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Estimation of Solar Energy Potential Using Sunshine-Based Model for Busa-Baso Kebele, Dirashe Woreda, Ethiopia

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Abstract: The purpose of this study was focused on estimation of solar photovoltaic power systems in Busa Baso, Dirashe Woreda, Ethiopia. Solar photovoltaics are being promoted to replace fuel-based lighting and off-grid electrical needs. It was conducted to assess and evaluate the data collections which were administered on selected site. The data collected were analyzed using descriptive survey. The radiation had to be predicted from sunshine hours by employing empirical models. Using data from National Aeronautics and Space Administration (NASA), linear monthly average solar radiation has been developed. The paper presents an estimation of the solar energy resource based on the primary data taken between January 2019 and December 2019.

Keywords: Photovoltaic System; Sunshine Duration; Clearness Index; Regression Constants, Renewable Energy

1. Introduction

Ethiopia has a large population with a rapidly growing economy and very low level of electrification. Solar Photovoltaic systems are cost-effective and reliable means to increase access not only to electricity but also to information and communication through mobile devices. Photovoltaic systems are already an important source of power for the mobile network in Ethiopia – it will also be important for of energizing social institutions such as schools, clinics and water supply. Since Ethiopia is located near the Equator; the solar resource potential is significant. The yearly mean average daily radiation reaching the ground is 5.2 kWh/m2/day [1]. The demand of energy, the consumption of fossil fuels and pollution level is increasing with an alarming rate worldwide. With the high demand for this commodity, various stakeholders have now become aware of the urgent need for management of resources and energy conversion activities. The energy consumed in the household sector is perhaps the single largest consumer of energy in the nation's economy in developing countries of the world and Ethiopia in particular. With the rapid depletion of fossil fuel reserves around the world due to high demand, it is feared that the world will soon run out of its non-renewable energy resources which present the huge amount of energy use in the world. This is a matter of concern for the developing countries like Ethiopia and others whose economy heavily depends on imported petroleum products. Under these circumstances it is highly desirable that alternate energy resources should be utilized with maximum conversion efficiency to cope with the increasing energy demand. Among the non-conventional energy resources, solar energy, wind energy and biomass has emerged as most prospective option for the future. The outlook for the solar electricity sector in Ethiopia is for rapid increase in installation for off-grid applications and later for grid connected applications. Off-grid applications will be dominant in the short term but grid connected PV may become important in the medium and long term. Short term plans that have direct relevance for the PV sector include plans to disseminate more than 3 million PV home systems and plans to increase mobile ownership to 40 million [2]. The global shift towards renewable energy is gaining momentum as the technology to harness those resources further matures. Recent researches in the areas of solar technology continue to produce promising innovative technologies that not only could bring the costs down but also do increase system efficiency. These factors certainly boost the initiatives by which developing countries like Ethiopia could benefit by utilizing their untapped renewable energy resources, albeit indirectly. This is good news for a country whose economy has experienced a strong and broad-based growth over the past decade, averaging 10.6% per year in 2004/05-2011/12 compared to the Sub-Sahara Africa that stood at an average of 5.2% [3, 4].

1.1. Geographical Location of the Site

Ethiopia is geographically located between 33° and 48° East longitudes and between 3° and 15° Latitude which is within the solar belt. This study further investigates the resource estimation by undertaking a data taken from global horizontal irradiation in selected site on Southern part of the country. This site is located in the area called Busa Baso, Dirashe Woreda, SNNP Region, Ethiopia. The elevation of the site is ranging from 1100m to 2300 m with a mean elevation of 1700 m above sea level. The site geographical coordinates are 37°15' to 37°31' E (longitude) and 5°18' to 5°74 N (latitude). In the area more than 90% of the population is engaged in agricultural sector.

Figure 1: Geographical location of study area

2. Methodology

2.1. Data Collection

The metrological data obtained from this site can be used to understand the weather parameters in the Woreda. A year (2019) sunshine duration data for a site has been collected from NASA. The sunshine duration data is manipulated to obtain the monthly average daily sunshine duration in hours, and the data again averaged using simple spreadsheet to find the monthly mean daily sunshine duration of the site and the result is presented on Table 1. This data will be used later to estimate the monthly average daily global horizontal radiation.

Table 1: Monthly Average Daily Sunshine Duration (hours) for study site

Month	K	H	n	H_0
Jan	0.69	6.59	8.16	6.87
Feb	0.65	6.54	8.79	7.21
Mar	0.65	6.77	9.07	7.66
Apr	0.57	5.96	9.32	6.23
May	0.59	5.94	9.20	6.21
Jun	0.47	4.64	9.31	5.73
Jul	0.46	4.60	9.15	5.65
Aug	0.45	4.58	9.19	5.42
Sep	0.50	5.09	9.19	5.93
Oct	0.52	5.26	9.28	6.32
Nov	0.55	5.28	9.15	6.41
Dec	0.60	5.54	8.87	6.54

2.2. Data Analysis

The sunshine duration data cannot be used directly as an input for sizing energy systems and economic feasibility of electrification projects. It has to be converted to monthly average daily solar radiation in KWh/m^2/day using Angstrom-Prescott model given by [5, 6, 7].

$$\frac{H}{H0} = a + b\frac{n}{N} \qquad (1)$$

Where, $\boldsymbol{H}$ = monthly average daily global radiation (Wh/m^2/day), $\boldsymbol{H_0}$= monthly average clear sky daily global radiation for the location in a given day, $\boldsymbol{n}$ = actual sunshine duration in a day, respectively, (hours), $\boldsymbol{N}$ = monthly average maximum possible bright sunshine duration in a day and also known as monthly mean length of the day in hours, **a** and **b** = empirical coefficients. These coefficients are location specific coefficients referred to as fractions of extraterrestrial radiation on overcast days and on average days, respectively. The ratio **n/N** is referred to as cloudless index. It gives information about atmospheric characteristics and conditions of the study area [7]. The ratio of solar radiation at the surface of the Earth (H) to extraterrestrial radiation (H_0), that is, H/H_0, is called the Clearness Index. Values of the monthly average daily extraterrestrial radiation ($\boldsymbol{H_0}$) is calculated from the following [8]:

$$H_0 = \frac{24x3600xH_{sc}}{\pi}\, x \left[1 + 0.033Cos\left(\frac{360xd}{365}\right)\right] x \left[Cos\varphi Cos\delta Sin\omega + \frac{\pi\omega}{180} Sin\varphi Sin\delta\right] \qquad (2)$$

Where, H_{sc} = solar constant with a value of 1367 Wm^{-2}, d = day of the year from January 1 to December 31 taking January 1st as 1, ϕ = latitude of the location, δ = declination angle, ω = sunset hour angle given by,

$$\omega = \cos^{-1}(-\tan\phi\tan\delta) \tag{3}$$

Declination angle can be obtained by the equation given by Cooper in 1969 [9, 10];

$$\delta = 23.45Sin\left[360\left(\frac{284+d}{365}\right)\right] \tag{4}$$

The maximum possible sunshine duration N (hours) for a horizontal surface is given by,

$$N = \frac{2\omega}{15} \tag{5}$$

Angstrom empirical constant or regression coefficients. Their values have been obtained from the relationship given by [10],

$$a = -0.110 + 0.235Cos\varphi + 0.323\frac{n}{N} \tag{6}$$

$$b = 1.449 - 0.553Cos\varphi - 0.694\frac{n}{N} \tag{7}$$

Table 2: Recommended Average Days for Months and Values of *d* by Months

Month	d for ith day of month	For average day of Month		
		Date	d	δ
January	i	17	17	-20.9
February	31 + i	16	47	-13.0
March	59 + i	16	75	-2.4
April	90 + i	15	105	9.4
May	120 + i	15	135	18.8
June	151 + i	11	162	23.1
July	181 + i	17	198	21.2
August	212 + i	16	228	13.5
September	243 + i	15	258	2.2
October	273 + i	15	288	-9.6
November	304 + i	14	318	-18.9
December	334 + i	10	344	-23.0

3. Result and Discussion

3.1. Average Monthly Solar Insolation for Busa-Baso Site

The average monthly daily sunshine duration, n is obtained for each month from the data (Table 1), and its average is used in equation 1, 2, 6 and 7 to calculate H, H_0, a and b respectively. The result is shown in Table 3. In the Table **d** is day of the year, 1 for January and 365 for December 31. N is mean length of day in hours, n is monthly mean daily sunshine duration in hours, H is monthly average daily global radiation in (MW-hr/m^2/day), H_0 is monthly average clear sky daily global radiation in (MW-hr/m^2/day), a and b are regression coefficients, and K is clearance index.

Table 3: Monthly mean H, H0, a, b, and K for study site

Month	Date	D	H	H_0	N	n	n/N	a	b	K	δ
Jan	15	15	6.59	6.87	11.71	8.16	0.69	0.35	0.42	0.69	-21.27
Feb	16	47	6.54	7.21	11.83	8.79	0.74	0.36	0.39	0.65	-12.95
Mar	15	74	6.77	7.66	11.96	9.07	0.76	0.37	0.37	0.65	-2.82
Apr	15	105	5.96	6.23	12.12	9.32	0.77	0.37	0.36	0.57	9.41
May	16	136	5.94	6.21	12.26	9.20	0.75	0.37	0.38	0.59	19.03
Jun	14	165	4.64	5.73	12.32	9.31	0.76	0.37	0.37	0.47	23.26
Jul	13	194	4.60	5.65	12.29	9.15	0.74	0.36	0.39	0.46	21.83
Aug	15	227	4.58	5.42	12.18	9.19	0.75	0.37	0.39	0.45	13.78
Sep	16	259	5.09	5.93	12.02	9.19	0.76	0.37	0.37	0.50	1.81
Oct	15	288	5.26	6.32	11.87	9.28	0.78	0.38	0.36	0.52	-9.60
Nov	17	321	5.28	6.41	11.73	9.15	0.80	0.38	0.34	0.55	-19.60
Dec	16	350	5.54	6.54	11.68	8.87	0.76	0.37	0.37	0.60	-23.37

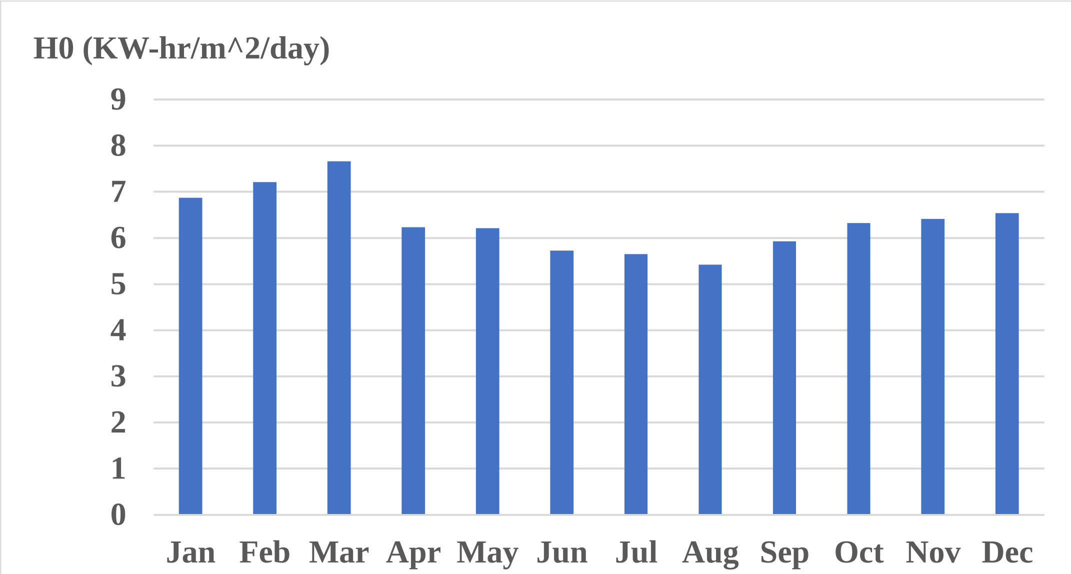

Fig 2: Monthly average solar irradiation of Busa-Baso Site

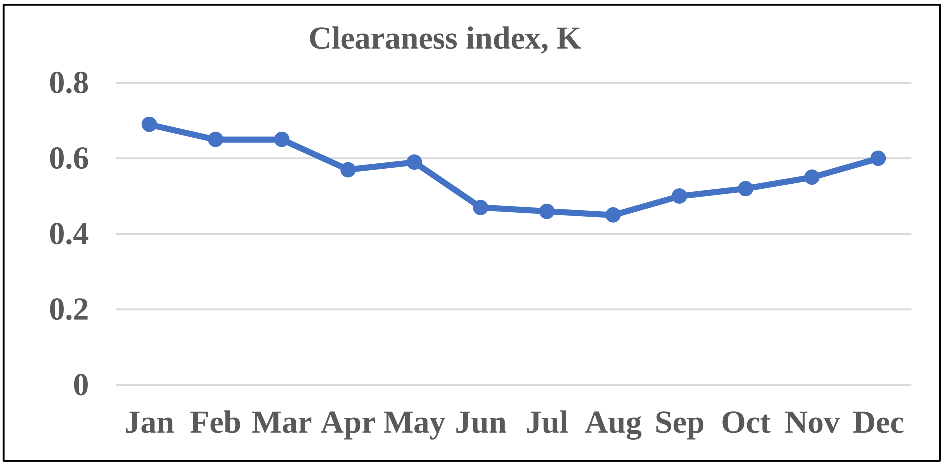

Fig 3: Monthly mean clearness index of study site

3.2. Estimating Parameters of Angstrom-Prescott Model for Busa-Baso Site

In this work the values of H_0 and N are calculated for each month using equations (2) and (5), respectively. A regression is related in between H/H_0 and n/N. The regression coefficients are the parameters “a” and “b” of the Angstrom-Prescott model. Results obtained are given in Table 4.

Table 4: Angstrom- Prescott Model for Busa-Baso Site

Site	a	b	Angstrom- Prescott Model
Busa-Baso	0.33	0.38	$H/H_0 = 0.33 + 0.38\ n/N$

4. Conclusion

In general, the country Ethiopia with having sun through the year is estimated to harvest good solar energy potential. In this paper, the result of estimate of solar energy potential for Busa-Baso, Dirashe Woreda is presented. First, the data pertaining to solar radiation of the site were gathered from NASA. Next, analytical method of solar radiation analysis was used to calculate the amount of radiation per month, the maximum amount of possible radiation per month, constant coefficients of equation, Monthly average daily extraterrestrial radiation on horizontal surface (KW-hr/m^2/day), Monthly average daily global radiation on horizontal surface (KW-hr/m^2/day). The radiation profile demonstrates the highest and lowest irradiance of the site. Accordingly, the site receives the highest solar radiation in March and the lowest solar radiation in August with annual average solar radiation of 6.54 KW-hr/m^2/day which is considered to be good solar resource.

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