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Solar Energy Potential and Future Prospects in Afar Region, Ethiopia

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Abstract: The objective of the study is to provide scientific information of the solar potential of Afar region, for photovoltaic (PV) solar energy industry sectors. The afar region being exceptional solar potential with high average solar radiation flux 239.9W/m^2 (105.4% of average photon energy surface area of Ethiopia), and average annual solar density of 2.102MW·h/m^2 (105.5% of the average yearly solar density of Ethiopia). This finding requests the photovoltaic system as an alternative principal energy resource to substitute the present energy system in afar region. These comprehensive indication of the solar energy marketplace in Afar region, Ethiopia, key visions into its governing framework, energy sector, of photovoltaic (PV) industry segments. Therefore, the photovoltaic energy system has the best opportunity for basic energy application in the pastoral community for daily life consumption, such as solar lighting, for solar cooker, small devices and for air conditioning. These studies show that the Afar region gifted with significantly high monthly average daily solar radiation as a potential candidate for development of PV energy systems in Afar region. Therefore, the PV system has the power to run an evaporative air conditioning system effectively. These findings indicate that photovoltaic energy system as most promising energy in the Afar region**.**

Keywords: Solar Energy, Solar Radiation Flux, Afar Region

1. Introduction

Ethiopia is sited in the Horn of Africa, located at 3-15°N latitude and 33-48°E longitude. Ethiopia covers an area of 1.13 million square kilometers. In terms of population, Ethiopia is household to over 110 million people, which makes it the second populated country in Africa next to Nigeria but 83% of which living in the rural areas World population prospects. In spite of Ethiopia has plentiful natural resources and huge energy resource in contradiction of that Ethiopia is experiencing serious energy deficiencies to encounter the growing energy demand, which is estimated to grow by approximately 30% annually [1]. The Ethiopia energy sector appearances the double challenges of inadequate access to present-day renewable energy alternative such as geothermal energy, solar energy and wind energy. Although Ethiopia has seen melodramatic economic progress in recent years, satisfying this development, the future will want theatrical growth of recent energy source with affordable cost [2].

Afar region is one of the nine governmental established regional states and it is the homeland of Afar people and located at (11.45°N and 41°E) its capital city of Samara [2]. Its climate has luminous average range temperatures from 27°C to 50°C [3]. As consequence of airing and air conditioning system is the serious issues of the afar region to be appropriate situations for living conditions and workers [4, 5]. Nowadays the afar region is energy sector relay on hydropower energy for the utility as well as basic living demands. Afar region is experiencing severe energy shortage and non-electrified locations, due to a number of problems such as high capital investment, low load factor, underprivileged voltage guideline and regular power supply disruptions. Access to energy provisions both profit generation events and the regional development program through civilizing education, dropping air effluence and guaranteeing atmosphere sustainability. The price to install and service the distribution of hydropower energy lines is significantly highly expensive and not cost effective in Afar region rural areas. In addition, there will be transmission losses to power supply consistency in rural grid [6, 7].

Furthermore, vast improvement of its efficiency from year to year shows that the photovoltaic PV energy can be an alternative primary energy source to replace the current operating system [8]. The goal of this research work is to assess the solar resource potential of Afar region in in compression with other regions and the whole country of Ethiopia. Additional objective is to provide a comprehensive overview of the solar energy capacity for pastoral community energy consumption, such as solar lighting, solar cooker, small DC applications in reasonable cost [9].

Figure 1. *Afar region map [17].*

2. Current Energy Scenario in Ethiopia

The major source of energy in Ethiopia is biomass, which financial statement for 91% of energy paid [10]. Petroleum supplies about 7% of whole prime energy and electricity used in only 2% of total energy use. The energy demand of Ethiopia is increasing rapidly due to the fast-developing nations on the continent. Ethiopia is gifted with numerous renewable energy resources such as hydropower (45 GW), geothermal (5 GW), wind (10 GW) and solar flux ranges from (4.5 to 7.5 kWh/m^2/day) [11]. In spite of Ethiopia have abundant green energy potential, the country is suffering energy deficiencies as it scraps to meet the growing energy demand, approximately 30% annually [12]. The development of Ethiopia's energy sectors derived from Growth and Transformation Strategy, which redesign the country into a middle-income state by 2025. The GTP I was reputed in 2010 and comprised a goal line of growing the Ethiopia energy capacity from 2 GW to 8 GW.

The energy sector of Ethiopia continues to be subject to more than 85% of hydropower energy to meet growing demand, which is becoming less reliable as droughts intensify. According to current Ethiopia energy scenarios, there are four sectors which determine the energy needs such as in agriculture, industry, service and transport sector for electrification [9-11]. Most important alternative investments conserve energy, improve environmental sustainability, improve energy equity and improve the country's development indicators as shown in table 1.

Table 1. *Energy demand from 2015 to 2037 in different sector.*

Years	AS/MW	IS/MW	SS/MW	TS /MW
2015	197	447	304	97
2020	1123	1007	381	319
2025	3342	2845	582	553
2030	3556	3994	950	879
2035	4756	4986	1498	1365
2037	5219	7002	2624	1564

AS: agriculture sector, IS: industry sector, SS: Service Sector, TS: transport sector

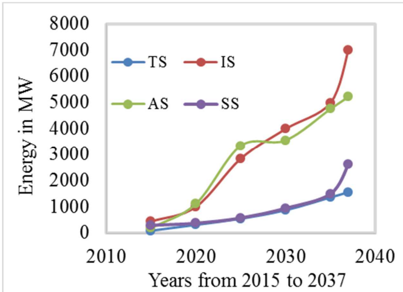

Figure 2. *Plot of Energy demand forecast of different energy sector vs energy in MW.*

The Ethiopian energy report predictable energy request in different sector from 2015 to 2037 by the Ethiopian Economic Plan [13, 14]. As different area energy needs as Agriculture Sector (197 to 5219MW) it increases 25.67% increase, Industrial Sector (447 to 7002MW) it increases 16.07%, service sector (304 to 2624) it increases 8.7% and transport sector (97 to 1564MW) it increases 16.4% in energy per time and power [15]. The Ethiopian Development and Transformation Proposal highlights the importance of energy efficiency and energy conservation as shown in figure 2.

3. Methods

In this research Solar shortwave radiation transfer model is implanted in each of small-scale meteorological numerical models (WRF, MM5, etc.). In this model, solar shortwave radiation reaching upper bound on earth-atmosphere system, scattering and absorption by the cloudless atmosphere (molecule in air, water vapor, aerosol, etc.). On solar radiation travel path and loss of solar shortwave radiation due to cloud reflection and absorption are calculated successively, thus the solar radiation power of unit area can be worked out. Based on integration for diverse regions and times, solar powers and solar energy reserves in different regions can be concluded. This provides conditions for statistics and assessment solar energy resource [16, 17]

4. Results and Discussion

4.1. Ethiopia Solar Energy Potential

According to various research reports of solar PV projects presents an extremely profitable opportunity for investors. The country's irradiation levels average around minimum range from 1858 Wh/m^2/month (in December) to 15,348 Wh/m^2/month, (in April) and at maximum range increase from lower peak 207,232Wh/m^2/month (in Fuberary) to highest peak 255,147Wh/m^2/month (in May) as shown in figure 3 (table 2). In addition, in mean value and St. Dev the variability of solar radiation approximately uniform throughout the year as shown in figure 3 [18]. This information provides Ethiopia has gotten attention for solar energy investment and for the development of utility-scale PV plants. Based on the standard meteorological assessment of solar energy resources annual total solar radiation in any region of the country range from 1400 kW·h/(m^2·a) to 1750 kW·h/(m^2·a). When we analyse annual total solar energy distribution in four different periods of time as (1980~2009, 1980~1990, 1991~1999, and 2000~2009). As Ethiopia topographies high in the north from 8°N to 14°N and low in the south, especially, annual total solar radiation exceeds 2100 kW·h/(m^2·a) in the central part of North Ethiopia as shown figure 4a in 1980~2009. In the second years interval as shown figure 4b in 1980~1990 total solar radiation distribution is similar as north from 8°N to 14°N but it is significantly different between the former period [19, 20].

Table 2. *Temporal monthly radiation in Ethiopia.*

Month	Min	Max	Mean	St. Dev
January	1930	221,940	136,288	16,161
Fuberary	2148	207,232	138,439	13212
March	3646	236,328	170,906	12,501
April	15,348	238,981	172,893	11,899
May	6961	255,147	176,442	14,233
June	3,286	250,390	167,735	14,906
July	4,026	257,094	175,074	14,788
August	11,533	249,714	178,741	12,792
September	6,624	239,322	174,338	12,143
October	2,376	224,323	153,691	13,549
November	1912	216,207	135,489	15,351
December	1858	219,516	130,485	16,523

In third period 1991~1999 GC solar radiation distribution is similar to 1980~1990 GC period. In fourth period 2000~2009 GC, solar radiation fell in Central Ethiopia and West Ethiopia as shown figure 4d. Low-radiation zone was more obvious in the southern parts of central west Ethiopia. In spite of the reduction in radiation quantity of the high - radiation zone, an area of such zone increased. In the southeast part, solar radiation of low-radiation zone increased, without obvious low-radiation zone.

The annual total solar energy distribution in four different periods of time shows that significantly higher solar radiation that the degree from 8°N in 14°N. Therefore, geographically Afar region is located 11.45°N and 41°E and Average Annual Total Solar Radiation recoded at 8°N to 14°N and at 35°E to 42°E in four different times. This indicates that afar region has potato solar radiation

Figure 5 illustrates average annual total Solar Radiation, distribution in northern Ethiopia at interval of 4°N to 14°N in four different years as shown table 3. As figure 5 shows that in four different -time interval years Solar Radiation, distribution increased in similar pattern [21].

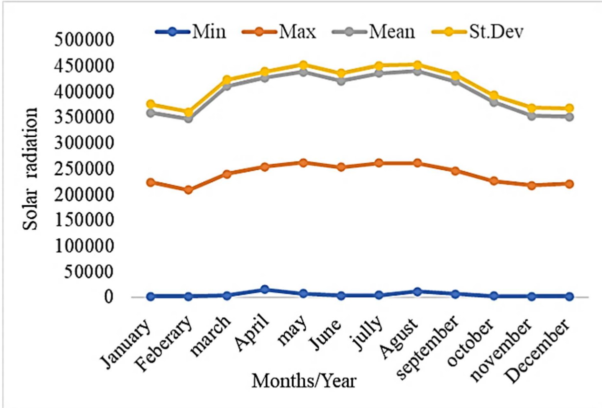

Figure 3. *Monthly global solar radiation of Ethiopia.*

Table 3. *Average Annual Total Solar Radiation, distribution kW·h/(m2·a)), (a) (1980~2009 GC) (b) 1980~1990 GC (c) 1990~1999 GC) (d) 2000~2009).*

Direction	a	b	c	d
4N	1500	1520	1500	1550
6N	1710	1720	1700	1690
8N	1830	1850	1800	1820
10N	2000	2010	2020	1970
14N	2130	2150	2160	2110

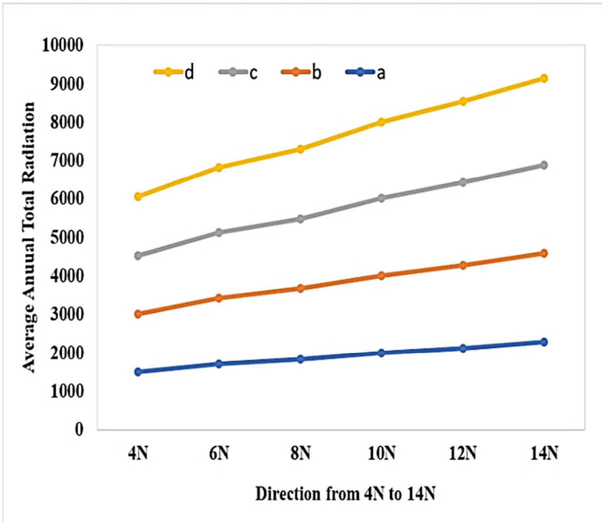

Figure 4. *Average Annual Total Solar Radiation, distribution kW·h/(m^2·a), in different degree of north direction.*

4.2. Afar Region Solar Energy Potential

Solar irradiation on the earth's surface is the fundamental energy for various biological, physical, and chemical processes. It is a renewable energy resource that has been used by humanity without age limit. Solar radiation data on the surface of the earth is significant for various applications in meteorology, agricultural sciences, engineering and in research in different fields of natural sciences as well as at the diversity of applications may include: solar heating system design, solar power generation. Ethiopia has plentiful solar energy resources. According to study solar energy potential on a regional basis, the yearly average radiation ranges from values as low in western Ethiopia in the areas in (Gambella regional, state) to values as high at northern Ethiopia around in (Tigray regional state and in Afar regional state) [3]. The solar and wind energy resource assessment (SWERA) reports show that, solar energy resource richest regions in Ethiopia are mainly centralized in the Afar State in the northeast, the desert region in Somali State in the southeast and some western and southern regions. Mid North region of Ethiopia is relatively weaker in solar energy resources. Average solar radiation power and average annual total solar energy of unit area are higher in Tigray (246.48 W/m^2), Amhara (240.34 W/m^2) and the Afar (239.9 W/m^2) respectively. For example, solar radiation power density in Tigray exceeds, solar radiation power density of Afar and Amhara regions

Table 4. *Solar Energy Resource in Different Regions of Ethiopia.*

Country /state	Area (1,000 km^2)	Av. S. flux (W/m^2)	T R P (TW)	Av. Aρ (MW·h/(m^2·a))	An. Anl TR (PW·h/a)
Afar	94.1	239.9	22.57	2.102	198
Amhara	155	240.34	37.26	2.105	326
Benshagul	49.5	232.52	11.5	2.037	101
Gambela	24.6	222.48	5.48	1.949	48
Oromiya	320	223.96	71.66	1.962	628
SNNP	109.9	226.65	24.91	1.986	218
Somali	300.3	217.19	65.21	1.903	571
Tigray	50.2	246.48	12.38	2.159	108
Ethiopia	1,104	227.42	250.98	1.992	2199

In comparison to other regions and total solar radiation, afar region cover third rank next to Tiger and Amara region. However, to consider total solar energy in different regions, it is necessary to consider areas of different regions. For this, Oromiya, Somali and Amhara are of advantage. In terms of average annual flux density Afar (2.102MW·h/(m^2·a)), Amhara (2.105MW·h/(m^2·a)), Tigray (2.159 MW·h/(m^2·a)) exceeds the average annual flux density of the whole country as shown in (Table 4). Solar flux in Different Regions of Ethiopia. It illustrates Solar flux in Afar region (239.9 W/m^2) per (1,000 km^2) which exceed other regions next to Tigray region (246.48 W/m^2) (50.2km^2).

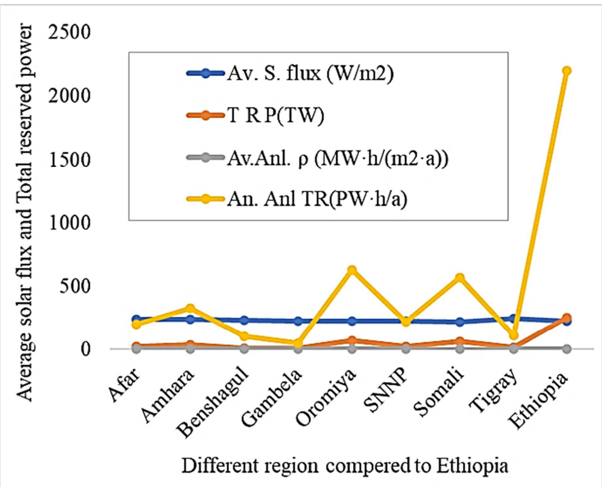

Figure 5. *Solar energy potential in different region in Ethiopia [17].*

5. Conclusion

The study indicates that the afar region being exceptional solar potential with significant AV. Solar flux of 239.9W/m2), AV. Annual. Density 2.102 MW·h/m^2·a, therefore the afar region is the prospective candidate for the development of PV power systems. Therefore, the PV system has the power to run an evaporative air conditioning system effectively. In order to save the energy bill and initial capital cost of this air conditioning system, the cooling load of the considered building has been estimated. The solar energy alternative has significant benefit to pastoral community and provide as Afar, more secure and healthier environment for women and children. The PV systems have been the main pillar of solar energy in Afar region so far, it is expected that these types of systems could bring more immediate solutions for inhabitants without access to common energy source in Afar region hydroelectric energy. Therefore, Solar energy can be the best alternative for daily life consumption, such as solar lighting, for solar cooker, small DC applications and for air conditioning applications. This shows, a great potential of Solar (PV) power system in future as one of renewable energy technology alternatives for hydroelectric power generation.

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