16].

Ethiopia is located in the world's tropical zone and has an excellent solar availability. The daily average total solar radiation over Ethiopia ranges from 5 to 8 kWh/m^2 per day. In terms of geographical distribution, solar radiation that reaches the surface increases as one travels from west to east. The insolation period is approximately 2200 hours of bright sunshine per year in the west increasing to over 3300 hours per year in the eastern semi-arid regions. The minimum average solar radiation for the most part of the country is said to be about 5.3 KWh/m²[17]. Ethiopia has got an ambitious plan for village electrification. Only less than 5% of the villages were electrified through the utility grid as at 2012 [18]. However, there are many other remote and isolated small communities and settlements that are too far from the power grid and might not be connected at all or might take a long time before the national grid crosses those locations. Boke in the western part of Ethiopia, near the Nekemte city is one of the villages facing this situation. They also have a decentralized community system which further makes grid connection expensive by the distances between communities or villages.

The aim of this study was to assess the potential and economic analysis of solar PV energy system for electrification of Boke, a rural village near Nekemte city of Oromiya region, Ethiopia, which not electrified via the national grid system.

2 Materials and Methods

2.1 Description of the research site

This research was conducted in Boke village near Nekemte city in the Oromiya region, of Ethiopia. The village is located 328 km west of Addis Ababa along Ambo road (Figure 1) on latitude and longitude of 9.0833° N and 36.4633° E respectively at an altitude of 2080 m above sea level. The measured global solar radiation data was obtained from NASA [19]. The sunshine hour data are collected from the National Meteorological Agency of Ethiopia (NMA) from 2006 to 2012 except 2008.

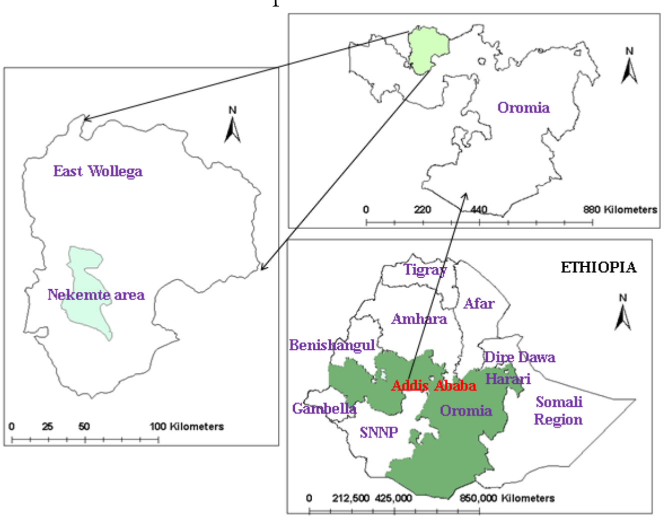

Figure 1: *Study area*

2.2 Solar energy data analysis

Solar radiation was determined to estimate the type and size of solar panels that were required to meet the energy need of a location per time.

2.2.1 Solar radiation estimations

For many developing countries like Ethiopia, solar radiation measurements are not easily available due to the high equipment cost and maintenance and calibration requirements of the measuring equipment. Due to that, there are very few meteorological stations that measure global solar radiation, especially in Ethiopia. For places where data is not directly measured, solar radiation can be estimated by using different models and empirical correlations [17,20,29–33,21–28]. One of the models developed by Angstrom in 1924 [20] which was later modified by Prescott in 1940 [21] was used to estimate the amounts of monthly average solar radiation from meteorological parameters such as the sunshine duration and extra-terrestrial radiation. This model has been extensively used to estimate global solar radiation particularly in a place where no measured radiation data were available [25,30,23–37]. The formula is:

$$\acute{H} = \acute{H}_o\left[a + b\left(\frac{\acute{n}_s}{\acute{N}_s}\right)\right] \acute{H} = \acute{H}_o\left(a + b\left(\frac{\acute{n}_s}{\acute{N}_s}\right)\right) \quad (1)$$

Where, $\acute{H}$ is monthly averaged daily solar radiation on a horizontal surface (MJ/m²); $\acute{H}_o$ is monthly average daily extraterrestrial radiation on a horizontal surface (MJ/m²); $\acute{n}_s$ is monthly average daily hours of bright sunshine; $\acute{N}_s$ is the monthly average of the maximum possible daily hours of bright sunshine; and a and b are regression coefficients.

Solar radiation, known as extra-terrestrial radiation, H_0, on a horizontal plane outside the earth's atmosphere, is calculated using the expression:

$$\acute{H}_o = \frac{24*3600}{\pi} G_{sc}\left[1 + 0.034\cos\left(\frac{360*n_d}{365}\right)\right] * \left[\cos\phi\cos\delta\sin\omega_s + \left(\frac{\pi\omega_s}{180}\right)\sin\phi\sin\delta\right] H_o = \frac{24*3600}{\pi} G_{sc}\left[1 + 0.034\cos\left(\frac{360n_d}{365}\right)\right] * \left[\cos\emptyset\cos\delta\sin\omega_s + \left(\frac{\pi\omega_s}{180}\right) s \in \emptyset\sin\delta\right] \quad (2)$$

where: n_d is the number of days, G_{sc} is the solar constant (1368 W/m²) [37] , φis the latitude of the location (⁰), δ is the declination angle (⁰), which is given as follows:

$$\delta = 23.45 * \sin\left(\frac{360*284+n_d}{365}\right) \quad (3)$$

The sunset hour angle ω_s is the solar hour angle corresponding to the time when the sun sets and it is given by

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (4)$$

The day length, N_s, is the maximum possible daily sunshine hour given by

$$\acute{N}_s = \frac{2}{15}\omega_s = \frac{2}{15} * [\cos^{-1}(-\tan\phi\tan\delta)] \quad (5)$$

As climatic conditions change from location to location, then, correlation for every climatic region must be established. At present there is no correlation of global radiation as a function of sunshine hours existing for the study areas. The present study is aimed to estimate such correlation parameters for each station of the study areas. These correction parameters (regression constants) a and b are given as:[38,39]

$$a = -0.110 + 0.235\cos\phi + 0.322\left(\frac{\acute{n}_s}{\acute{N}_s}\right) \quad (6a)$$

$$b = 1.449 - 0.553\cos\phi - 0.694\left(\frac{\acute{n}_s}{\acute{N}_s}\right) \; a = -0.110 - 0.235\cos\emptyset + 0.322\left(\frac{\acute{n}_s}{\acute{N}_s}\right) \quad (6b) \; b = 1.449 - 0.553\cos\emptyset - 0.694\left(\frac{\acute{n}_s}{\acute{N}_s}\right)$$

2.2.2 Comparison of Models

There are many parameters which deal with the assessment and comparison of monthly average daily solar radiation estimation models. Here the statistical parameters like the mean bias error (MBE) and the root mean square error (RMSE) helped to calculate the error or the deviation of the calculated value from the measured value [22,30,31,40–42].

a) **Correlation coefficient (r):** measures the relationship between variables based on a scale of ±1[22,30,31,40–42]. The value which approaches 1 is statistically acceptable (r →1).

$$r = \frac{\sum_1^n [H_{i,c} - \acute{H}_c] * [H_{i,m} - \acute{H}_m]}{\sqrt{\left(\sum_1^n [H_{i,c} - \acute{H}_c]\right)^2 * \left(\sum_1^n [H_{i,m} - \acute{H}_m]\right)^2}} \quad (7a)$$

Where, n is the number of data pairs, H_m is measured global solar radiation (GSR) and H_c estimated GSR.

b) **Root mean square error (RMSE)**: Provides information on the short-term performance of the correlations. A few large errors in the sum can produce a significant increase in RMSE [22,30,31,40–42]. Low RMSE (close to zero) is statistically accepted value and it is defined as:

$$RMSE = \left(\frac{1}{n}\sum_1^n [H_{i,c} - H_{i,m}]^2\right)^{1/2} \quad (7b)$$

c) **Mean bias error (MBE):** Provides information on the long-term performance. Overestimation of an individual observation will cancel underestimation in a separate observation [22,30,31,40–42]. Low RMSE (close to zero) is statistically accepted value and it is defined as:

$$MBE = \frac{1}{n}\sum_1^n [H_{i,c} - H_{i,m}] \quad (7c)$$

d) **Mean percentage error (MPE):** Provides long-term performance of the examined regression equations. An overall measure of forecast bias [22,30,31,40–42]. The value between −10% and +10% is considered as acceptable value and it is given by:

$$MPE(\%) = \frac{1}{n}\sum_1^n \left(\frac{[H_{i,c} - H_{i,m}]}{H_{i,m}}\right) * 100 \quad (7d)$$

2.2.3 Sizing of Solar PV panel

The following steps are required to design a solar PV system for the considered community (Figure 2).

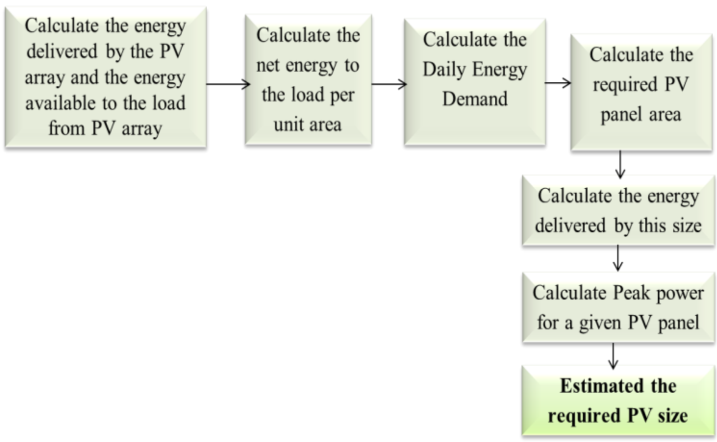

Figure 2: *Schematic diagram for sizing Solar panels*

3 Results and Discussion

3.1 Solar energy potential assessment

The monthly mean daily global solar radiation of Nekemte area was estimated by using equations (1) to (6). The calculated parameters for each month are shown in Table 1. The accuracy of the correlation (equation 1) was tested through the statistical testing methods using equations (7a) to (7d) between the calculated and measured or observed (obtained from NASA) values of the monthly mean daily global radiation.

The results showed that the estimated values of monthly mean daily global solar radiation are in good agreement with the measured values of monthly mean daily global solar radiation at a correlation of r = 0.8874 (Table 1). The statistical test results fell within the acceptable range for the desired station. The MPE of the model is −8.672% with the lowest RMSE value (1.2604). Moreover, MBE values are close to zero (- 0.414). The negative and positive values of MBE and MPE showed overestimation and underestimation of global solar radiation respectively. The computed data obtained are reasonably comparable and compatible with the measured data for the study area.

The Angstrom models modified by Prescott have good skill in estimating monthly mean daily global solar radiation for Nekemte area. The measured and estimated (calculated) value of the monthly average daily global radiation is illustrated in Figure 3.

Table 1: *Comparison between measured and calculated values of* $\bar{H}$ *for Nekemte*

Months	$\acute{n}_s$	δ	ωs	$\acute{N}_s$	$\acute{H}_o$	a	b	Ḣ(kWh/m²/d)	Nasa	Statistical	tests
Jan	8.7	-21.3	93.6	12.5	11.5	0.35	0.42	7.3	6.26	RMSE	1.2604
Feb	8.3	-13.7	92.2	12.3	11.7	0.34	0.43	7.4	6.65	MBE	-0.413
Mar	8.0	-2.9	90.5	12.1	11.2	0.34	0.44	7.0	6.67	MPE	-8.672
Apr	7.7	9.3	88.5	11.8	9.8	0.33	0.45	6.1	6.61	r	0.8874
May	6.5	18.7	86.9	11.6	8.1	0.30	0.52	4.8	6.06		
Jun	4.9	23.3	86.0	11.5	7.0	0.26	0.61	3.6	5.37		
Jul	2.9	21.6	86.4	11.5	7.0	0.20	0.73	2.7	4.89		
Au	2.7	13.9	87.8	11.7	8.0	0.20	0.74	3.0	5.04		
Sep	3.8	2.3	89.6	12.0	9.5	0.23	0.68	4.2	5.61		
Oct	6.9	-9.5	91.5	12.2	10.5	0.30	0.51	6.2	5.74		
Nov	7.9	-19.1	93.2	12.4	11.0	0.33	0.46	6.8	6.05		
Dec	8.1	-23.3	94.0	12.5	11.1	0.33	0.45	7.0	6.17		
Av	6.4			12.0	9.7	0.29	0.54	5.52	5.93		

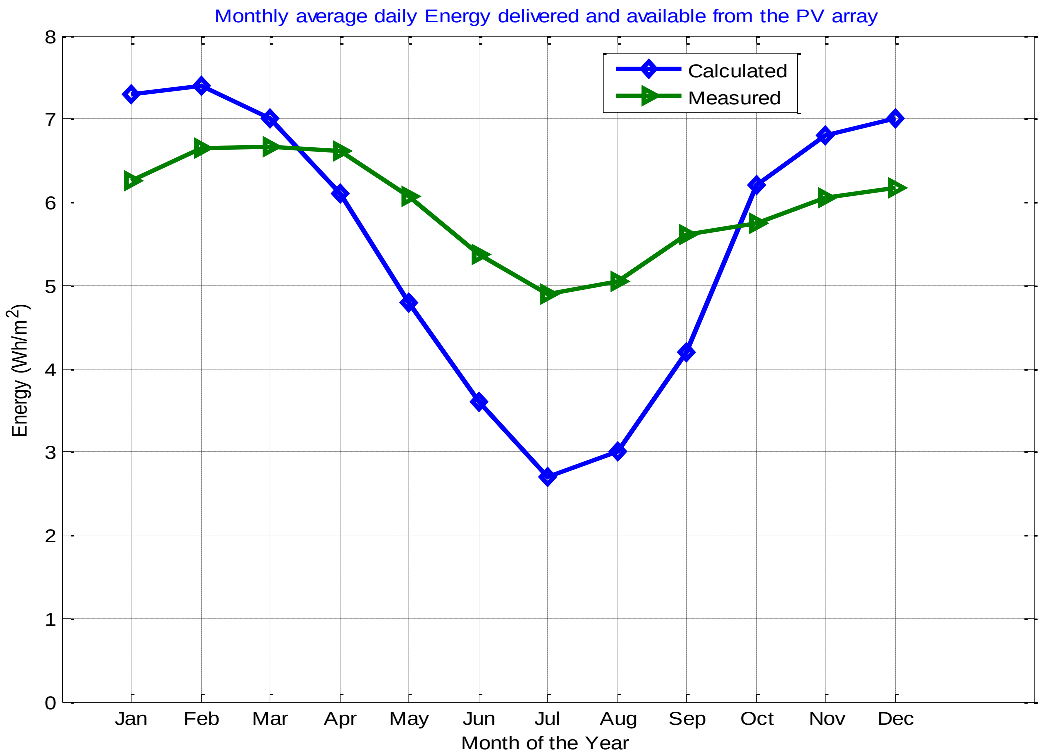

Figure 3: *Measured monthly daily global radiation versus computed radiation*

It shows a good agreement for the assessed period. Therefore, the AP-model is recommended for future research on monthly average daily global solar radiation for Nekemte area. The calculated global solar radiation decreased from February to July and increased from July to January (Figure 3). The minimum radiation occurred between June-August due to the peak period of the cloud covering the country in the rainy season ($\acute{H}$< 4 kWh/m²/day). The major maximum monthly average daily global solar radiation occurred between October-April (H > 6 kWh/m²/day). Generally, the higher value of solar radiation was obtained in the dry season. September and May showed moderate radiations. The result shows that the monthly average daily global solar radiation on a horizontal surface for Nekemte area was between 2.7 KWh/m²/day (in July) and 7.4 KWh/m²/day (in February). The annual average value was estimated to be 5.52 KWh/m²/day.

3.2 Design of solar PV energy system

The stand-alone PV system of the following household block diagram consists of a PV array, charge controller battery and inverter (Figure 4). PV array convert the sunlight directly into DC electrical power while the battery is to store the excess power via the battery charger. The inverter is to convert the DC to AC electrical power to match the requirements of the common household AC appliances.

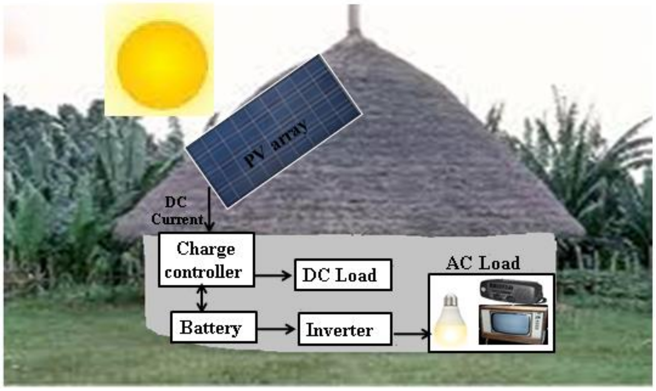

Figure 4: *The block diagram of the household stand-alone PV system*

3.2.1 Energy of the PV array

The power delivered by the PV array (E_P) can be calculated by equation (8a) [43]:

$$E_P = A_P \eta_P \acute{H} \quad (8a)$$

Where: A_P = module area (1m²) & η_P = Efficiency of PV Module (for this study 12%)

The array energy available to the load and the battery (E_a) can be obtained by the relations in equation (8b) [43]:

$$E_a = E_P(1-\lambda_P)(1-\lambda_c) \quad (8b)$$

Where: λ_P is total loss like dust cover on the PV array (assuming 4%) and λ_c is Power conditioning losses commonly taken as 10%.

Using equation (8a) and (8b), daily averaged power delivered by the PV array (E_P) and daily average total energy available from the PV array (E_a) were determined and presented in Figure 5.

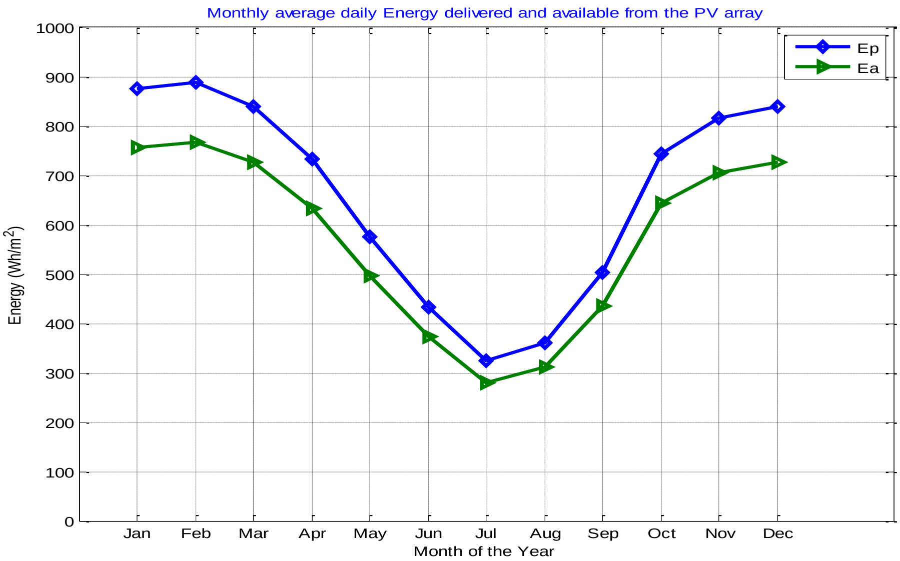

Figure 5: *Monthly average daily energy delivered (E_p) and available to the load (E_a)*

Table 2: *Electricity load*

Energy Demand	Appliance	Watt (W)	Total No.	Daily use/hour	Daily Energy (Wh/day)	Total
Household	Lamp 1(Living room)	11	1	4 (from 18 - 22)	44	313
	Lamp 2 (Bed room)	11	1	5 (from 18 - 23)	55	
	Lamp 3 (kitchen)	11	1	2 (from 18 - 20)	22	
	Television (21 color)	60	1	3 (from 19 - 22)	180	
	Radio	3	1	4 (7-8, 12-14, 19-20)	12	
School	Bulb for class	11	8	3	264	2064
	Desktop Computers	150	1	8	1200	
	Printer	120	1	2	240	
	Photocopying	180	1	2	360	
Clinic	Refrigerator	70	1	24	1680	2040
	Microscopes	50	2	8	160	
	Radio	3	1	8	24	
	Light bulb	11	2	8	176	

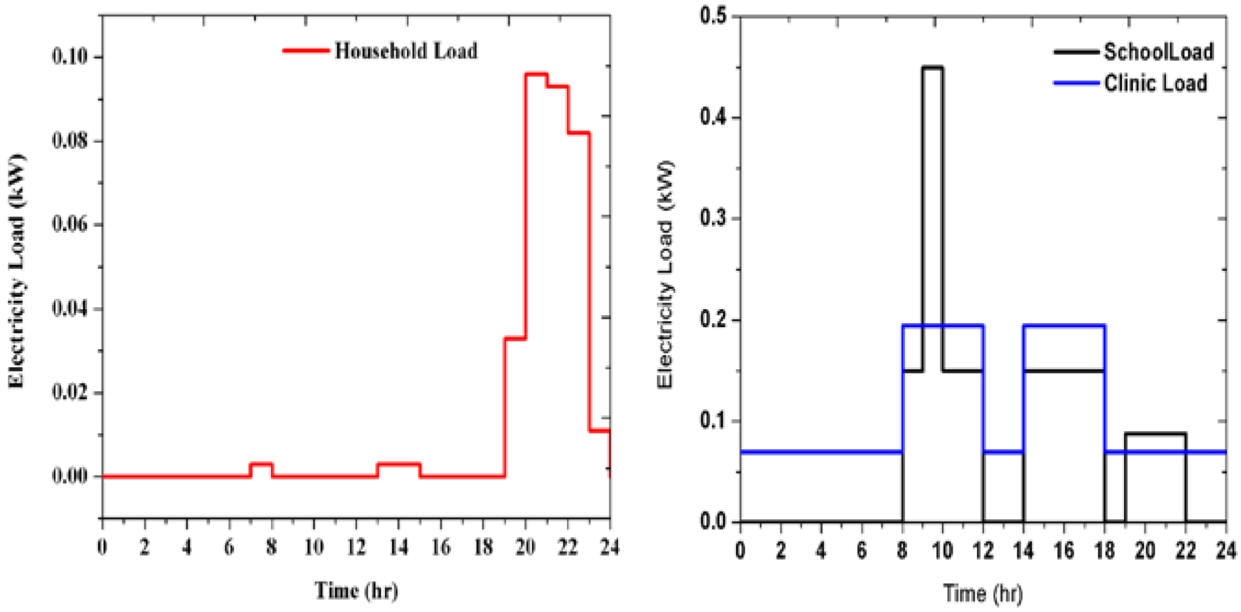

Figure 6: *The load profile of the community.*

The major maximum monthly average daily energy available to the load occurred during the months of February (767.2 Wh/m^2) and January (756.8 Wh/m^2) while the minimum occurred during the summer seasons (June to August) in the range of 279.9 - 373.2Wh/m^2.

3.2.2 Energy demand

The considered load system for a community like Boke village, near Nekemte city. For practical reasons, a complete village setting was taken which included a single household, a local school and clinic. The energy demand of the community is summarized in Table 2. The result revealed that the rated power of the community was 96, 450 and 195 W for a household, school and clinic respectively (Figure 6).

3.2.3 Sizing of the solar panels

The PV panel was sized with the annual minimum of daily available PV electric energy (E_h) which occurred in the month of July (279.9Wh/m^2) as presented in Figure 5. Hence, the required PV panel area (A_P) was estimated by equation (9) [28,43]:

$$A_P = \frac{\text{DailyEnergyDemand}}{E_h \eta_b \eta_c} \quad (9)$$

Where, η_b is the efficiency of battery (~ 90%) and η_c is the efficiency of charge controller (~90%).
The energy delivered by this size of the PV panel was calculated from equation (10) [28,34]:

$$E_P = E_h * A_P \quad (10)$$

To select a PV panel, the specific power requirement in peak watts was estimated at

1000W/m² and 25°C of irradiation and cell temperature respectively. The monthly global irradiance ranged from 2.7 KWh/day in July to 7.4 KWh/day in February. Therefore, the effective hours with peak radiation (1000W/m²) for the minimum case was 2.7 hours. As the temperature of the PV panel is not constant, a given correction factor (f_t) was taken at 0.89 [26]. The peak power for a given PV panel was determined by equation (11) [28, 43]:

$$P_P = \frac{E_P}{EH * f_t} \quad (11)$$

Using equations (9) to (10) the required PV area, energy delivered by size and peak power were calculated for the community (Table 4). The standard size of solar module 65Wp Kyocera Solar PV Module (KC65T) at standard test conditions (i.e., 1000 W/m² and 25°C) was selected. The average cost of the Kyocera Solar PV Module panel per peak watt was found to be $2/$W_P$ [33,34]. Hence, the total cost price of the 65 W_p module was $130. A total of 3, 17 and 16 modules were required to power a household, school and clinic respectively. Therefore, the total cost price of the required solar module for a household, school and clinic were $390, $2210 and $2080 respectively. The results of cost analysis are summarized in Table 3.

3.2.4 Sizing of battery

Assuming that the working voltage for direct current is 12V and cloudy days, the energy demand of a battery was two days. A battery can store 30% to 90% of energy assuming a depth of discharge (DOD) at 30%. The total commercial capacity of the battery was calculated as [16,28]:

$$C_{bn} = N_C \frac{DailyEnergyDemand}{\eta_b V_{cc} * DOD} \quad (12)$$

Where, η_b is efficiency of the battery (assuming 90%), N_C is the largest number of continuous cloudy days of the site (assuming 2 days) and DOD is minimum permissible depth of discharge of the battery.

Using equation (12) the required battery size was estimated for the community (Table 3). To be safer, the best battery size, Vision 6FM250D of 12 V and 250 Ah was used. The average cost of the battery per Ampere-hour was found to be $1.705/Ah [16]. Therefore, the total cost price of Vision 6FM250D battery (250 Ah) was $420.25. The total cost of required battery for a household, school and clinic were $420.25, $2101.25 and $2101.25, respectively (Table 3).

Table 3: *Size and cost summary of the solar photovoltaic system*

		Household	School	Clinic
PV	Daily Demand (Wh/day)	313	2064	2040
	Required PV area (A_P in m²)	1.38	9.1	8.99
	Energy delivered (E_P in Wh/day)	386.42	2548.1	2518.5
	Peak power(P_P)	160.81W_p	1060W_p	1048.1 W_P
	Selected PV type	65 W_p	65W_p	65 W_P
	required PV modules	3	17	16
	Unit price ($)	$2/$W_p$	$2/$W_p$	$2/$W_p$
	Total cost ($)	390	2210	2080
Battery	Capacity of the battery	193.2 Ah	1274.1 Ah	1259.3 Ah
	Selected Battery type	250 Ah (Vision 6FM250D)	250 Ah (Vision 6FM250D)	250 Ah (Vision 6FM250D)
	Required size	1 batteries	5 batteries	5 batteries
	Cost for one battery	$420.25	$420.25	$420.25
	Total cost	$420.25	$2101.25	$2101.25
Charge controller	Maximum Current	26.1 A	172 A	170 A
	Unit Price	$5.878/A	$5.878/A	$5.878/A
	Total cost	$153.42	$1011.02	$999.26
Inverter	Rated Power (W)	96	450	195
	Rated Power (20% higher)	115.2	540	234
	Unit Price ($)	$0.831/W	$0.831/W	$0.831/W
	Total cost	$95.73	$448.74	$194.45

Table 4: *Cost break down of solar PV system*

No	Description	Household			School			Clinic		
		Qty	Unit Price	Total Price ($)	Qty	Unit Price	Total Price ($)	Qty	Unit Price	Total Price ($)
1	PV Modules (65Wp)	3	$130	390	17	$130	2210	16	$130	2080
2	Battery (250 Ah)	1	$420.25	420.25	5	$420.25	2101.25		$420.25	2101.25
3	Charge Regulator		$5.878/A	153.42		$5.878/A	1011.02		$5.878/A	999.26
4	Inverter	1	$0.831/W	195.73		$0.831/W	448.74		$0.831/W	194.45
5	Cabling, Switch, Holder, plug, Divider and PV panel support			20			130			120
Total				1179.40			5901.01			5494.96

3.2.5 Sizing of charge controller

A charge controller ensures safe charging and a longer lifespan of the batteries. It has to be capable of carrying the short circuit current of the PV array. The charge controller must work at a maximum current, which was given by [28]:

$$I_T = \frac{\text{DailyEnergyDemand}}{V_{cc}} \quad (13)$$

The average cost of the charge controller per unit Amper was found to be $5.878/A [5] (Table 3).

3.2.6 Sizing of inverter

The used inverter must be able to handle the maximum expected power of AC loads. Therefore, it was selected to be 20% higher than the rated power of the total AC loads determined for the community (Table 2). That is, the rated powers of the inverter were 115.2, 540 and 234 W for household, school and clinic respectively. The average cost of the inverter per unit Watt was found to be $0.831/W [16] (Table 3).

Other accessories required for the installation of PV panel were wire connections from (1) solar panel to charge controller, (2) charge controller to battery, (3) inverter to charges; key of charges control; switches and cables etc.

3.3 Cost analysis of solar photovoltaic power generation system

3.3.1 Cost evaluation of solar photovoltaic power generation

The total cost of the solar PV system for Boke village, near Nekemte city of Ethiopia, was presented in Table 4. The total costs of the system were $1179.40, $5901.01 and $5494.96 for a household, school and clinic respectively.

3.3.2 Financial evaluation of solar PV power system

The annual payment: To evaluate the system, an assumption of 10% interest rate and 25 years life span were taken into consideration. The annual payment was calculated as [16,28]:

$$C_A = \frac{C_I}{\frac{(1+i)^n - 1}{i(1+i)^n}} + C_m \quad (14)$$

Where, C_A is annual payment, C_I is capital cost, n is life span (assuming 25 years), i is interest rate (assuming 10 %) and C_m is maintenance and operation cost (assuming 2% of PV cost).

The monthly Payment (MP) of the Systems was calculated as:

$$MP = \frac{C_A}{12} \quad (15)$$

The unit energy cost (P_e) was determined by:

$$P_e = \frac{C_A}{365 * E_d} \quad (16)$$

Where, E_d is daily energy consumption (household = 313 Wh/day, school = 2064 Wh/day and clinic = 2040 Wh/day).

Using equations (14) to (16), annual payment (C_A), the monthly payment (MP) and unit energy cost (P_e) of the system for the community were determined. The summarized result is presented in Table 5.

The findings of this study show that a household, school and clinic in a remote area with no immediate or long-term access to the Ethiopian national grid may be powered at the cost of about $1.2/kWh, $0.92/kWh and $0.87/kWh respectively. Although this price is very high compared to the current unit cost of electricity in Ethiopia (< \$0.05/kWh [28]), the cost will decrease with time as the future initial cost of the PV modules decreases. There is anticipation of an increase in the national unit cost of electricity in rural Ethiopia due to the rapid increase in the conventional fuel prices. This will, therefore, make PV energy generation a cost-efficient and clean promising option for rural electrification in Ethiopia.

Table 5: *Summary of Financial Evaluation of solar PV system*

	Household	School	Clinic
Annual payment (\$)	137.73	694.30	646.97
Monthly payment (\$)	11.48	57.86	53.91
Unit energy cost (\$/kWh)	1.2	0.92	0.87

4 Conclusion

In the present study, potential and economic viability of a solar PV energy system for Boke village were analyzed. The site was found to have an average solar energy potential of 5.52 kWh/m^2/day and a monthly average daily global solar radiation on a horizontal surface for Nekemte area to fall in the range of 2.7 kWh/m^2/day (in July) and 7.4 kWh/m^2/day (in February). Angstrom-Prescott model based on statistical error analysis was suitable for the estimation of global solar radiation for Nekemte area. The study estimated the cost of energy from a solar PV system for a household, school and clinic to be \$1.2/kWh, \$0.92/kWh and \$0.87/kWh respectively. The cost of energy although on a higher side has a potential of drastic reduction considering the rate of drop in solar PV panel cost in the past five years. Furthermore, it could supply power to about 23% of national coverage with electricity shortage and about 5% of rural areas with no electrification. Solar PV system installation and electrification in remote areas of Ethiopia are beneficial and suitable as a long-term investment.

5 Declarations

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5.2 Competing Interests

The author declared that no conflict of interest exists in publishing this article.

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