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A feasibility analysis of PV-based off-grid rural electrification for a pastoral settlement in Ethiopia

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Abstract

Ethiopia's electric grid relies mostly on hydropower for electricity generation. Compared to metropolitan regions, rural areas have only 5% access to power, and 83% of remote areas rely on traditional biomass energy for lighting and cooking. This paper studies a feasibility analysis, design, and simulation of an off-grid solar PV system for electrifying a pastoral village in Borena. It also discusses the national energy policy and a strategic plan. Using solar radiation base data from the National Aeronautics and Space Administration, a case study is performed at Moyale, Yabelo, and Dire, which have 454 households, 367 households, and 379 households, respectively. Through the HOMER software, the optimization determines the inverter, battery size and number, and solar array's capacity. The daily energy usage and peak power demand in the pastoral communities of Moyale, Yabelo, and Dire were 498.102kWh/day, 447.114Kwh/day, and 454.02kWh/day, or 36.89kW, 35.41kW, and 35.68 kW, respectively. Due to the country's subsidizing of all clean energy costs, off-grid solar PV systems are more economically feasible than diesel generators, which have a level cost of electricity of 0.4 US$/kWh. National energy strategic plans and policies ultimately support the full involvement of off-grid solar PV electrification at remote sites.

Keywords:
HOMER, Photovoltaic, Solar energy, Rural electrification, Renewable Energy, National Aeronautics Space Administration

1. Introduction

Energy links to all economic sectors and also functions as a sector on its own, driving socioeconomic growth in areas like eradicating poverty and enhancing quality of life [27]. By enhancing education, lowering indoor air pollution, and increasing environmental sustainability, modern energy access promotes both income-generating activities and the country's development agenda[28]. More than 700 million Africans lack access to electricity[29] and In Sub-Saharan region, more than 60% live in rural area, and more 80% have no access to modern energy sources[30][31]. Ethiopia's total installed capacity of electric generation is now around 4.5 GW (2019), primarily generated by hydro (90%) and wind energy (7.6%)[3]. The country is one of the Sub-Saharan East African countries with abundant solar energy resources[2] and the country's average annual irradiance is estimated to be around 5.2 kWh/m2/day [7]. According to [9], about 14 MW of solar PV have been used for telecom service, lighting, powering water pumps in rural areas, and for water heating in major cities.[11]. Currently, Ethiopia has launched a 100 MW solar PV project, and Energy Green Power (EGP) for one's project is located near Metehara, while the remaining sites, located near

Mekelle and Humera, were not awarded [10]. In addition, the country intends to build 125 MW solar power plants, which will help scale solar generation in the Somali region and solar dicheto phase I in the Afar region. Per capital energy consumption in all African countries particularly Ethiopia, which is 500 kWh [4]. Therefore, to solve this problem, the government of Ethiopia gave strategies priorities in the energy sector, including universal electrification access, energy efficiency improvement, developing decentralized off-grid power generators, and exporting electricity to neighboring countries[5],[6]. However, until recently, countries' use of PV for meeting off-grid power needs was confined to projects funded by donors that use PV-based technology or distance education radios and vaccine fridges in remote rural areas [12] [5]. Close to 60 % of the land area in Ethiopia is pastoral. Pastoral communities are some of the most vulnerable communities in Ethiopia. Pastoral and agro-pastoral societies in the arid and semi-arid parts of Ethiopia are enduring a downward spiral of increasing poverty, food insecurity, and escalating instability. This problem is ultimately caused by factors that limit the traditional pattern of resource use [1]. Such factors include human population growth, degradation, and fragmentation of traditional grazing areas. In most developing countries, electrifying remote areas by extending the main grid is a major challenge due to economic and technical reasons. There is a way out of the problem of supplying electricity to remote areas. The reason to electrify the remote area will have a significant impact on addressing the problems related to deforestation, global warming, the ecosystem effect, and introducing sustainable green environmental development. The remote area requires low electricity consumption; the government should prioritize an off-grid solar solution as an immediate solution for an electrical solution for un electrified rural households far from the electric grid and not covered by the denitrification program in the short term[13]. The feasibility of off-grid solar PV system in sub-Saharan Africa is analyzing focusing in terms of affordability. [32] presents expenditure on glass-coverage kerosene lamps(taking into consideration the average purchase cost of the device, the operating cost, the average life time of the product and the number of unit of the device per household) is estimated to be US $ 40-90 per household per year in countries in sub-saharan-Africa. An average annual expenditure of US $ 57 per household (US $ 4.75 per month), or 2.6 % of monthly household income. Household expenditure on kerosene is roughly equal to the amount a household would have to power to finance a PV system to under annuity conditions. Using the estimate of the LCOE for the solar PV system of $0.83 per kWh, the annual cost of a solar PV system would be US $51 (US $4.2 per month), or 2.3 % of household income. This can be compared with house hold expenditure on kerosene lamps, which are the most common alternative lighting sources, followed by dry cell batteries and candles[33].
This study, which examined the feasibility of an off-grid solar solution-based system to supply power to remote pastoral communities, was conducted in the Oromia region of south-east Ethiopia, specifically in the pastoral communities of Moyale, Dire, and Yabelo. The study's findings are presented in this paper, along with a national energy strategic plan and policy for the best configuration for the three sites.

2. Methodology

To assess the relevance of the site, relevant data collection has been undertaken from two main sources:

- Site visits and interviews: to assess the electric demand, a site visit and an informal interview of local people and government officials have been done both in person and by phone.
- Internet (website): satellite-based solar radiation data has been taken from NASA data-base websites.

2.1. Solar radiation potential

Since Ethiopia is located near the equator, its solar resources obviously have significant potential. The annual average daily radiation reaching the ground in Ethiopia is estimated to be 5.2 kWh/m2/day, ranging from a low of 4.5 kWh/m2/day in July to a maximum value of 6.5 kWh/m2/day in February and March, respectively. The solar radiation potential for different regions throughout the country has been indicated in Figure 1, which ranges from 5.3 kWh/m2 to 7.5 kWh/m2. The solar resources are relatively lower in the most populous northern, central, and western highlands of the country, while the rift valley region and western and eastern lowlands of the country receive the highest annual average irradiance (above 6 kWh/m2/day)[9].This

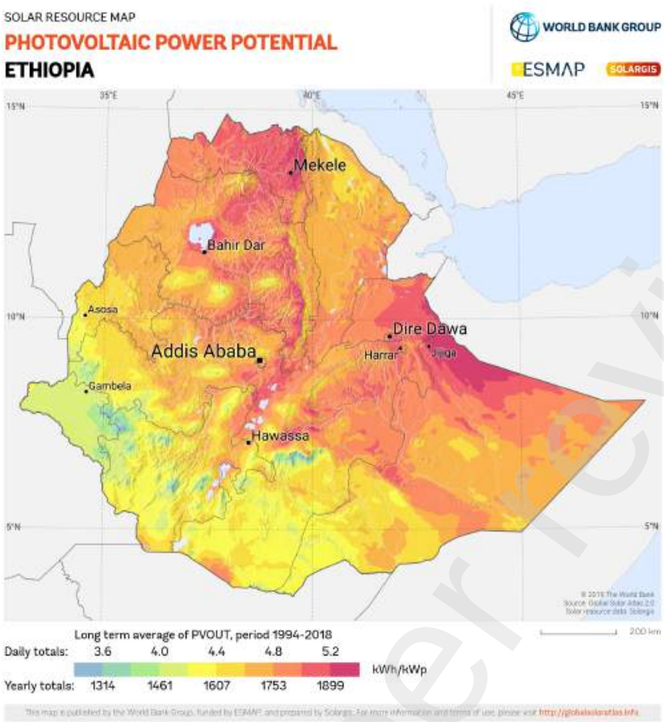

Fig. 1: Solar radiation potential in different regions of Ethiopia

study also confirms the solar radiation potential in the Oromia region's Yabelo, Moyale, and Dire of Borena Zones, which have the highest potential value of 6.23876 kWh/m2/day in Ethiopia, following the Somali region's 7.5 kWh/m2/day[20]. The best way to know the amount of global solar radiation is to install pyranometers or PV sensors at as many locations as possible in a given region and follow their day-to-day recording [34]. In the case of Ethiopia, since only sunshine duration is measured by the National Meteorological Statics Agency (NMSA) and the National Aeronautics and Space Administration (NASA).

2.2. *Ethiopian Electrification Rate*

[21]It's one of the few countries in sub-Saharan Africa, if not the world, that generates more than 90 % of its electricity from renewable energy resources. Economically, Ethiopia is one of the world's fastest-growing nations, bringing an enormous increase in energy demand to growth rates of 10% to 14% per year until 2037. The existing total electricity generation capacity installed in Ethiopia is about 42,444.67 MW.[22] of which hydropower takes the lion's share. However, there are significant disparities in access to electricity in urban and rural areas[23][24].This indicates that the majority of the country's population (greater than 75 %) does not have access to electricity. However, trends show that the government of Ethiopia's electrification rate increased from 5% in 2000 to 45% in 2016, resulting in the flourishing off-grid access in rural areas depicted in Figure 2[25].Today just 27% of the citizen have electricity access[35]. To expand the 27% and connect more communities to modern energy, the government is extending the main grid and increasing the number of off-grid and mini-grid systems in the country. The majority of current PV electricity production is consumed in the telecommunications industry. Also, other uses of existing solar power include health care centers, educational facility lighting, and village well lamps. The government is planning to connect over 150,000 households to electricity through a PV system. The Ethiopian government is planning to install over 500 MW of solar capacity by 2020[36].

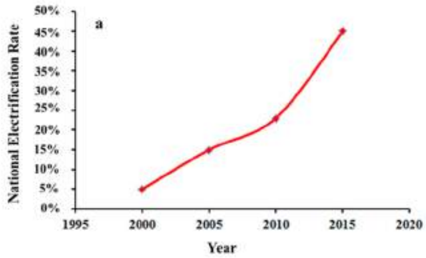

Fig. 2: National Electrification rate

2.3. Description of the Study Area

The study has been conducted at three sites in south-east Ethiopia: Moyale, Yabelo, and Dire are in the Borena zone of the Oromia region.

2.3.1. Moyale

Moyale is one of the woredas in the Oromia regional state. The geographical data of latitude and longitude for Moyale and the most sensitive household site are shown in Table 1 and Figure 3. It is located 770 kilometers south of Ethiopia's capital, Addis Abeba. The wereda has an area of 14,810 km2, and it's divided into 18 associations, two of which are located in Moyale town. The Wereda borders Ethiopian Somalia a regional state, and Kenya. The longer border it shares with Kenya. The aggro-ecology of the wereda is characterized by a rid to semi-rid type environment. It has a biomedical rainfall pattern in which the main rainfall, which accounts for 65% of the annual total, is received in April through June and the remaining 35% in October through November. The long dry season runs from December to March. Rainfall is low and erratic. The range land is covered with various aspects of acacia, shrubs, and Savannah grasses. A majority of the inhabitants of the wereda are pastoral and aggro pastoral. Moyale is one of the most drought-prone weredas in the Oromia regional state. The wereda suffer from the impacts of frequent drought. The trans-African highway cuts through the middle of Kenya. Moyale is an important trade center for imported manufactured goods from Kenya. It's also a major market outlet for cattle from the Borena plateau. The main sources of water for the wereda are motorized wells, traditional wells, porids, and cisterns. Human health services in the wereda are inadequate. Poorly trained human resources, a lack of facilities, and vital health equipment to provide efficient service were the major factors that affected the effectiveness of the service. The nature of the education coverage in the wereda is poor, and the condition of these schools is also a serious concern. The veterinary service coverage of the wereda is not adequate. The community is forced to walk more than 40 kilometers to seek livestock health services[1].

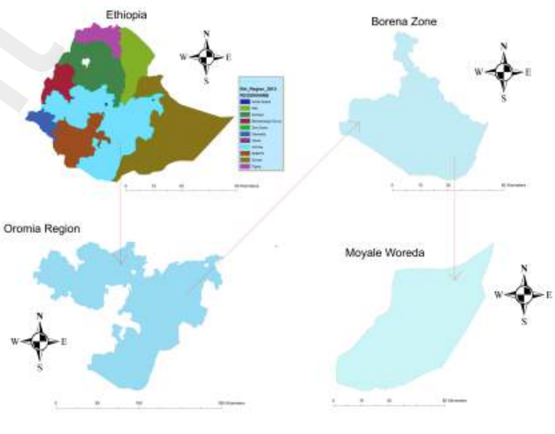

Fig. 3: ArcGIS Map of Moyale Wereda

2.3.2. Yabelo

Yabelo is one of the weredas in the Borena zone of Oromia. The geographical data (latitude and longitude) of Yabelo and the selected most sensitive household site are shown in Table 1 and Figure 4. It is located 570 kilometers from Ethiopia's capital, Addis Abeba. It's the second-largest wereda in the zone, with a total land mass of 5523 km2.There are 20% pastoral associations in the wereda. A semi-arid environment characterizes the agro-ecology of the wereda. It has a bimodal rainfall pattern, with 65% of the rainfall received from April to June and the other 35% from September to Novembe. The wereda is endowed with Savannah-type vegetation suitable mainly for cattle. Land degradation, including soil erosion and bush encroachment, is severe in the wereda. The human population of this wereda is 75,350, with a household number of 15,061. A substantial number of the wereda population about 25% lives in towns, of which 90–95% live in Yabelo town. Pastorals are the dominant form of livelihood pursued by rural people. Similar to other weredas in Borena Zone, Yabelo is a drought-prone wereda. It's vulnerable to environmental shocks. Since 1991, the wereda has suffered more than three droughts that have led to the loss of livelihood for many households[1].

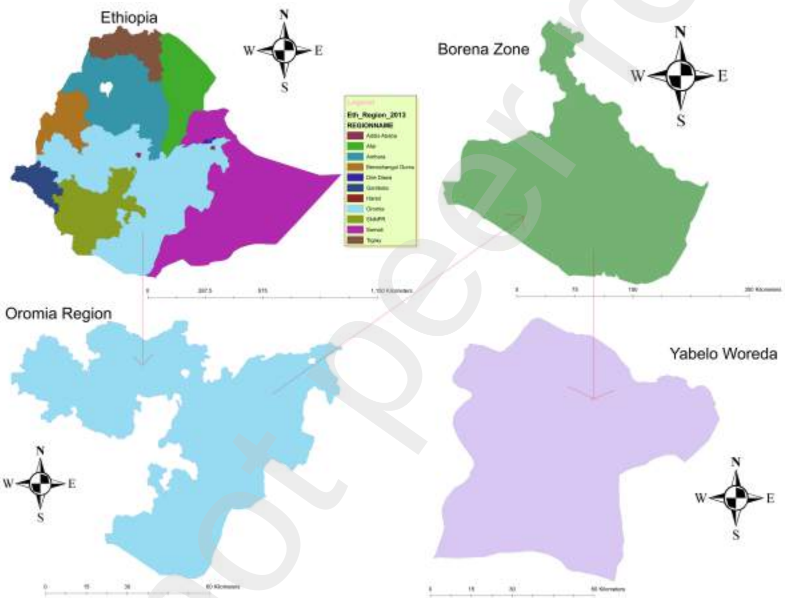

Fig. 4: ArcGIS Map of Yabelo Wereda

2.3.3. Dire

Dire is one of the weredas in the Borena zone of the regional state of Oromia, which is shown in Figure 5. The geographical data of latitude and longitude for Dire and the selected most sensitive household site are shown in Table 1. It is located 670 kilometers from Ethiopia's capital, Addis Ababa.It's the largest wereda in the zone, with an area of 12,722 km2. 31% pastoral association in the wereda. An arid and semi-arid environment characterizes the aggro-ecology of the wereda. It has a bimodal rainfall pattern, in which the main rainfall is received from April to June and the other from September to November. The wereda is endowed with Savannah-type vegetation suitable mainly for cattle. The human population of the wereda is 112,262 (56,351 males and 55,921 females), with a household number of 22,452. Only 2% of the population lives in urban areas. Dire is the center of the Borena pastoral production. system, where the majority of the tulla wells, which are the focal point of the Borena system, are located.[1].

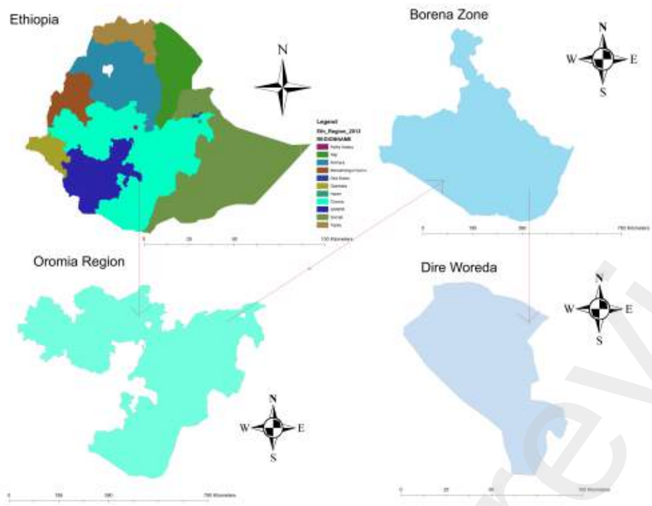

Fig. 5: ArcGIS Map of Dire Wereda

Table 1: A Summary of the geographical data for the three sites of households

Name of Cities	Longitude	Latitude	Altitude	Number of Households
Moyale	39.0260	3.5383	1090	454
Yabelo	38.1636	4.9242	1857	367
Dire	37.0389	4.887	2400	379

2.4. *Energy Demand Profile*

Electrical load assessment in the design of a solar photovoltaic renewable power system is the basic step to determine the size of system components. The electric consumption of the community was related to socio-economic, religious, cultural, geographical, demographic, and technological situations. Energy demand at the sites is for lighting, fans, health and veterinary clinics, water pumps, schools, and telecommunication. The load profile for each pasture was assessed by a field survey. The information for electrified villages and towns is obtained by the Ethiopian Electric Power Corporation. The survey at selected sites was conducted to determine the number of households. Peak load occurs for the three sites between 7:00PM and 6:00AM, due to household lighting, vaccine refrigerators in health and veterinary clinics, and telecommunications which is shown in Figure 6. A summary of the load profile after the variability has been applied to the average load for all three sites is shown in Table 2. The power demand has a low load factor, as shown in Table 2, and is characterized by maximum energy demand during the day and peak demand during the evening. This is due to the fact that electricity is primarily used for lighting applications and the lack of commercial and industrial demand at the selected sites.

Table 2: Summary of the load profile

Name of Cities	Households	Average Daily Demand (kWh/day)	Average Power (kW)	Peak Power (kW)	Load Factor
Moyale	454	498.102	36.89	101.77	0.36
Yabelo	367	447.114	35.41	96.73	0.37
Dire	379	454.02	35.68	97.44	0.37

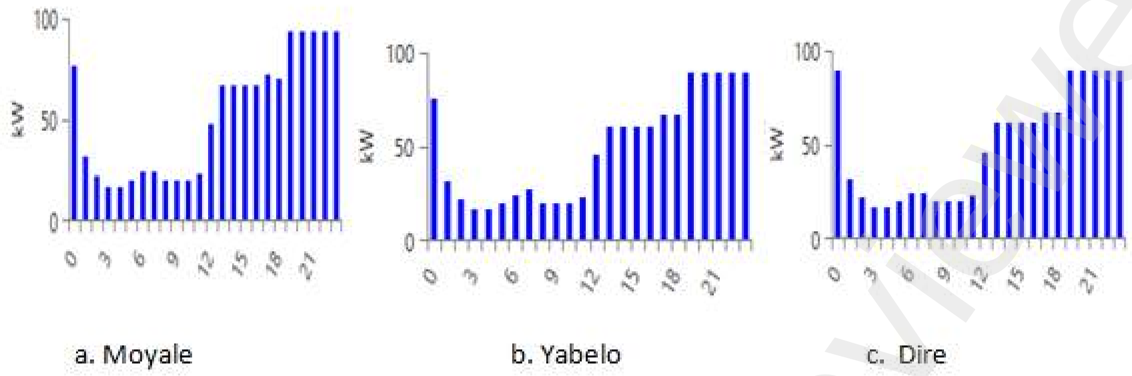

Fig. 6: Energy Demand Profile for three sites

Table 3: Detail of the load profile

Load Type	Quantity	Power(watt)	hr/day	Whr/day	kWhr/day
Domestic Load					
Celing Fans	1	14	12	168	0.168
Lcd Tv	1	60	4	240	0.24
Lamp	2	15	6	180	0.18
Health Clinic					
Vaccine Refrigerator	1	320	24	7680	7.680
Laboratory Mictroscope	1	20	10	200	0.2
Lamp	3	15	10	450	0.45
Lcd Tv	1	60	6	360	0.36
Fan	3	14	8	336	0.336
Veterinary Clinics					
Vaccine Refrigerator	1	350	24	8400	8.4
Laboratory Microscope	1	80	10	800	0.8
Lamp	2	15	10	300	0.3
Fan	2	14	8	224	0.224
Lcd Tv	1	60	6	360	0.36
Differable Load					
Water pump for irrigation	1	1500	2	3000	3.00
Water pump for drink	1	1500	2	3000	3.00
School					
Lamp	6	15	12	1080	1.08
Fan	6	15	8	720	0.72
Tv or Radio	1	60	4	240	0.24
Telecommunication	1	8500	24	204000	204.000

2.5. *Solar Energy Sources*

The most common data on solar energy resources is the average daily sunshine hours, which is collected at many of the meteorological stations throughout the countries. The available sunshine hour data from NASA was used to estimate the solar energy resource at the sites. Figure 7 shows that seven years' average daily sunshine hours occur in each month for the sites under study.

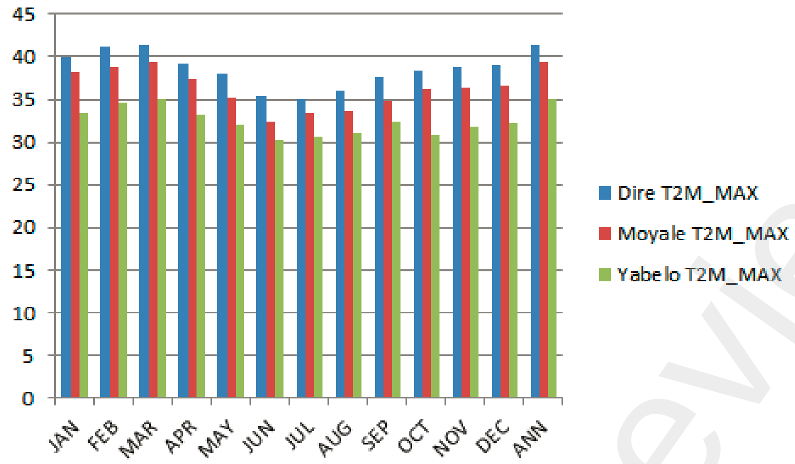

Fig. 7: Maximum-Temperature

2.6. Analytical method of estimating solar radiation

The available sunshine hours data have been converted to monthly average daily global solar radiation, H_G, from monthly average daily extraterrestrial radiation, H_O, using the Angestrom-Page estimation model given by equation [26].

$$H_o = \left(a + b\frac{n}{N}\right) \tag{1}$$

- a- is Angestrom correlation parameters
- b- is Angestrom correlation parameters
- n- is monthly average daily hours of sunshine from sunshine records
- N- is monthly average of maximum possible hours of sunshine
- H_G - is monthly average daily global radiation
- H_O - is monthly average daily extraterrestrial solar radiation

H_O is determine based on the solar constant average day of the month and declination angle. The value for N, a, and b were determined by using equation 2, equation 3,and equation 4.

$$N = \frac{2}{15} arccose\,(-tan\phi tan\sigma) \tag{2}$$

$$-0.309 + 0.539cos\phi - 0.0693E_o + 0.290\left(\frac{n}{N}\right) \tag{3}$$

$$1.527 - 1.027cos\phi + 0.0926E_o - 0.359\left(\frac{n}{N}\right) \tag{4}$$

Where:-

- E_O - is Altitude of site in kilometers
- σ - is declination angle for the average day in the month
- a- is Hellman coefficient
- ϕ - is latitude of the site

2.7. Results of the Solar Radiation Estimation Model

A study of solar energy resources was conducted by comparing global solar radiation measurements to corresponding calculated values using Angstrom's relations [14]. The regression coefficient was obtained, and the correlation equation was determined to predict the global solar radiation. The results show that Angstrom's relationship is valid for the location under study[15]. The sunshine hour used records from 21 meteorological stations in the country to illustrate the general availability of the resources[16]. The annual average daily solar radiation is estimated to be 4.25 kwh/m2 to 6.25 kwh/m2 which is shown in Figure 8. Solar radiation maps of the country produced based on satellite data also indicate that the country has significant solar radiation potential[17]. The Angstrom estimation model was used to find the monthly average daily global solar radiation by using inputs such as latitude, altitude, the average day in the month, the declination angle for the day, and the sunshine hour data. Input data for each month was employed in equations 1–4 to calculate the parameters N, a, b, H_O, and H_G. The monthly clearness index, defined as the ratio of solar radiation, has been calculated for each site as well. The results of the estimation model indicate very close values for the solar radiation at the three sites. This is due to the fact that the sites are located

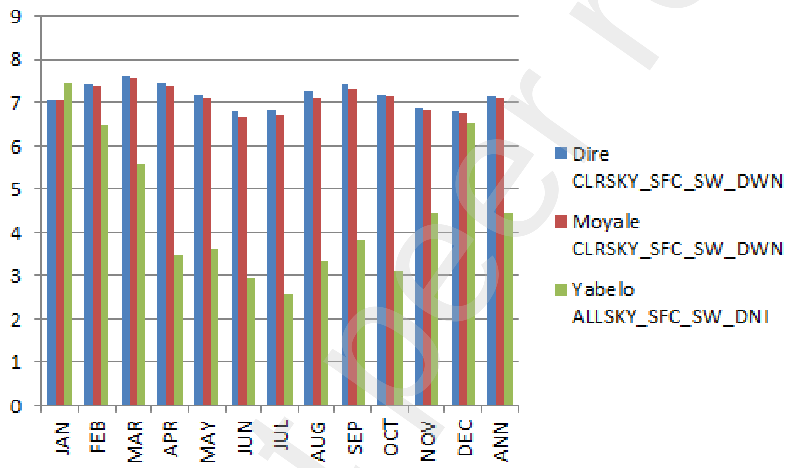

Fig. 8: Solar Radiation calculated for each month

close to each other and there is only a slight variation in the altitude of the sites. This is due to the fact that the sites are located close to each other and there is only a slight variation in the altitude of the sites. The average daily global solar radiation varies from around 5.0 kW/m2/day in the rainy month of July to just above 7.0 kW/m2/day in the dry months. Similarly, the cleaners' index varies from the lowest value of 0.5 in July to the highest value of 0.67 in most of the other months of the year. Thus, according to Kudish and Ianetz, the three sites can be classified as having a clear sky for most times of the year and partially cloudy during the rainy season.

2.8. Results from the solar system analysis and optimization using HOMER

HOMER software models were created for conducting the analysis based on the load profile discussed in Subsection 4, and appropriate sizes and numbers of equipment to be considered for each site were selected.The results discussed in Subsection 7 provided the necessary solar energy input. The figure 8 below depicts the equipment representation of the solar system for Moyale, Yabelo, and Dire. The equipment configuration of the three sites is similar, with the only difference being their capacity with deferrable loads. The results of the optimization in HOMER for the three sites are discussed in the subsequent sections. A description is provided below each table that shows a listing of feasible system options. Among the options, the following tables show the system architecture for the least-cost system, which is a 100 percent renewable energy system, and for each case, a Figure 9 showing the electricity production contribution of each technology on a monthly basis.

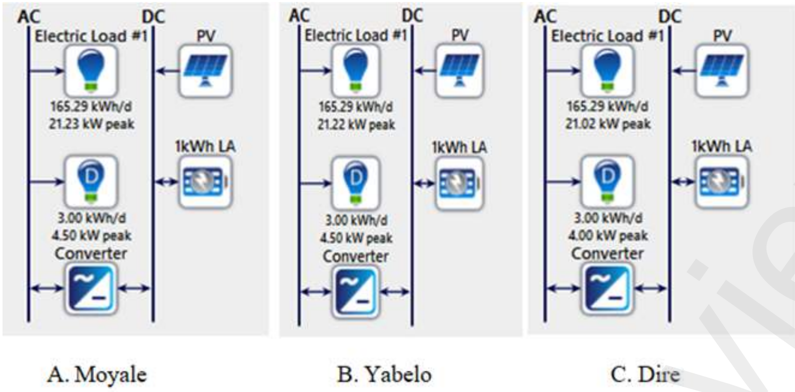

Fig. 9: Equipment representation of three sites:(A) Moyale,(B) Yabelo,(C) Dire

Table 4: Cost Summary of Moyale

Components	**Capital ($)**	**Replacement($)**	**Operational and Maintenance cost ($)**	**Salvage($)**	**Total Cost($)**
Generic 1Kwh Lead Acid	158,400.00	140,160.46	68,257.29	18,777.59	348,040.16
Generic Flat Plate Pv	323,304.15	0.00	16,718,08	0.000	340,022.23
System Converter	18,764.17	7,961.15	0.00	1,498.37	25,226.95
System	500,468.32	148,121.60	84,975.37	20,275.96	713,289.34

2.8.1. Moyale

The findings are summarized by total cost in Table 4 and average monthly electric production in Figure 10. The Moyele site is the highest-cost for the solar PV option. This is primarily because of the lead acid solar batteries of the site, the average daily load demand, the higher price per installed capacity, and the higher capital cost when compared to the Yabelo and Dire sites. Figure 10 shows the average monthly electricity production by solar PV. As shown in Figure 10, solar PV provides the majority of the electric production in the January, February, March, and December months. During the sunny months, the maximum electric production is 20 MWh. On the contrary, electric production in June and July is lower, at 10.5 MWh and 13 MWh, respectively, because most of these months are rainy during the summer.

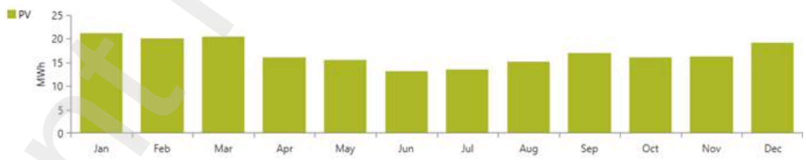

Fig. 10: Moyale Average Monthly Electricity Production

Table 4 shows the cost summary of system components such as generic 1 kWh lead acid batteries, generic flat plate PV, and system converter. Generally, the cost summary for the Moyale site of the system is expressed in terms of capital cost, replacement cost, and operation and maintenance cost, Salvage and total cost are 500.468 USD, 148.121.60 USD, 84.975.37 USD, 20,275.96 USD, and 713.289.34 USD, respectively. This is because Moyale sites have a higher demand for households than Yabelo and Dire sites.

2.8.2. Yabelo Site

Similarly, the optimization results for the Yabelo site are shown in Table 5. Compared to Moyale sites, the Yabelo site is the most cost-effective option for this site. This is because a solar source is essential for this site, primarily. Although the initial capital costs are lower at the Yabelo site, production is higher than at the Moyale site. Figure 11 shows the average monthly electricity production by solar PV. Most of

Fig. 11: Yabelo's average monthly electricity production

the energy production is produced in January, March, and December, which is 23 MWh during the sunny season, and the lowest energy production takes place in June and July, which is 16 MWh most of the time during these months, which are the rainy summer season in Ethiopia. In Table 5, summarize the cost of

Table 5: Cost Summary of Yabelo

Components	Capital ($)	Replacement($)	Operational and Maintenance cost ($)	Salvage($)	Total Cost($)
Generic 1Kwh Lead Acid	101,100.00	152,983.75	43,565.73	1,810.61	295,838.87
Generic Flat Plate Pv	338,000.00	0.000	17,478.00	0.00	355,478.00
System Converter	8,548.71	3,626.99	0.000	682.64	11,493.06
System	447,648.71	156,610.74	61,043.73	2,493.25	662,809.94

system components such as generic 1 kWh lead acid batteries, generic flat PV systems, system converters, and systems in terms of capital cost, replacement cost, operation and maintenance cost, and total cost. In the end, the system of capital cost, replacement cost, operation and maintenance cost, salvage, and total cost for the Yabelo site are 447.648.71$, 156,610.74$, 61,043.73$, 2,493.25$, and 629,809.94$, respectively.

2.8.3. Dire Site

When the Dire site's results are compared to those of the Moyale and Yabelo sites, the solar PV system is the most cost-effective option for the Dire site. This is due to lower capital costs, which are shown in Table 6. The maximum electricity production at this site is higher compared to Moyale sites and similar to that at Yabelo sites. Figure 12 shows the average monthly electricity production by solar PV. From Figure 11, most electrical energy production takes place in December, January, and March months, which is 23 MWh, and

Fig. 12: Dire Average Monthly Electricity Production

the lowest electrical energy production is in June and July months, which is about 16 MWh, and most of these months are rainy months during summer in Ethiopia. Table 6 summarizes the system component costs, such as the generic 1 kW lead acid battery, generic flat plate PV, system converter, and system. Generally, the system cost summary of Dire Site in terms of capital cost, replacement cost, operation and maintenance cost, salvage, and total cost is 451,209.69$, 159,096.24$,62,853.59$, 5,929.17$, and 667,230.34$ respectively.

Table 6: Cost Summary of Dire

Components	Capital ($)	Replacement($)	Operational and Maintenance cost ($)	Salvage($)	Total Cost($)
Generic 1Kwh Lead Acid	105,300.000	155,740.37	45,375.58	5,297.56	301,118.38
Generic Flat Plate Pv	338,000.00	0.000	17,478.00	0.000	355,478.00
System Converter	7,909.69	3,355.88	0.00	631.61	10,633.96
System	451,209.69	159,096.24	62,853.59	5,929.17	667,230.34

2.9. Summary of the Results

The analysis of the three locations, Moyale, Yabelo, and Dire, can be summarized in terms of feasibility and the National Energy Strategic Plan and Policy. In Sub-Saharan Africa, the viability of off-grid solar PV is typically evaluated in light of five key factors: affordability, cost-effectiveness, financing, environmental influence, and poverty alleviation.

Table 7: Summary of Optimization Results for the Three Sites

	Name of Sites		
Parametes	**Moyale**	**Yabelo**	**Dire**
PV(kW)	129	135	135
Battery(1kWhLA)	528	337	351
Converter(kW)	62.5	28.5	26.4
NPC($)	713.289	662.810	667.23
COE($)	0.899	0.835	0.841
Operation Cost($/yr)	16.463	16.644	16.710
Initial Capital ($)	500.468	447.649	451.210
Renewable fraction (%)	100	100	100
PV Captial Cost($)	323.304	338.00	338.00

2.9.1. Feasibility

In terms of cost-effective feasibility, the comparison is determined by the levelized cost per kWh of energy (LCOE) between solar PV and small diesel generation[38]. According to Table 7, the LCOE of the chosen sites is US$0.899 per kWh, US$0.835 per kWh, and US$0.841 per kWh for Moyale, Yabelo, and Dire, respectively, with the projected LCOE of a solar PV system being US$0.83 per kWh at a 10% discount rate. In Africa, these selected sites have a very high cost per unit of electric generation compared to the conventional grid tariff rates, which are US0.08$ perkWh and US$0.08perkWh. It's not necessary to compare a solar PV system with a conventional grid because the conventional grid does not reflect the true cost of power generation. Despite the limitations mentioned above, most sub-Saharan African countries use small to medium diesel generators as a benchmark for comparison and use them for household and enterprise needs[39]. However, the diesel generators' LCOE is estimated to be US$0.42perKwh[40]. Based on the benchmarks, the LCOE of solar PV is higher than that of the diesel generator, and the LCOE differences between solar PV and the diesel generator are US$0.469perkWh, US$0.415perkWh, and US$0.42perkWh for the Moyale, Yabelo, and Dire sites, respectively. However, most of the time the diesel generator is used for water pumping, milling, irrigation, or any other income-generating activities; as a result, the running cost of the diesel generator is higher than solar PV for lighting, radio, and TV[41]. Consumers must be able to repay the credit while also covering the costs of operation and maintenance, which are the main reasons why the rural poor cannot afford solar PV systems even with the most favorable credit schemes and subsidies[42]. Regarding subsidies, the government of Ethiopia gives high priority to the solar PV Through government initiatives, the Ethiopian Electric Utility (EEU) selects mini-grid sites and places bids for private companies

to contest. This bid can be an "MST" (minimum subsidy tender), through which the company is responsible for handling the whole process under government supervision[50].
In terms of affordability, The estimated LCOE for a solar PV system in comparison to household expenditure on kerosene lamps, the most common alternative lighting source, The estimate of the LCOE for the solar PV system is 0.83 kWh; the annual cost of the solar PV system would be US$51(US$4.2per month), or 2.3% of household income[43][45]. Table 7 shows that the LCOE for the selected sites is US0.899$perkWh, US$0.835perkWh, and US$0.841perkWh for Moyale, Yabelo, and Dire, respectively. Solar systems at selected sites cost US$ 52 per year, US$ 51 per year, and US$ 52 per year, respectively, and US$ 4.3 per month, US$ 4.2 per month, and US$ 4.3 per month for Moyale, Yabelo, and Dire. Expenditure on glass-covered kerosene lamps (taking into consideration the average purchase cost, the average lifetime of the product, and the number of units of the device per household) is estimated to be US$40-98per household per year in different sub-Saharan African countries[46]. In the end, the average annual and month cost of solar energy at selected sites is within the range of the average annual and month expenditure of kerosene, which are US$52peryear,US$51peryear, and US$52peryear and US$4.3permonth,US$4.2permonth,and US$4.3permonth for Moyale, Yabelo, and Dire, respectively. Therefore, the household expenditure on kerosene is roughly equal to the amount of money a household would have to pay to finance a PV system under annuity and monthly conditions[47].
In terms of financing, the end users should finance a solar PV system from their current income and savings, paying not only the initial investment cost but also the operation and maintenance costs occurring throughout the lifetime of the system. The financing cost of a solar PV system is too high for most rural households, so solar will be automatically excluded from the lighting options[48]. According to the National Energy Policy[54], to strengthen energy sector finance, provide adequate funding, and seek funds for energy technology development, promote energy resources to financiers and investors, and establish an "energy fund" by instituting mechanisms such as a green tax to promote sustainable energy sector development.
In terms of the environment, solar PV technology is often promoted in sub-Saharan Africa for health and global environmental reasons. Burning kerosene indoors for lighting emits fine particles, carbon monoxide, nitric oxide, and sulfur dioxide, which increase the risk of respiratory illness and long-term cancer[49][53]. The household use of cooking, kerosene, and candles for lighting increases greenhouse gas emissions. Most people, particularly in the pastoral community in the selected site of Ethiopia, are forced to use kerosene for lighting, forest wood, and charcoal for cooking. Deforestation exists as a result of this, and it emits carbon dioxide into the environment. However, by injecting 100% renewable energy into these selected sites, solar PV can pinpoint the source of the problem.
The expectation that solar PV technology will reduce poverty has been one of the main forces behind efforts to spread solar PV in sub-Saharan Africa in terms of problem priority and poverty alleviation[51]. There are certain social benefits from lighting, TV, radio, and the powering of telecommunication devices by a solar PV system[52]. Ethiopian government initiatives will improve people's living standards and connect the pastoral community to the rest of the nation and the world by providing electric access for lighting, health centers, veterinary centers, telecommunications, and water pumps. The majority of these people lead nomadic lives and are involved in cattle production, allowing them to compete in the cattle market after gathering market information.

2.9.2. National Energy Strategic Plan and Policy

According to the national energy strategic plan of [50] the government, the "Growth and Transformations Plan (GTPII)" was released in 2015, with the goal of increasing GDP by 11% to 15% per year from 2015 to 2020. This plan aims to increase total capacity from 4206 MW to 14561 MW, with hydropower contributing 77%, wind and geothermal contributing 8%, solar contributing 2%, biomass contributing 3%, and the remaining sugarcane bagasse contributing 14%. The Ministry of Water, Irrigation, and Electricity (MoWIE) has priorities in the energy sector to boost national electricity access. This strategic priority includes energy efficiency improvements, decentralization of off-grid solar generation to rural areas, and exporting energy to neighboring countries. With these strategies, they aim to attain universal electrification access by 2025, whereby 35% of the population will have power access by 2025 through off-grid solar power electrification[51]. As a result, the government has been working on strategies to bring electricity to rural areas in order to meet the 2025 goal of universal access. There are two main strategies in place through which off-grid solar projects are implemented in rural areas:

- Through government initiatives, the Ethiopian Electric Utility (EEU) selects mini-grid sites and places bids for private companies to contest. This bid can be an "MST" (minimum subsidy tender), through which the company is responsible for handling the whole process under government supervision. In many other cases, the entire process is dealt with by EEU as Engineering, Procurement, and Construction[52].

- Strategy: Through private company initiatives, they get loans from financial entities and import solar power products. The private companies work as retailers and sell products to the end users, or they work as investors who bring solar home system kits and install them. As a result, these companies receive payments from the customers through what is commonly known as "pay-as-you-go"[51].

In the end, the Ethiopian National Energy Policy[54] supports ensuring the availability, accessibility, affordability, safety, and reliability of energy services to support accelerated and sustainable social and economic development and transformation of the country. In terms of the national energy policy, solar off-grid electrification can be achieved:

- Improving the security and reliability of energy supply
- Increasing access to affordable modern energy
- Promoting efficient, cleaner, and appropriate energy technology and conservation measures
- Ensuring environmental and societal safety and sustainability of energy supply and utilization
- strengthening energy sector financing

3. Conclusion

Like many other parts of the country, the south-east part of Ethiopia is characterized by low access to electricity. Most of the people located in this area are pastoral, and they depend on wood for fuel, dung for cooking, and kerosene for lamps. The nature of pastoral settlements is dispersed due to nomadic life and overgrazing for cattle. For this kind of area, it's difficult to provide electricity through grid extension due to low energy demand. This paper presents remote pastoral electrification through an off-grid PV system. It's shown that the three sites selected for the case study have high potential solar sources. The three chosen sites, Moyale, Yabelo, and Dire of Pastoral, have an abundance of solar resources that can be used to produce electricity. The optimal PV system configuration in terms of net present cost, initial capital cost, and LCOE was determined through simulation in HOMER. Moyale's net present cost, starting capital cost, and LCOE are US$713.289, US$500.468, US$0.899; Yabelo's are US$662.810, US$0.835, US$447.648; and Dire's are US$667.23, US$0.841, US$451.209. In terms of feasibility, such as cost effectiveness, affordability, finance, environment, problem priority, and poverty alleviation, the leveled cost of electricity for the solar PV system investigated and compared with a diesel generator, which is commonly US$0.42 per Kwh, shows that the solar PV system is preferable with the country's subsidized electricity price, especially for pastoral people living in remote areas. It will provide 100% clean energy and raise the standard of living for pastoral people. In the end, the national strategic plan and national policy backed and facilitated the complete involvement of off-grid solar PV electrification for specific pastoral sites. In terms of reducing grid extension costs, achieving a national energy policy and a national strategic plan, improving pastoral living standards in terms of cattle production, and gaining access to education, telecommunications, health centers, and veterinary clinics, this will be extremely beneficial to pastoralists and the country as a whole.

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References

[1] Solomon Desta, Wassie Berhanu, Wassie Berhanu, Getachew Gebru and Dadhi Amosha,October,2008, *Pastoral drop-out study in selected weredas of Borana Zone, Oromia Regional State" USAID, Care International, Addis Ababa, Ethiopia.*
[2] Sato, Misato and Singer, Gregor and Dussaux, Damien and Lovo, Stefania and others,2015,*International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency?*,Grantham Research Institute on Climate Change and the Environment.
[3] Van de Graaf, Thijs,2014,*International energy agencyHandbook of governance and security*,Edward Elgar Publishing,489–503.
[4] Mengistu, MG and Simane, B and Eshete, G and Workneh, TS,2015,*A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia*, Renewable and sustainable energy reviews,Elsevier,48,306–316
[5] Mondal, Md Alam Hossain and Bryan, Elizabeth and Ringler, Claudia and Mekonnen, Dawit and Rosegrant, Mark, 2018,*Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions*,Energy,Elsevier,149,161–172
[6] Benka-Coker, Megan L and Tadele, Wubshet and Milano, Alex and Getaneh, Desalegn and Stokes, Harry,2018,*A case study of the ethanol CleanCook stove intervention and potential scale-up in Ethiopia*,Energy for Sustainable Development,Elsevier,46,53–64
[7] Mondal, Md and Alam, Hossain and Gebremeskel, Abiti Getaneh and Gebrehiwot, Kiflom and Ringler, Claudia,2018,*Ethiopian universal electrification development strategies*,Intl Food Policy Res Inst
[8] Outlook, Africa Energy,2014,*A focus on energy prospects in Sub-Saharan Africa*,International Energy Agency IEA
[9] Shanko, M,2009,*Target market analysis: Ethiopia's solar energy market*, Project Development Programme East Africa, GTZ GmbH
[10] Senshaw, Dereje Azemraw,2014,*Modeling and analysis of long-term energy scenarios for sustainable strategies of Ethiopia*
[11] Kruger, Wikus and Fezeka, S and Olakunle, A,2019,*Ethiopia country report*,Report 5: Energy and Economic Growth Research Programme (W01 and W05) PO Number: PO00022908
[12] Kebede, Kassahun Y,2015,*Viability study of grid-connected solar PV system in Ethiopia*,Sustainable Energy Technologies and Assessments,Elsevier,10,63–70
[13] Hailu, Ashebir Dingeto and Kumsa, Desta Kalbessa,2021,*Ethiopia renewable energy potentials and current state*,AIMS Energy,Aims Press,9,1,1–14
[14] Argaw, Neway,1996,*Estimation of solar radiation energy of Ethiopia from sunshine data*,International journal of solar energy,Taylor & Francis,18,2,103–113
[15] Yakob, M and Frances, D,1996,*Assessment of Wind and Solar Energy in Ethiopia*,Solar energy,57,4,323–334
[16] Kebede, Kassahun Y and Mitsufuji, Toshio,2017,*Technological innovation system building for diffusion of renewable energy technology: A case of solar PV systems in Ethiopia*,Technological Forecasting and Social Change,Elsevier,114,242–253
[17] Schillings, Christoph and Meyer, Richard and Trieb, Franz,2004, *Solar and Wind Energy Resource Assessment (SWERA)*,DLR—activities within SWERA. Available online: https://openei.org/datasets/files/712/pub/sri_lanka_10km_solar_country_ report. pdf (accessed on 10 May 2019)
[18] Senshaw DA, 2014,*Modeling and analysis of long-term energy scenarious for sustain able strategies in Ethiopia*
[19] Dorothal M, 2019, *Ethiopian Solar Report*, Solarplaza International BV
[20] AddisAbeba University,*Renewable Energy Resources Technology:Study of Feasibility option for rural electrification in Ethiopia*, Faculty of Technology, Electrical Engineering Department, Final Report, Vol III, Addis Ababa Ethiopia,2011
[21] Girum Ayalnech Tiruye, Abreham Tesfaye Besha, Yedilfana Setarge Mekonnen, Natie Ermia Benti, Gebrehiwet Abraham Gebreslase, and Ramote Ashu Tufa,2021, *Opportunities and Challenge of Renewable Energy Production in Ethiopia*, Sustainability, MDPI
[22] Megistu, M.G.; Simane, B.; Eshete, G.; Workneh, T.S., 2015, *A review of biogas technology and its contribution to sustainable rural livelihood in Ethiopia*, Renew.Sustain.Energy Rev.,48, 306-316, [CrossRef]
[23] MoWE,2012,*Scaling-up Renewable Energy program investment plan*, https://www.OPCD.org/env/cc/,Tadele-FDRE Ethiopia Scaling-up Renewable Energy Program(accesed on 15 September 2021)
[24] IEA,IRENA, UNSD, World Bank, WHO, and Tracking SDG7, 2021, *The Energy Progress Report*, Avaliable online: https://tracking Sdg7.esmap.org/data/files/download-document/2021-tracking-sdg7-report.pdf(accessed on 15 September 2021)
[25] Negash, M.; Riera, O. Bio, 2014,*Diesel value chain and access to energy in Ethiopia: Policies and business prospects*, Renew.Sustain.Energy Review, 39, 975-985, [CrossRef]
[26] John A. Duffie, William A. Beckman, 2013,*Solar Engineering of Thermal Process*, John Wiley and Sons, NewYork

[27] [Minster of water, 2013, *Irrigation, and Energy, Ethiopian Energy national policy, Minster of Water, Irrigation, and Energy,*, Addis Ababa

[28] Alam Hossain Mondal, Abiti Getaneh Gebremeskel, Kiflom Gebrehiwot and Claudia Ringle, 2020, *Minster of water, irrigation and energy, Research program on water, land and Ecosystem*, International Food policy Research Institute, Addis Ababa, Ethiopia

[29] International Energy Agency,2020, *SDG7: Data and Projection:access to affordable,reliable,sustainable,and modern energy for all*, retrieved from flagship report, website:https://www.iea.org/reports/sdg7-data-and-projection/access-to-electricity

[30] Lee,K., Brewer, E., Christiano,C., Meyo,F., Miguel,E., Podolsky, M., Wolfram, C., 2016,*Electrification for "under grid" households in rural kenja*, Development Eng.1.26-35, https://doi.org/10.1016/j.Deveng.2015.12.001

[31] Indicators,2026, *[Internet]Washingorn:The World Bank:2016-[cited 2016 Jan 8]* Avaliable from:(http://data.worldbank.org/indicator)

[32] Lighting Africa,2011, *The off-grid lighting market in sub-saharan Africa: Market research Synthesis report washigton:*" The World Banke

[33] Lighting Africa,2013,*Lighting Africa Market trends Report 2012, Overview of the off-grids lighting market in Africa Washington*, The World Bank

[34] Samuel Tesema, Getachewu Bekele, 2015, *Resources assessment and optimization study of efficient type hybrid power system for electrification fo Rural District in Ethiopia*, International Journal of Energy and Power Engineering, Science Publishing Group

[35] Solar Energy Development Association Ethiopia, Ethio Resources Group, April,28,2021, *Solar Energy Vision for Ethiopia opportunity for creating a PV industry in Ethiopia*, https://www.Sun-connect-news.org/fileading/DATEIEN/PV-Industry-ET-04-09-12-finalpdf

[36] World Bank, April 30,2021, *Project Appraisal Documents on a proposed credit in the amount of SDR 86 million (US $130 million equivalent) to the FDRE for a sound Electricity Acess Rural Expansion project*, https://documents1.world bank.org/curent/en/15475/4680/38131697/pdf/38158.pdf

[37] Kost C, Mayor JN, Thomsen J, Hart Mann N, Senkpiel C, Philipps S, 2013, *Levelized Cost of Electricity renewable energy technologies*, Munic:Frown hofer, Institute for Solar Energy System

[38] EberhardA, Rosnes O.,Shkaratan M., Vennemo H.,2011,*Africa Power infrastructure Investment integration Bank for Reconstruction and Development*, The World Bank

[39] Karakezi S, Kimani J., 2002, *Status of power sector reform in Africa*: impact on poor energy policy:30(11-12):924-45

[40] Karakezi S, Kithjoma W., 2002, *Renewable energy strategies for rural Africa: is a PV led Renewable Energy strategies is the right approach for providing modern energy to the rural poor of Sub Africa?*, Energy Policy:30(11-12):1071-86

[41] Financing GTZ,2002,*Mechanisims for solar home system in developing countries, The role of financing in the dissemination process,*,Eschborn: Deutsche Gesellschaft fur Technische Zusammenbeit(GTZ)GmbH

[42] Lighting Africa,2011, *The off-grid lighting market in sub-Sahara Africa:* market research Synthesis report, Washington:The World Bank

[43] Lighting Africa,2010,Solar light for the base of the pyramid -overview fo an emerging market,Washington:The World Bank

[44] Saule Baurzhan, Glennp P.Senits,2016,*Off-grid solar PV: is it an affordable or appropriate solution for rural electrification in sub-saharan Africa countriest*, Renewable and sustainable Energy Review , Elsevier, Vol.60, pp.1405-1418

[45] Hankers M.,2013, April[cited 2014 Nov13]] *Why Africa is missing the solar boat*, renewable energy world.com[internet], Nashua Renewable Energy World.com

[46] Apple J., Vicente R. Yarberry A. Lohye N. Mills E. Joabson A. etal,2010:2015, *Characterization of particular matter size distribution and indoor concentration from Kerosene and diesel lamps*,indoor Air,:399-411

[47] Mowie,2019,*National Electrification Program,2.0:Integrating Planning for Universal Access-lighting to All*, Addis Ababa, Ethiopia

[48] Vemukonya, N., 2007,*Solar home System electrification as viable technology options for Africa development*, Energy policy,35(1):6-14,

[49] Martinose E, Chaurery A, Lew D, Moreira JR, Wamukonya N, 2002,*Renewable Energy Market in developing countries*, Annu Rev Energy Environment,27:309-48

[50] MOFED,2010,*Growth and Transformation Plan*,11-20.14/15, Addis Ababa, Ethiopia

[51] Mondal, M.A.H.,Bryan,E.,Ringler,C., Rosegrant,M.,2017,*Ethiopian Power Sector development:Renewable based universal electricity access and export strategies* , Renew.sustain.Energy Rev 75, 11-20. https://doi.org/10.1016/j.Energy.2018.02.067

[52] Mowie,2019,*National Electrification Program,2.0*,Integrating Planning for Universal Access-lighting to All, Addis Ababa, Ethiopia

[53] Barrie, J.,Cruicshank, H.J.,2017, *Shedding Light on the mile: a study on the diffusion of pas you go solar home system in central East Africa*, Energy po1.107,425-436,https://doi.org/10.1016//j.enpo1.05.016

[54] Ministry of Water and Energy, 2013, *Ethiopian National Energy Policy*, 2nd Draft, Addis Ababa, Ethiopia

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A feasibility analysis of PV-based off-grid rural electrification for a pastoral settlement in Ethiopia

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Abstract

Ethiopia's electric grid relies mostly on hydropower for electricity generation. Compared to metropolitan regions, rural areas have only 5% access to power, and 83% of remote areas rely on traditional biomass energy for lighting and cooking. This paper studies a feasibility analysis, design, and simulation of an off-grid solar PV system for electrifying a pastoral village in Borena. It also discusses the national energy policy and a strategic plan. Using solar radiation base data from the National Aeronautics and Space Administration, a case study is performed at Moyale, Yabelo, and Dire, which have 454 households, 367 households, and 379 households, respectively. Through the HOMER software, the optimization determines the inverter, battery size and number, and solar array's capacity. The daily energy usage and peak power demand in the pastoral communities of Moyale, Yabelo, and Dire were 498.102kWh/day, 447.114Kwh/day, and 454.02kWh/day, or 36.89kW, 35.41kW, and 35.68 kW, respectively. Due to the country's subsidizing of all clean energy costs, off-grid solar PV systems are more economically feasible than diesel generators, which have a level cost of electricity of 0.4 US$/kWh. National energy strategic plans and policies ultimately support the full involvement of off-grid solar PV electrification at remote sites.

Keywords:
HOMER, Photovoltaic, Solar energy, Rural electrification, Renewable Energy, National Aeronautics Space Administration

1. Introduction

Energy links to all economic sectors and also functions as a sector on its own, driving socioeconomic growth in areas like eradicating poverty and enhancing quality of life [27]. By enhancing education, lowering indoor air pollution, and increasing environmental sustainability, modern energy access promotes both income-generating activities and the country's development agenda[28]. More than 700 million Africans lack access to electricity[29] and In Sub-Saharan region, more than 60% live in rural area, and more 80% have no access to modern energy sources[30][31]. Ethiopia's total installed capacity of electric generation is now around 4.5 GW (2019), primarily generated by hydro (90%) and wind energy (7.6%)[3]. The country is one of the Sub-Saharan East African countries with abundant solar energy resources[2] and the country's average annual irradiance is estimated to be around 5.2 kWh/m2/day [7]. According to [9], about 14 MW of solar PV have been used for telecom service, lighting, powering water pumps in rural areas, and for water heating in major cities.[11]. Currently, Ethiopia has launched a 100 MW solar PV project, and Energy Green Power (EGP) for one's project is located near Metehara, while the remaining sites, located near

Mekelle and Humera, were not awarded [10]. In addition, the country intends to build 125 MW solar power plants, which will help scale solar generation in the Somali region and solar dicheto phase I in the Afar region. Per capital energy consumption in all African countries particularly Ethiopia, which is 500 kWh [4]. Therefore, to solve this problem, the government of Ethiopia gave strategies priorities in the energy sector, including universal electrification access, energy efficiency improvement, developing decentralized off-grid power generators, and exporting electricity to neighboring countries[5],[6]. However, until recently, countries' use of PV for meeting off-grid power needs was confined to projects funded by donors that use PV-based technology or distance education radios and vaccine fridges in remote rural areas [12] [5]. Close to 60 % of the land area in Ethiopia is pastoral. Pastoral communities are some of the most vulnerable communities in Ethiopia. Pastoral and agro-pastoral societies in the arid and semi-arid parts of Ethiopia are enduring a downward spiral of increasing poverty, food insecurity, and escalating instability. This problem is ultimately caused by factors that limit the traditional pattern of resource use [1]. Such factors include human population growth, degradation, and fragmentation of traditional grazing areas. In most developing countries, electrifying remote areas by extending the main grid is a major challenge due to economic and technical reasons. There is a way out of the problem of supplying electricity to remote areas. The reason to electrify the remote area will have a significant impact on addressing the problems related to deforestation, global warming, the ecosystem effect, and introducing sustainable green environmental development. The remote area requires low electricity consumption; the government should prioritize an off-grid solar solution as an immediate solution for an electrical solution for un electrified rural households far from the electric grid and not covered by the denitrification program in the short term[13]. The feasibility of off-grid solar PV system in sub-Saharan Africa is analyzing focusing in terms of affordability. [32] presents expenditure on glass-coverage kerosene lamps(taking into consideration the average purchase cost of the device, the operating cost, the average life time of the product and the number of unit of the device per household) is estimated to be US $ 40-90 per household per year in countries in sub-saharan-Africa. An average annual expenditure of US $ 57 per household (US $ 4.75 per month), or 2.6 % of monthly household income. Household expenditure on kerosene is roughly equal to the amount a household would have to power to finance a PV system to under annuity conditions. Using the estimate of the LCOE for the solar PV system of $0.83 per kWh, the annual cost of a solar PV system would be US $51 (US $4.2 per month), or 2.3 % of household income. This can be compared with house hold expenditure on kerosene lamps, which are the most common alternative lighting sources, followed by dry cell batteries and candles[33].
This study, which examined the feasibility of an off-grid solar solution-based system to supply power to remote pastoral communities, was conducted in the Oromia region of south-east Ethiopia, specifically in the pastoral communities of Moyale, Dire, and Yabelo. The study's findings are presented in this paper, along with a national energy strategic plan and policy for the best configuration for the three sites.

2. Methodology

To assess the relevance of the site, relevant data collection has been undertaken from two main sources:

- Site visits and interviews: to assess the electric demand, a site visit and an informal interview of local people and government officials have been done both in person and by phone.
- Internet (website): satellite-based solar radiation data has been taken from NASA data-base websites.

2.1. Solar radiation potential

Since Ethiopia is located near the equator, its solar resources obviously have significant potential. The annual average daily radiation reaching the ground in Ethiopia is estimated to be 5.2 kWh/m2/day, ranging from a low of 4.5 kWh/m2/day in July to a maximum value of 6.5 kWh/m2/day in February and March, respectively. The solar radiation potential for different regions throughout the country has been indicated in Figure 1, which ranges from 5.3 kWh/m2 to 7.5 kWh/m2. The solar resources are relatively lower in the most populous northern, central, and western highlands of the country, while the rift valley region and western and eastern lowlands of the country receive the highest annual average irradiance (above 6 kWh/m2/day)[9].This

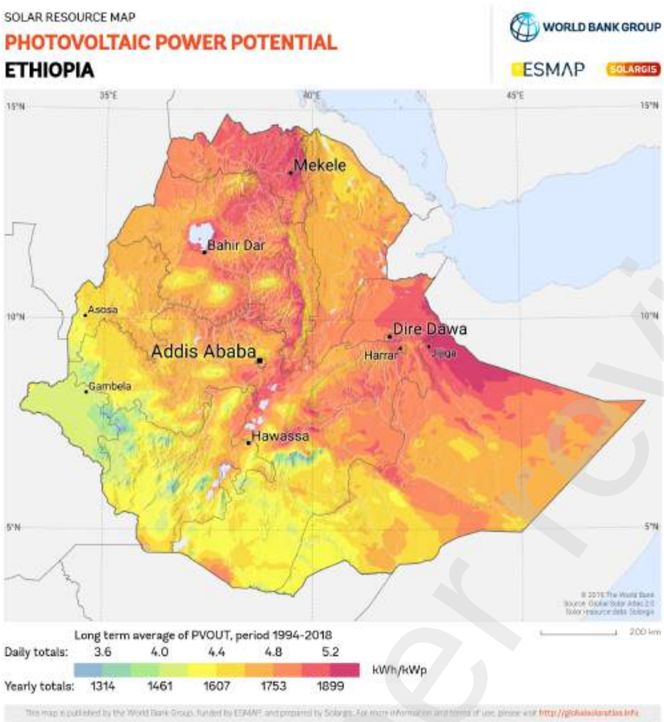

Fig. 1: Solar radiation potential in different regions of Ethiopia

study also confirms the solar radiation potential in the Oromia region's Yabelo, Moyale, and Dire of Borena Zones, which have the highest potential value of 6.23876 kWh/m2/day in Ethiopia, following the Somali region's 7.5 kWh/m2/day[20]. The best way to know the amount of global solar radiation is to install pyranometers or PV sensors at as many locations as possible in a given region and follow their day-to-day recording [34]. In the case of Ethiopia, since only sunshine duration is measured by the National Meteorological Statics Agency (NMSA) and the National Aeronautics and Space Administration (NASA).

2.2. Ethiopian Electrification Rate

[21]It's one of the few countries in sub-Saharan Africa, if not the world, that generates more than 90 % of its electricity from renewable energy resources. Economically, Ethiopia is one of the world's fastest-growing nations, bringing an enormous increase in energy demand to growth rates of 10% to 14% per year until 2037. The existing total electricity generation capacity installed in Ethiopia is about 42,444.67 MW.[22] of which hydropower takes the lion's share. However, there are significant disparities in access to electricity in urban and rural areas[23][24].This indicates that the majority of the country's population (greater than 75 %) does not have access to electricity. However, trends show that the government of Ethiopia's electrification rate increased from 5% in 2000 to 45% in 2016, resulting in the flourishing off-grid access in rural areas depicted in Figure 2[25].Today just 27% of the citizen have electricity access[35]. To expand the 27% and connect more communities to modern energy, the government is extending the main grid and increasing the number of off-grid and mini-grid systems in the country. The majority of current PV electricity production is consumed in the telecommunications industry. Also, other uses of existing solar power include health care centers, educational facility lighting, and village well lamps. The government is planning to connect over 150,000 households to electricity through a PV system. The Ethiopian government is planning to install over 500 MW of solar capacity by 2020[36].

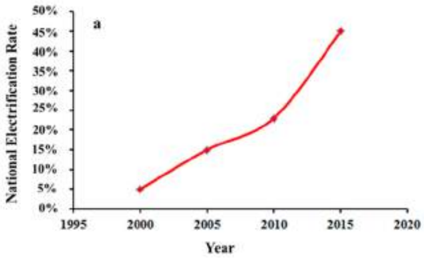

Fig. 2: National Electrification rate

2.3. *Description of the Study Area*

The study has been conducted at three sites in south-east Ethiopia: Moyale, Yabelo, and Dire are in the Borena zone of the Oromia region.

2.3.1. *Moyale*

Moyale is one of the woredas in the Oromia regional state. The geographical data of latitude and longitude for Moyale and the most sensitive household site are shown in Table 1 and Figure 3. It is located 770 kilometers south of Ethiopia's capital, Addis Abeba. The wereda has an area of 14,810 km2, and it's divided into 18 associations, two of which are located in Moyale town. The Wereda borders Ethiopian Somalia a regional state, and Kenya. The longer border it shares with Kenya. The aggro-ecology of the wereda is characterized by a rid to semi-rid type environment. It has a biomedical rainfall pattern in which the main rainfall, which accounts for 65% of the annual total, is received in April through June and the remaining 35% in October through November. The long dry season runs from December to March. Rainfall is low and erratic. The range land is covered with various aspects of acacia, shrubs, and Savannah grasses. A majority of the inhabitants of the wereda are pastoral and aggro pastoral. Moyale is one of the most drought-prone weredas in the Oromia regional state. The wereda suffer from the impacts of frequent drought. The trans-African highway cuts through the middle of Kenya. Moyale is an important trade center for imported manufactured goods from Kenya. It's also a major market outlet for cattle from the Borena plateau. The main sources of water for the wereda are motorized wells, traditional wells, porids, and cisterns. Human health services in the wereda are inadequate. Poorly trained human resources, a lack of facilities, and vital health equipment to provide efficient service were the major factors that affected the effectiveness of the service. The nature of the education coverage in the wereda is poor, and the condition of these schools is also a serious concern. The veterinary service coverage of the wereda is not adequate. The community is forced to walk more than 40 kilometers to seek livestock health services[1].

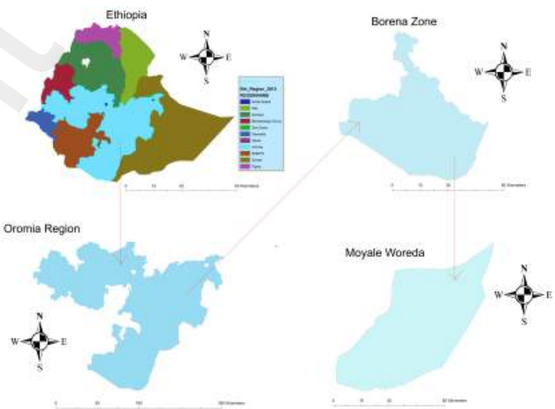

Fig. 3: ArcGIS Map of Moyale Wereda

2.3.2. Yabelo

Yabelo is one of the weredas in the Borena zone of Oromia. The geographical data (latitude and longitude) of Yabelo and the selected most sensitive household site are shown in Table 1 and Figure 4. It is located 570 kilometers from Ethiopia's capital, Addis Abeba. It's the second-largest wereda in the zone, with a total land mass of 5523 km2.There are 20% pastoral associations in the wereda. A semi-arid environment characterizes the agro-ecology of the wereda. It has a bimodal rainfall pattern, with 65% of the rainfall received from April to June and the other 35% from September to Novembe. The wereda is endowed with Savannah-type vegetation suitable mainly for cattle. Land degradation, including soil erosion and bush encroachment, is severe in the wereda. The human population of this wereda is 75,350, with a household number of 15,061. A substantial number of the wereda population about 25% lives in towns, of which 90–95% live in Yabelo town. Pastorals are the dominant form of livelihood pursued by rural people. Similar to other weredas in Borena Zone, Yabelo is a drought-prone wereda. It's vulnerable to environmental shocks. Since 1991, the wereda has suffered more than three droughts that have led to the loss of livelihood for many households[1].

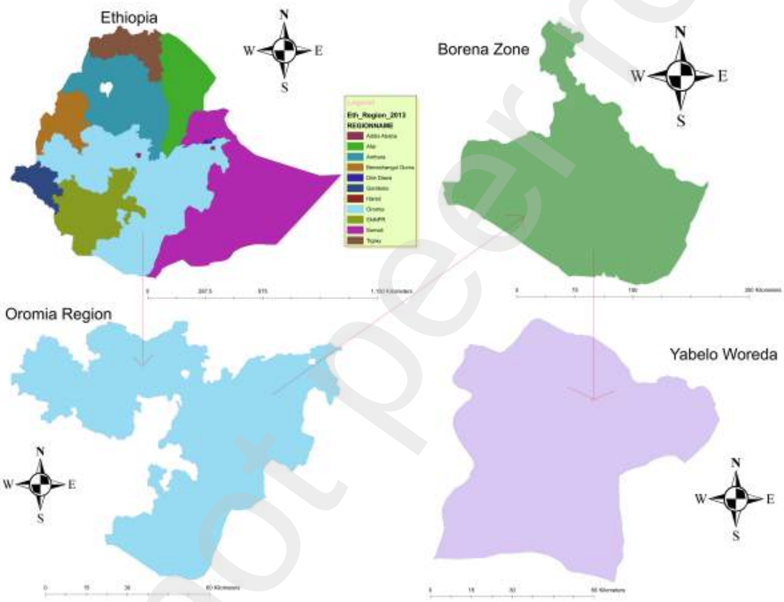

Fig. 4: ArcGIS Map of Yabelo Wereda

2.3.3. Dire

Dire is one of the weredas in the Borena zone of the regional state of Oromia, which is shown in Figure 5. The geographical data of latitude and longitude for Dire and the selected most sensitive household site are shown in Table 1. It is located 670 kilometers from Ethiopia's capital, Addis Ababa.It's the largest wereda in the zone, with an area of 12,722 km2. 31% pastoral association in the wereda. An arid and semi-arid environment characterizes the aggro-ecology of the wereda. It has a bimodal rainfall pattern, in which the main rainfall is received from April to June and the other from September to November. The wereda is endowed with Savannah-type vegetation suitable mainly for cattle. The human population of the wereda is 112,262 (56,351 males and 55,921 females), with a household number of 22,452. Only 2% of the population lives in urban areas. Dire is the center of the Borena pastoral production. system, where the majority of the tulla wells, which are the focal point of the Borena system, are located.[1].

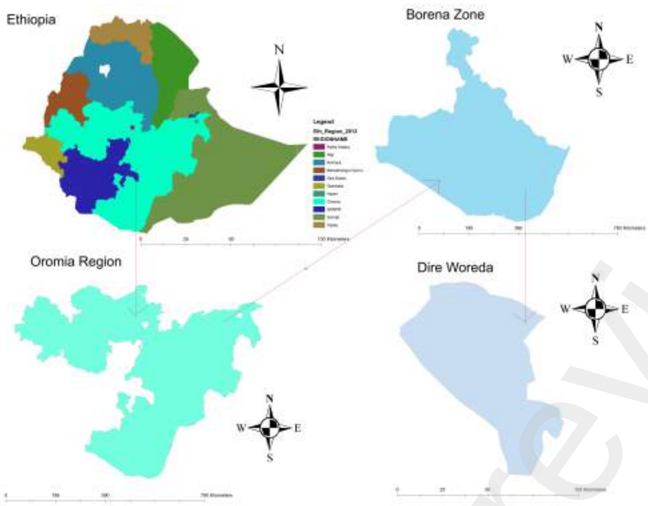

Fig. 5: ArcGIS Map of Dire Wereda

Table 1: A Summary of the geographical data for the three sites of households

Name of Cities	Longitude	Latitude	Altitude	Number of Households
Moyale	39.0260	3.5383	1090	454
Yabelo	38.1636	4.9242	1857	367
Dire	37.0389	4.887	2400	379

2.4. Energy Demand Profile

Electrical load assessment in the design of a solar photovoltaic renewable power system is the basic step to determine the size of system components. The electric consumption of the community was related to socio-economic, religious, cultural, geographical, demographic, and technological situations. Energy demand at the sites is for lighting, fans, health and veterinary clinics, water pumps, schools, and telecommunication. The load profile for each pasture was assessed by a field survey. The information for electrified villages and towns is obtained by the Ethiopian Electric Power Corporation. The survey at selected sites was conducted to determine the number of households. Peak load occurs for the three sites between 7:00PM and 6:00AM, due to household lighting, vaccine refrigerators in health and veterinary clinics, and telecommunications which is shown in Figure 6. A summary of the load profile after the variability has been applied to the average load for all three sites is shown in Table 2. The power demand has a low load factor, as shown in Table 2, and is characterized by maximum energy demand during the day and peak demand during the evening. This is due to the fact that electricity is primarily used for lighting applications and the lack of commercial and industrial demand at the selected sites.

Table 2: Summary of the load profile

Name of Cities	Households	Average Daily Demand (kWh/day)	Average Power (kW)	Peak Power (kW)	Load Factor
Moyale	454	498.102	36.89	101.77	0.36
Yabelo	367	447.114	35.41	96.73	0.37
Dire	379	454.02	35.68	97.44	0.37

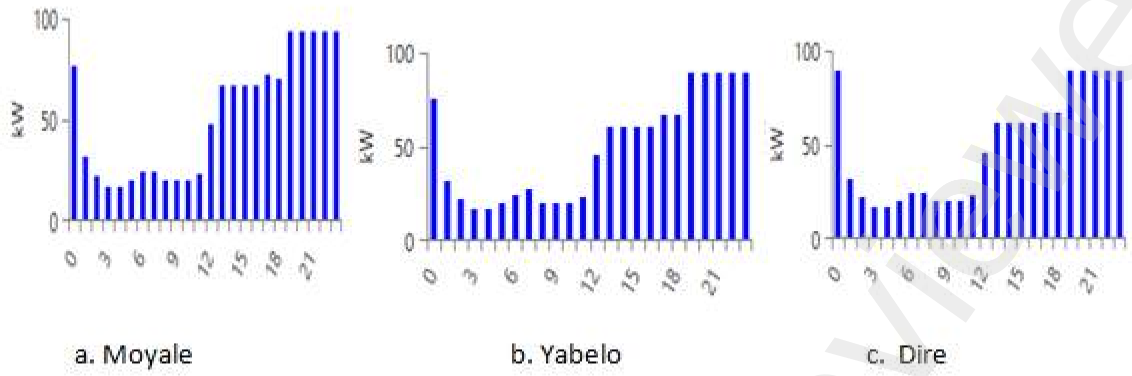

Fig. 6: Energy Demand Profile for three sites

Table 3: Detail of the load profile

Load Type	Quantity	Power(watt)	hr/day	Whr/day	kWhr/day
Domestic Load					
Celing Fans	1	14	12	168	0.168
Lcd Tv	1	60	4	240	0.24
Lamp	2	15	6	180	0.18
Health Clinic					
Vaccine Refrigerator	1	320	24	7680	7.680
Laboratory Mictroscope	1	20	10	200	0.2
Lamp	3	15	10	450	0.45
Lcd Tv	1	60	6	360	0.36
Fan	3	14	8	336	0.336
Veterinary Clinics					
Vaccine Refrigerator	1	350	24	8400	8.4
Laboratory Microscope	1	80	10	800	0.8
Lamp	2	15	10	300	0.3
Fan	2	14	8	224	0.224
Lcd Tv	1	60	6	360	0.36
Differable Load					
Water pump for irrigation	1	1500	2	3000	3.00
Water pump for drink	1	1500	2	3000	3.00
School					
Lamp	6	15	12	1080	1.08
Fan	6	15	8	720	0.72
Tv or Radio	1	60	4	240	0.24
Telecommunication	1	8500	24	204000	204.000

2.5. Solar Energy Sources

The most common data on solar energy resources is the average daily sunshine hours, which is collected at many of the meteorological stations throughout the countries. The available sunshine hour data from NASA was used to estimate the solar energy resource at the sites. Figure 7 shows that seven years' average daily sunshine hours occur in each month for the sites under study.

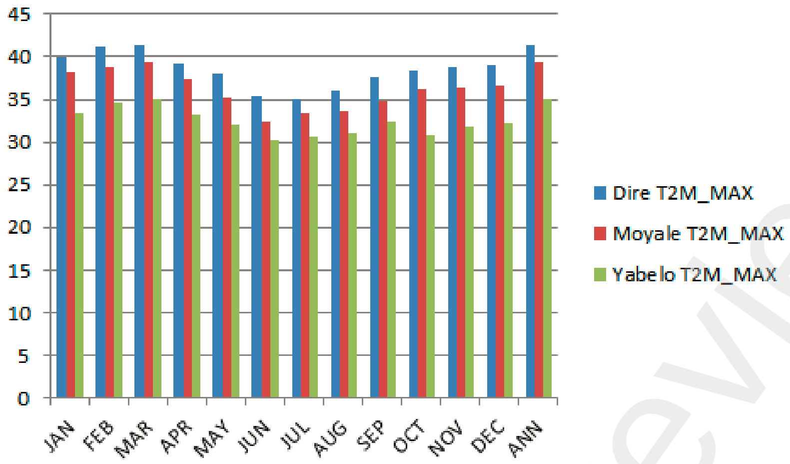

Fig. 7: Maximum-Temperature

2.6. Analytical method of estimating solar radiation

The available sunshine hours data have been converted to monthly average daily global solar radiation, H_G, from monthly average daily extraterrestrial radiation, H_O, using the Angestrom-Page estimation model given by equation [26].

$$H_o = \left(a + b\frac{n}{N}\right) \tag{1}$$

- a- is Angestrom correlation parameters
- b- is Angestrom correlation parameters
- n- is monthly average daily hours of sunshine from sunshine records
- N- is monthly average of maximum possible hours of sunshine
- H_G - is monthly average daily global radiation
- H_O - is monthly average daily extraterrestrial solar radiation

H_O is determine based on the solar constant average day of the month and declination angle. The value for N, a, and b were determined by using equation 2, equation 3,and equation 4.

$$N = \frac{2}{15} arccose\,(-tan\phi tan\sigma) \tag{2}$$

$$-0.309 + 0.539cos\phi - 0.0693E_o + 0.290\left(\frac{n}{N}\right) \tag{3}$$

$$1.527 - 1.027cos\phi + 0.0926E_o - 0.359\left(\frac{n}{N}\right) \tag{4}$$

Where:-

- E_O - is Altitude of site in kilometers
- σ - is declination angle for the average day in the month
- a- is Hellman coefficient
- ϕ - is latitude of the site

2.7. Results of the Solar Radiation Estimation Model

A study of solar energy resources was conducted by comparing global solar radiation measurements to corresponding calculated values using Angstrom's relations [14]. The regression coefficient was obtained, and the correlation equation was determined to predict the global solar radiation. The results show that Angstrom's relationship is valid for the location under study[15]. The sunshine hour used records from 21 meteorological stations in the country to illustrate the general availability of the resources[16]. The annual average daily solar radiation is estimated to be 4.25 kwh/m2 to 6.25 kwh/m2 which is shown in Figure 8. Solar radiation maps of the country produced based on satellite data also indicate that the country has significant solar radiation potential[17]. The Angstrom estimation model was used to find the monthly average daily global solar radiation by using inputs such as latitude, altitude, the average day in the month, the declination angle for the day, and the sunshine hour data. Input data for each month was employed in equations 1–4 to calculate the parameters N, a, b, H_O, and H_G. The monthly clearness index, defined as the ratio of solar radiation, has been calculated for each site as well. The results of the estimation model indicate very close values for the solar radiation at the three sites. This is due to the fact that the sites are located

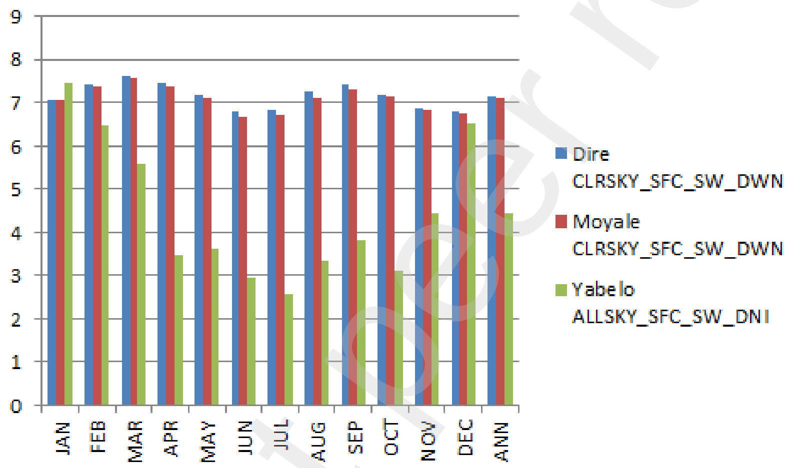

Fig. 8: Solar Radiation calculated for each month

close to each other and there is only a slight variation in the altitude of the sites. This is due to the fact that the sites are located close to each other and there is only a slight variation in the altitude of the sites. The average daily global solar radiation varies from around 5.0 kW/m2/day in the rainy month of July to just above 7.0 kW/m2/day in the dry months. Similarly, the cleaners' index varies from the lowest value of 0.5 in July to the highest value of 0.67 in most of the other months of the year. Thus, according to Kudish and Ianetz, the three sites can be classified as having a clear sky for most times of the year and partially cloudy during the rainy season.

2.8. Results from the solar system analysis and optimization using HOMER

HOMER software models were created for conducting the analysis based on the load profile discussed in Subsection 4, and appropriate sizes and numbers of equipment to be considered for each site were selected.The results discussed in Subsection 7 provided the necessary solar energy input. The figure 8 below depicts the equipment representation of the solar system for Moyale, Yabelo, and Dire. The equipment configuration of the three sites is similar, with the only difference being their capacity with deferrable loads. The results of the optimization in HOMER for the three sites are discussed in the subsequent sections. A description is provided below each table that shows a listing of feasible system options. Among the options, the following tables show the system architecture for the least-cost system, which is a 100 percent renewable energy system, and for each case, a Figure 9 showing the electricity production contribution of each technology on a monthly basis.

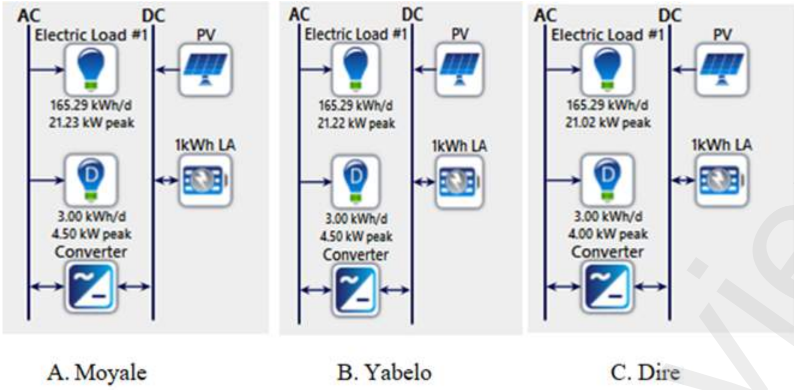

Fig. 9: Equipment representation of three sites:(A) Moyale,(B) Yabelo,(C) Dire

Table 4: Cost Summary of Moyale

Components	**Capital ($)**	**Replacement($)**	**Operational and Maintenance cost ($)**	**Salvage($)**	**Total Cost($)**
Generic 1Kwh Lead Acid	158,400.00	140,160.46	68,257.29	18,777.59	348,040.16
Generic Flat Plate Pv	323,304.15	0.00	16,718,08	0.000	340,022.23
System Converter	18,764.17	7,961.15	0.00	1,498.37	25,226.95
System	500,468.32	148,121.60	84,975.37	20,275.96	713,289.34

2.8.1. Moyale

The findings are summarized by total cost in Table 4 and average monthly electric production in Figure 10. The Moyele site is the highest-cost for the solar PV option. This is primarily because of the lead acid solar batteries of the site, the average daily load demand, the higher price per installed capacity, and the higher capital cost when compared to the Yabelo and Dire sites. Figure 10 shows the average monthly electricity production by solar PV. As shown in Figure 10, solar PV provides the majority of the electric production in the January, February, March, and December months. During the sunny months, the maximum electric production is 20 MWh. On the contrary, electric production in June and July is lower, at 10.5 MWh and 13 MWh, respectively, because most of these months are rainy during the summer.

Fig. 10: Moyale Average Monthly Electricity Production

Table 4 shows the cost summary of system components such as generic 1 kWh lead acid batteries, generic flat plate PV, and system converter. Generally, the cost summary for the Moyale site of the system is expressed in terms of capital cost, replacement cost, and operation and maintenance cost, Salvage and total cost are 500.468 USD, 148.121.60 USD, 84.975.37 USD, 20,275.96 USD, and 713.289.34 USD, respectively. This is because Moyale sites have a higher demand for households than Yabelo and Dire sites.

2.8.2. Yabelo Site

Similarly, the optimization results for the Yabelo site are shown in Table 5. Compared to Moyale sites, the Yabelo site is the most cost-effective option for this site. This is because a solar source is essential for this site, primarily. Although the initial capital costs are lower at the Yabelo site, production is higher than at the Moyale site. Figure 11 shows the average monthly electricity production by solar PV. Most of

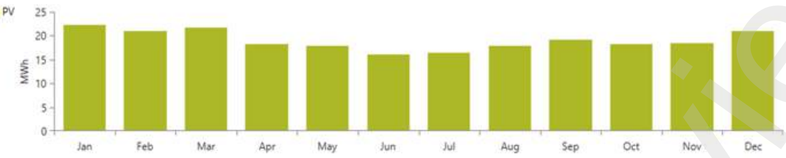

Fig. 11: Yabelo's average monthly electricity production

the energy production is produced in January, March, and December, which is 23 MWh during the sunny season, and the lowest energy production takes place in June and July, which is 16 MWh most of the time during these months, which are the rainy summer season in Ethiopia. In Table 5, summarize the cost of

Table 5: Cost Summary of Yabelo

Components	Capital ($)	Replacement($)	Operational and Maintenance cost ($)	Salvage($)	Total Cost($)
Generic 1Kwh Lead Acid	101,100.00	152,983.75	43,565.73	1,810.61	295,838.87
Generic Flat Plate Pv	338,000.00	0.000	17,478.00	0.00	355,478.00
System Converter	8,548.71	3,626.99	0.000	682.64	11,493.06
System	447,648.71	156,610.74	61,043.73	2,493.25	662,809.94

system components such as generic 1 kWh lead acid batteries, generic flat PV systems, system converters, and systems in terms of capital cost, replacement cost, operation and maintenance cost, and total cost. In the end, the system of capital cost, replacement cost, operation and maintenance cost, salvage, and total cost for the Yabelo site are 447.648.71$, 156,610.74$, 61,043.73$, 2,493.25$, and 629,809.94$, respectively.

2.8.3. Dire Site

When the Dire site's results are compared to those of the Moyale and Yabelo sites, the solar PV system is the most cost-effective option for the Dire site. This is due to lower capital costs, which are shown in Table 6. The maximum electricity production at this site is higher compared to Moyale sites and similar to that at Yabelo sites. Figure 12 shows the average monthly electricity production by solar PV. From Figure 11, most electrical energy production takes place in December, January, and March months, which is 23 MWh, and

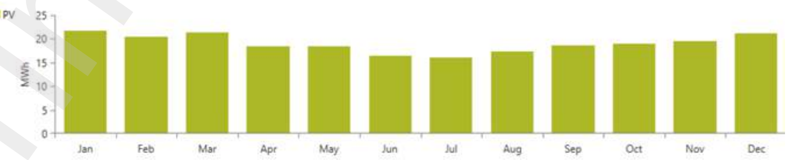

Fig. 12: Dire Average Monthly Electricity Production

the lowest electrical energy production is in June and July months, which is about 16 MWh, and most of these months are rainy months during summer in Ethiopia. Table 6 summarizes the system component costs, such as the generic 1 kW lead acid battery, generic flat plate PV, system converter, and system. Generally, the system cost summary of Dire Site in terms of capital cost, replacement cost, operation and maintenance cost, salvage, and total cost is 451,209.69$, 159,096.24$,62,853.59$, 5,929.17$, and 667,230.34$ respectively.

Table 6: Cost Summary of Dire

Components	Capital ($)	Replacement($)	Operational and Maintenance cost ($)	Salvage($)	Total Cost($)
Generic 1Kwh Lead Acid	105,300.000	155,740.37	45,375.58	5,297.56	301,118.38
Generic Flat Plate Pv	338,000.00	0.000	17,478.00	0.000	355,478.00
System Converter	7,909.69	3,355.88	0.00	631.61	10,633.96
System	451,209.69	159,096.24	62,853.59	5,929.17	667,230.34

2.9. Summary of the Results

The analysis of the three locations, Moyale, Yabelo, and Dire, can be summarized in terms of feasibility and the National Energy Strategic Plan and Policy. In Sub-Saharan Africa, the viability of off-grid solar PV is typically evaluated in light of five key factors: affordability, cost-effectiveness, financing, environmental influence, and poverty alleviation.

Table 7: Summary of Optimization Results for the Three Sites

	Name of Sites		
Parametes	**Moyale**	**Yabelo**	**Dire**
PV(kW)	129	135	135
Battery(1kWhLA)	528	337	351
Converter(kW)	62.5	28.5	26.4
NPC($)	713.289	662.810	667.23
COE($)	0.899	0.835	0.841
Operation Cost($/yr)	16.463	16.644	16.710
Initial Capital ($)	500.468	447.649	451.210
Renewable fraction (%)	100	100	100
PV Captial Cost($)	323.304	338.00	338.00

2.9.1. Feasibility

In terms of cost-effective feasibility, the comparison is determined by the levelized cost per kWh of energy (LCOE) between solar PV and small diesel generation[38]. According to Table 7, the LCOE of the chosen sites is US$0.899 per kWh, US$0.835 per kWh, and US$0.841 per kWh for Moyale, Yabelo, and Dire, respectively, with the projected LCOE of a solar PV system being US$0.83 per kWh at a 10% discount rate. In Africa, these selected sites have a very high cost per unit of electric generation compared to the conventional grid tariff rates, which are US0.08$ perkWh and US$0.08perkWh. It's not necessary to compare a solar PV system with a conventional grid because the conventional grid does not reflect the true cost of power generation. Despite the limitations mentioned above, most sub-Saharan African countries use small to medium diesel generators as a benchmark for comparison and use them for household and enterprise needs[39]. However, the diesel generators' LCOE is estimated to be US$0.42perKwh[40]. Based on the benchmarks, the LCOE of solar PV is higher than that of the diesel generator, and the LCOE differences between solar PV and the diesel generator are US$0.469perkWh, US$0.415perkWh, and US$0.42perkWh for the Moyale, Yabelo, and Dire sites, respectively. However, most of the time the diesel generator is used for water pumping, milling, irrigation, or any other income-generating activities; as a result, the running cost of the diesel generator is higher than solar PV for lighting, radio, and TV[41]. Consumers must be able to repay the credit while also covering the costs of operation and maintenance, which are the main reasons why the rural poor cannot afford solar PV systems even with the most favorable credit schemes and subsidies[42]. Regarding subsidies, the government of Ethiopia gives high priority to the solar PV Through government initiatives, the Ethiopian Electric Utility (EEU) selects mini-grid sites and places bids for private companies

to contest. This bid can be an "MST" (minimum subsidy tender), through which the company is responsible for handling the whole process under government supervision[50].
In terms of affordability, The estimated LCOE for a solar PV system in comparison to household expenditure on kerosene lamps, the most common alternative lighting source, The estimate of the LCOE for the solar PV system is 0.83 kWh; the annual cost of the solar PV system would be US$51(US$4.2per month), or 2.3% of household income[43][45]. Table 7 shows that the LCOE for the selected sites is US0.899$perkWh, US$0.835perkWh, and US$0.841perkWh for Moyale, Yabelo, and Dire, respectively. Solar systems at selected sites cost US$ 52 per year, US$ 51 per year, and US$ 52 per year, respectively, and US$ 4.3 per month, US$ 4.2 per month, and US$ 4.3 per month for Moyale, Yabelo, and Dire. Expenditure on glass-covered kerosene lamps (taking into consideration the average purchase cost, the average lifetime of the product, and the number of units of the device per household) is estimated to be US$40-98per household per year in different sub-Saharan African countries[46]. In the end, the average annual and month cost of solar energy at selected sites is within the range of the average annual and month expenditure of kerosene, which are US$52peryear,US$51peryear, and US$52peryear and US$4.3permonth,US$4.2permonth,and US$4.3permonth for Moyale, Yabelo, and Dire, respectively. Therefore, the household expenditure on kerosene is roughly equal to the amount of money a household would have to pay to finance a PV system under annuity and monthly conditions[47].
In terms of financing, the end users should finance a solar PV system from their current income and savings, paying not only the initial investment cost but also the operation and maintenance costs occurring throughout the lifetime of the system. The financing cost of a solar PV system is too high for most rural households, so solar will be automatically excluded from the lighting options[48]. According to the National Energy Policy[54], to strengthen energy sector finance, provide adequate funding, and seek funds for energy technology development, promote energy resources to financiers and investors, and establish an "energy fund" by instituting mechanisms such as a green tax to promote sustainable energy sector development.
In terms of the environment, solar PV technology is often promoted in sub-Saharan Africa for health and global environmental reasons. Burning kerosene indoors for lighting emits fine particles, carbon monoxide, nitric oxide, and sulfur dioxide, which increase the risk of respiratory illness and long-term cancer[49][53]. The household use of cooking, kerosene, and candles for lighting increases greenhouse gas emissions. Most people, particularly in the pastoral community in the selected site of Ethiopia, are forced to use kerosene for lighting, forest wood, and charcoal for cooking. Deforestation exists as a result of this, and it emits carbon dioxide into the environment. However, by injecting 100% renewable energy into these selected sites, solar PV can pinpoint the source of the problem.
The expectation that solar PV technology will reduce poverty has been one of the main forces behind efforts to spread solar PV in sub-Saharan Africa in terms of problem priority and poverty alleviation[51]. There are certain social benefits from lighting, TV, radio, and the powering of telecommunication devices by a solar PV system[52]. Ethiopian government initiatives will improve people's living standards and connect the pastoral community to the rest of the nation and the world by providing electric access for lighting, health centers, veterinary centers, telecommunications, and water pumps. The majority of these people lead nomadic lives and are involved in cattle production, allowing them to compete in the cattle market after gathering market information.

2.9.2. National Energy Strategic Plan and Policy

According to the national energy strategic plan of [50] the government, the "Growth and Transformations Plan (GTPII)" was released in 2015, with the goal of increasing GDP by 11% to 15% per year from 2015 to 2020. This plan aims to increase total capacity from 4206 MW to 14561 MW, with hydropower contributing 77%, wind and geothermal contributing 8%, solar contributing 2%, biomass contributing 3%, and the remaining sugarcane bagasse contributing 14%. The Ministry of Water, Irrigation, and Electricity (MoWIE) has priorities in the energy sector to boost national electricity access. This strategic priority includes energy efficiency improvements, decentralization of off-grid solar generation to rural areas, and exporting energy to neighboring countries. With these strategies, they aim to attain universal electrification access by 2025, whereby 35% of the population will have power access by 2025 through off-grid solar power electrification[51]. As a result, the government has been working on strategies to bring electricity to rural areas in order to meet the 2025 goal of universal access. There are two main strategies in place through which off-grid solar projects are implemented in rural areas:

- Through government initiatives, the Ethiopian Electric Utility (EEU) selects mini-grid sites and places bids for private companies to contest. This bid can be an "MST" (minimum subsidy tender), through which the company is responsible for handling the whole process under government supervision. In many other cases, the entire process is dealt with by EEU as Engineering, Procurement, and Construction[52].
- Strategy: Through private company initiatives, they get loans from financial entities and import solar power products. The private companies work as retailers and sell products to the end users, or they work as investors who bring solar home system kits and install them. As a result, these companies receive payments from the customers through what is commonly known as "pay-as-you-go"[51].

In the end, the Ethiopian National Energy Policy[54] supports ensuring the availability, accessibility, affordability, safety, and reliability of energy services to support accelerated and sustainable social and economic development and transformation of the country. In terms of the national energy policy, solar off-grid electrification can be achieved:

- Improving the security and reliability of energy supply
- Increasing access to affordable modern energy
- Promoting efficient, cleaner, and appropriate energy technology and conservation measures
- Ensuring environmental and societal safety and sustainability of energy supply and utilization
- strengthening energy sector financing

3. Conclusion

Like many other parts of the country, the south-east part of Ethiopia is characterized by low access to electricity. Most of the people located in this area are pastoral, and they depend on wood for fuel, dung for cooking, and kerosene for lamps. The nature of pastoral settlements is dispersed due to nomadic life and overgrazing for cattle. For this kind of area, it's difficult to provide electricity through grid extension due to low energy demand. This paper presents remote pastoral electrification through an off-grid PV system. It's shown that the three sites selected for the case study have high potential solar sources. The three chosen sites, Moyale, Yabelo, and Dire of Pastoral, have an abundance of solar resources that can be used to produce electricity. The optimal PV system configuration in terms of net present cost, initial capital cost, and LCOE was determined through simulation in HOMER. Moyale's net present cost, starting capital cost, and LCOE are US$713.289, US$500.468, US$0.899; Yabelo's are US$662.810, US$0.835, US$447.648; and Dire's are US$667.23, US$0.841, US$451.209. In terms of feasibility, such as cost effectiveness, affordability, finance, environment, problem priority, and poverty alleviation, the leveled cost of electricity for the solar PV system investigated and compared with a diesel generator, which is commonly US$0.42 per Kwh, shows that the solar PV system is preferable with the country's subsidized electricity price, especially for pastoral people living in remote areas. It will provide 100% clean energy and raise the standard of living for pastoral people. In the end, the national strategic plan and national policy backed and facilitated the complete involvement of off-grid solar PV electrification for specific pastoral sites. In terms of reducing grid extension costs, achieving a national energy policy and a national strategic plan, improving pastoral living standards in terms of cattle production, and gaining access to education, telecommunications, health centers, and veterinary clinics, this will be extremely beneficial to pastoralists and the country as a whole.

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References

[1] Solomon Desta, Wassie Berhanu, Wassie Berhanu, Getachew Gebru and Dadhi Amosha,October,2008, *Pastoral drop-out study in selected weredas of Borana Zone, Oromia Regional State" USAID, Care International, Addis Ababa, Ethiopia.*

[2] Sato, Misato and Singer, Gregor and Dussaux, Damien and Lovo, Stefania and others,2015,*International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency?*,Grantham Research Institute on Climate Change and the Environment.

[3] Van de Graaf, Thijs,2014,*International energy agencyHandbook of governance and security*,Edward Elgar Publishing,489–503.

[4] Mengistu, MG and Simane, B and Eshete, G and Workneh, TS,2015,*A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia*, Renewable and sustainable energy reviews,Elsevier,48,306–316

[5] Mondal, Md Alam Hossain and Bryan, Elizabeth and Ringler, Claudia and Mekonnen, Dawit and Rosegrant, Mark, 2018,*Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions*,Energy,Elsevier,149,161–172

[6] Benka-Coker, Megan L and Tadele, Wubshet and Milano, Alex and Getaneh, Desalegn and Stokes, Harry,2018,*A case study of the ethanol CleanCook stove intervention and potential scale-up in Ethiopia*,Energy for Sustainable Development,Elsevier,46,53–64

[7] Mondal, Md and Alam, Hossain and Gebremeskel, Abiti Getaneh and Gebrehiwot, Kiflom and Ringler, Claudia,2018,*Ethiopian universal electrification development strategies*,Intl Food Policy Res Inst

[8] Outlook, Africa Energy,2014,*A focus on energy prospects in Sub-Saharan Africa*,International Energy Agency IEA

[9] Shanko, M,2009,*Target market analysis: Ethiopia's solar energy market*, Project Development Programme East Africa, GTZ GmbH

[10] Senshaw, Dereje Azemraw,2014,*Modeling and analysis of long-term energy scenarios for sustainable strategies of Ethiopia*

[11] Kruger, Wikus and Fezeka, S and Olakunle, A,2019,*Ethiopia country report*,Report 5: Energy and Economic Growth Research Programme (W01 and W05) PO Number: PO00022908

[12] Kebede, Kassahun Y,2015,*Viability study of grid-connected solar PV system in Ethiopia*,Sustainable Energy Technologies and Assessments,Elsevier,10,63–70

[13] Hailu, Ashebir Dingeto and Kumsa, Desta Kalbessa,2021,*Ethiopia renewable energy potentials and current state*,AIMS Energy,Aims Press,9,1,1–14

[14] Argaw, Neway,1996,*Estimation of solar radiation energy of Ethiopia from sunshine data*,International journal of solar energy,Taylor & Francis,18,2,103–113

[15] Yakob, M and Frances, D,1996,*Assessment of Wind and Solar Energy in Ethiopia*,Solar energy,57,4,323–334

[16] Kebede, Kassahun Y and Mitsufuji, Toshio,2017,*Technological innovation system building for diffusion of renewable energy technology: A case of solar PV systems in Ethiopia*,Technological Forecasting and Social Change,Elsevier,114,242–253

[17] Schillings, Christoph and Meyer, Richard and Trieb, Franz,2004, *Solar and Wind Energy Resource Assessment (SWERA)*,DLR—activities within SWERA. Available online: https://openei.org/datasets/files/712/pub/sri_lanka_10km_solar_country_ report. pdf (accessed on 10 May 2019)

[18] Senshaw DA, 2014,*Modeling and analysis of long-term energy scenarious for sustain able strategies in Ethiopia*

[19] Dorothal M, 2019, *Ethiopian Solar Report*, Solarplaza International BV

[20] AddisAbeba University,*Renewable Energy Resources Technology:Study of Feasibility option for rural electrification in Ethiopia*, Faculty of Technology, Electrical Engineering Department, Final Report, Vol III, Addis Ababa Ethiopia,2011

[21] Girum Ayalnech Tiruye, Abreham Tesfaye Besha, Yedilfana Setarge Mekonnen, Natie Ermia Benti, Gebrehiwet Abraham Gebreslase, and Ramote Ashu Tufa,2021, *Opportunities and Challenge of Renewable Energy Production in Ethiopia*, Sustainability, MDPI

[22] Megistu, M.G.; Simane, B.; Eshete, G.; Workneh, T.S., 2015, *A review of biogas technology and its contribution to sustainable rural livelihood in Ethiopia*, Renew.Sustain.Energy Rev.,48, 306-316, [CrossRef]

[23] MoWE,2012,*Scaling-up Renewable Energy program investment plan*, https://www.OPCD.org/env/cc/,Tadele-FDRE Ethiopia Scaling-up Renewable Energy Program(accesed on 15 September 2021)

[24] IEA,IRENA, UNSD, World Bank, WHO, and Tracking SDG7, 2021, *The Energy Progress Report*, Avaliable online: https://tracking Sdg7.esmap.org/data/files/download-document/2021-tracking-sdg7-report.pdf(accessed on 15 September 2021)

[25] Negash, M.; Riera, O. Bio, 2014,*Diesel value chain and access to energy in Ethiopia: Policies and business prospects*, Renew.Sustain.Energy Review, 39, 975-985, [CrossRef]

[26] John A. Duffie, William A. Beckman, 2013,*Solar Engineering of Thermal Process*, John Wiley and Sons, NewYork

[27] [Minster of water, 2013, *Irrigation, and Energy, Ethiopian Energy national policy, Minster of Water, Irrigation, and Energy,*, Addis Ababa

[28] Alam Hossain Mondal, Abiti Getaneh Gebremeskel, Kiflom Gebrehiwot and Claudia Ringle, 2020, *Minster of water, irrigation and energy, Research program on water, land and Ecosystem*, International Food policy Research Institute, Addis Ababa, Ethiopia

[29] International Energy Agency,2020, *SDG7: Data and Projection:access to affordable,reliable,sustainable,and modern energy for all*, retrieved from flagship report, website:https://www.iea.org/reports/sdg7-data-and-projection/access-to-electricity

[30] Lee,K., Brewer, E., Christiano,C., Meyo,F., Miguel,E., Podolsky, M., Wolfram, C., 2016,*Electrification for "under grid" households in rural kenja*, Development Eng.1.26-35, https://doi.org/10.1016/j.Deveng.2015.12.001

[31] Indicators,2026, *[Internet]Washingorn:The World Bank:2016-[cited 2016 Jan 8]* Avaliable from:(http://data.worldbank.org/indicator)

[32] Lighting Africa,2011, *The off-grid lighting market in sub-saharan Africa: Market research Synthesis report washigton:*" The World Banke

[33] Lighting Africa,2013,*Lighting Africa Market trends Report 2012, Overview of the off-grids lighting market in Africa Washington*, The World Bank

[34] Samuel Tesema, Getachewu Bekele, 2015, *Resources assessment and optimization study of efficient type hybrid power system for electrification fo Rural District in Ethiopia*, International Journal of Energy and Power Engineering, Science Publishing Group

[35] Solar Energy Development Association Ethiopia, Ethio Resources Group, April,28,2021, *Solar Energy Vision for Ethiopia opportunity for creating a PV industry in Ethiopia*, https://www.Sun-connect-news.org/fileading/DATEIEN/PV-Industry-ET-04-09-12-finalpdf

[36] World Bank, April 30,2021, *Project Appraisal Documents on a proposed credit in the amount of SDR 86 million (US $130 million equivalent) to the FDRE for a sound Electricity Acess Rural Expansion project*, https://documents1.world bank.org/curent/en/15475/4680/38131697/pdf/38158.pdf

[37] Kost C, Mayor JN, Thomsen J, Hart Mann N, Senkpiel C, Philipps S, 2013, *Levelized Cost of Electricity renewable energy technologies*, Munic:Frown hofer, Institute for Solar Energy System

[38] EberhardA, Rosnes O.,Shkaratan M., Vennemo H.,2011,*Africa Power infrastructure Investment integration Bank for Reconstruction and Development*, The World Bank

[39] Karakezi S, Kimani J., 2002, *Status of power sector reform in Africa*: impact on poor energy policy:30(11-12):924-45

[40] Karakezi S, Kithjoma W., 2002, *Renewable energy strategies for rural Africa: is a PV led Renewable Energy strategies is the right approach for providing modern energy to the rural poor of Sub Africa?*, Energy Policy:30(11-12):1071-86

[41] Financing GTZ,2002,*Mechanisims for solar home system in developing countries, The role of financing in the dissemination process,*,Eschborn: Deutsche Gesellschaft fur Technische Zusammenbeit(GTZ)GmbH

[42] Lighting Africa,2011, *The off-grid lighting market in sub-Sahara Africa:* market research Synthesis report, Washington:The World Bank

[43] Lighting Africa,2010,Solar light for the base of the pyramid -overview fo an emerging market,Washington:The World Bank

[44] Saule Baurzhan, Glennp P.Senits,2016,*Off-grid solar PV: is it an affordable or appropriate solution for rural electrification in sub-saharan Africa countriest*, Renewable and sustainable Energy Review , Elsevier, Vol.60, pp.1405-1418

[45] Hankers M.,2013, April[cited 2014 Nov13]] *Why Africa is missing the solar boat*, renewable energy world.com[internet], Nashua Renewable Energy World.com

[46] Apple J., Vicente R. Yarberry A. Lohye N. Mills E. Joabson A. etal,2010:2015, *Characterization of particular matter size distribution and indoor concentration from Kerosene and diesel lamps*,indoor Air,:399-411

[47] Mowie,2019,*National Electrification Program,2.0:Integrating Planning for Universal Access-lighting to All*, Addis Ababa, Ethiopia

[48] Vemukonya, N., 2007,*Solar home System electrification as viable technology options for Africa development*, Energy policy,35(1):6-14,

[49] Martinose E, Chaurery A, Lew D, Moreira JR, Wamukonya N, 2002,*Renewable Energy Market in developing countries*, Annu Rev Energy Environment,27:309-48

[50] MOFED,2010,*Growth and Transformation Plan*,11-20.14/15, Addis Ababa, Ethiopia

[51] Mondal, M.A.H.,Bryan,E.,Ringler,C., Rosegrant,M.,2017,*Ethiopian Power Sector development:Renewable based universal electricity access and export strategies* , Renew.sustain.Energy Rev 75, 11-20. https://doi.org/10.1016/j.Energy.2018.02.067

[52] Mowie,2019,*National Electrification Program,2.0*,Integrating Planning for Universal Access-lighting to All, Addis Ababa, Ethiopia

[53] Barrie, J.,Cruicshank, H.J.,2017, *Shedding Light on the mile: a study on the diffusion of pas you go solar home system in central East Africa*, Energy po1.107,425-436,https://doi.org/10.1016//j.enpo1.05.016

[54] Ministry of Water and Energy, 2013, *Ethiopian National Energy Policy*, 2nd Draft, Addis Ababa, Ethiopia