American Journal of Applied Scientific Research
2023; 9(3): 97-108
http://www.sciencepublishinggroup.com/j/ajasr
doi: 10.11648/j.ajasr.20230903.13
ISSN: 2471-9722 (Print); ISSN: 2471-9730 (Online)

Review Article

The Status of Solar Energy Utilization and Development in Ethiopia

Ashenafi Bekele Mulatu*, Workneh Ayall Negash, Menberu Teshome

Department of Development and Environmental Management Studies, University of Gondar, Gondar, Ethiopia

Email address:
ashenafibekele63@gmail.com (Ashenafi Bekele Mulatu)
*Corresponding author

To cite this article:
Ashenafi Bekele Mulatu, Workneh Ayall Negash, Menberu Teshome, The Status of Solar Energy Utilization and Development in Ethiopia. *American Journal of Applied Scientific Research*. Vol. 9, No. 3, 2023, pp. 97-108. doi: 10.11648/j.ajasr.20230903.13

Received: February 17, 2023; **Accepted**: July 8, 2023; **Published**: July 24, 2023

Abstract: Ethiopia is endowed with abundant solar renewable energy resources, which can meet the ambitions of nationwide electrification. However, despite all its available potential, the country's energy sector especially solar energy is still in its infancy stage. The main objective of this systematic review is to identify the present status of solar energy utilization and development in Ethiopia and any possible challenges that may hinder its' utilization and development. Regarding the methodology of the study, a systematic review was used to collect data. Data were collected from selected articles and journals based on inclusion and exclusion criteria; mainly based on their level of relevance to the topic under study. Hence, this paper was prepared by reviewing the findings of empirical research results which were conducted in different parts of Ethiopia. Literature was collected thoroughly from main scientific databases like the Web of Science, Journal of citation report, Scopus, Google Scholar, citation tracing and science direct. Those articles dealing with the status of solar energy utilization have been considered for the selection process by using inclusion and exclusion criteria. The criteria employed to incorporate different related studies into a systematic review were the time of publication, similarity, type of publication and scope of the journal between 2015 and 2022 years. From the total of 192 articles assessed, only 12 were identified for this systematic review. Most of the articles included in the study were case studies and qualitative and mixed studies. The analysis result of this research shows that increasing the participation of photovoltaic energy in the renewable energy market requires raising awareness regarding its benefits; increasing the research and development of new technologies; implementing public policies and a program that will encourage photovoltaic energy generation. It also found that the main applications of solar energy in Ethiopia are dominated by telecommunications, water pumping, public lighting, agriculture, water heating, and grain drying.

Keywords: Solar Energy, Utilization, Development

1. Introduction

1.1. Background of the Study

Solar energy is essentially a free resource that can be found to varying degrees anywhere on Earth. Solar photovoltaic power plants generate electricity by converting solar radiation. In the current era of global climate change, photovoltaic technology offers countries and communities the opportunity to transform or develop their energy infrastructure and accelerate their low-carbon energy transition [44]. Both the theory of metabolic rift and ecological modernization theory (EMT) can be used to understand the empirical phenomenon of increasing adoption of solar energy technology [38]. Most developing countries are geographically positioned to absorb the sun's rays to the greatest extent possible. Many can be found along the equator or on vast desert expanses. Year-round sunlight is abundant in these locations, but there is a scarcity of water, biomass, and, in some cases, wind. Solar photovoltaic systems are ideal for maximizing energy production potential in these environments [37].

More than half of Africa's population lives in rural and remote areas. Most of these communities lack access to electricity due to a lack of or weak grid infrastructure isolating them. Solar energy, with its year-round availability in the region, is the best option for overcoming this issue via off-grid solutions [18].

The same empirical phenomenon is addressed by both the ecological modernization theory (EMT) and the metabolic rift theory. According to the metabolic gap theory, civilization, industry, and urbanization have damaged the natural metabolic link between humans and the environment. EMT, on the other hand, contends that countries in an advanced stage of industrialization adopt environmentally friendly political and production practices, arguing that contemporary cultures may be on the right track to lessen the ecological harm brought on by capitalism. Although the assumptions made by these two theories about contemporary economies and technologies are fundamentally different, both can be used as a theoretical lens to look at the phenomenon of the adoption of solar energy technology [38].

Energy is a necessary component of any nation's social and economic development. With an increase in agricultural and industrial activities in Africa, modern forms of energy are required for optimal start-up, efficiency, and sustainability of these activities, which are required for the African continent's development. Unfortunately, access to modern forms of energy has eluded Africans, with only about 30% of the population having access to electricity and 90% relying on traditional cooking fuels [20].

Africa has a high amount of solar energy, with most parts of the continent receiving annual average irradiance levels of more than 2 000 kWh/m2. The continent's estimated theoretical solar photovoltaic potential could provide more than 660, 000 TWh of electricity per year, far exceeding its projected needs. However, it only has 5 GW of installed solar photovoltaic (PV) capacity, which accounts for less than 1% of global capacity. Solar, if properly planned and implemented with the appropriate policies, has the potential to become one of Africa's primary energy sources [17].

Solar photovoltaics (PV) would be the second-largest power generating source by 2050, right behind wind power, and would pave the way for a radical restructuring of the world's electricity market. By 2050, solar PV would supply 25% of the world's electricity demands, making it a significant generation source [28].

Ethiopia, like other tropical countries, receives a lot of solar energy. The country's average solar energy potential is about 5.2 kWh/m2 per day. This potential, however, varies by season, with the lowest being 4.55 kWh/m2 per day and the highest being around 6.25 kWh/m2 per day [32].

The energy of the sun as a stable electricity source would never be damaged and environmentally friendly [22].

The solar resource is relatively lower in the country's most populous northern, central, and western highlands, whereas the rift valley regions and western and eastern lowlands receive higher annual average irradiance (above 6 kWh/m2/day). Even though the country had abundant solar energy resources, only about 14 MW of solar photovoltaics were used for telecom service, lighting, powering water pumps in rural areas, and water heating in major cities [17]. So, this study is intended to review the status of solar energy utilization, development, opportunities and challenges in Ethiopia.

1.2. Statement of the Problem

Solar energy is one of the most appealing renewable energy sources on the planet. It is abundant in nature and is free, with the main disadvantage to date being the low efficiency and high cost per kWh of solar cells. Due to the low efficiency of solar cells, large areas (huge solar cells) are required for large-scale solar production. As a result, various recent studies are focusing on solar cell designs to make them cheaper and/or more efficient, as efficiency is what makes them competitive with other renewable energy systems. The lack of energy storage technology is also a challenge for the system, as there is a significant difference in power output during the day [26].

Access to energy is among the key elements of Ethiopia's economic and social development. The energy sector in Ethiopia can be generally categorized into two major components: traditional and modern (traditional biomass usage and modern fuels i.e., electricity and petroleum). As more than 80% of the country's population is engaged in the small-scale agricultural sector and lives in rural areas, traditional energy sources represent the principal sources of Energy in Ethiopia Domestic energy requirements in rural and urban areas are mostly met from wood, animal dung and agricultural residues. At the national level, it is estimated that biomass fuels meet 88 % of the total energy consumed in the country. In urban areas, access to petroleum fuels and electricity has enabled a significant proportion of the population there to employ these for cooking and other domestic energy requirements. Access to biomass fuels has declined significantly in all areas of the country and drastically in some parts. Reduced access to woody biomass has had serious developmental and social impacts. Less access to wood means more has to come from other biomass sources to meet the fuel demand. This has eroded the balance between what goes in for agricultural production and animal manure for fertilizer, and what goes out of it, i.e., food for humans and animals [31].

Remote homes and villages in developing countries derive their energy from environmentally harmful practices due to the inaccessibility of clean, renewable energy sources. The traditional and most important energy source is fuelwood and charcoal made from fuelwood. Also called potentially renewable biomass, these are the main sources of energy for heating and cooking for roughly half the world’s population. Within a few decades, one-fourth of the world’s population in developed countries may face an oil shortage, but half the world’s population in developing countries already faces a fuelwood shortage [37].

Having a focus on thermal collectors, thin film panels, and monocrystalline cells, various solar energy technologies. The examination looks at things including the system's effectiveness, durability, and particular restrictions [11].

About 5 MW installed capacity of solar electricity generating units has been put in use (excluding water pumping for which data could not be obtained). Even though the total exploited solar energy looks insignificant, the energy demand being addressed through these solar installations is vital, serving remotely located rural communities, schools and health centres with badly needed electricity services, that otherwise would not have been served [32].

There is great uncertainty about how climatic change will affect future energy production in Ethiopia. The effects of climate change are debatable. In the Ethiopian highlands, precipitation may increase rather than decrease, which may increase water availability for hydroelectric power generation. However, if increases in precipitation only occur during the rainy season this may not translate to increased hydroelectric energy production as water scarcity normally arises during the dry season. Hence, increased precipitation may not necessarily benefit hydroelectric production unless it occurs during the dry season. Increases in the intensity of precipitation may increase the risk of flooding, siltation, and sedimentation, which directly affect the capacity of hydroelectric reservoirs. Ethiopia needs to invest in relatively expensive renewable energy resources in pursuit of green energy development, poverty alleviation, and energy security; however, such an effort is hindered due to the high capital costs of alternative energy resources [16].

Application of solar energy utilization improves human wealth, reduces environmental and health risks that arise from household air pollution, reduces the expenditure on kerosene, improves the access to electricity supply improves electricity generation capacity and improves the development of renewable energy [12]. Several researchers study about solar energy utilization in the country [13] Analysis of Solar Energy in Ethiopia, [19]. Techno-economic analysis of solar energy system for electrification of a rural school in Southern Ethiopia, [5] Standalone Solar Power generation to supply backup Power for samara university in Ethiopia, [24] Solar Energy Potential and Future Prospects in Afar Region, Ethiopia [3]. Assessment of Solar Energy Potential of East Gojjam Zone Ethiopia. However, unlike previous studies, the purpose of this study was to conduct a systematic review of related literature to assess the status of solar energy utilization of solar energy development, opportunities and challenges in Ethiopia.

1.3. Objectives of the Study

1.3.1. General Objectives of the Study

The main objective of this systematic review is to identify the present status of solar energy utilization and development in Ethiopia and any possible challenges that may hinder its utilization and development.

1.3.2. Specific Objectives of the Study

1) To examine the Status of solar energy utilization in Ethiopia
2) To assess solar energy potential and development opportunities in Ethiopia
3) To identify the main challenges in utilizing solar energy in Ethiopia

1.3.3. Research Questions

Key research question, which the study seeks to find an answer for:

1) To what extent does solar energy utilization exist in Ethiopia?
2) How many solar energy potentials and opportunities exist in Ethiopia?
3) What are the main challenges in utilizing solar energy in Ethiopia?

1.4. Significance of the Study

The study is significant because it provides information on current solar energy utilization in Ethiopia. Also, provide information on how solar energy technologies are used in the country to light homes, produce hot water, heat homes, and generate electricity. And it can also demonstrate the country's solar energy potential.

2. Methods

This section aims to show how journals were identified, the search strategies, and the eligibility criteria i.e., inclusion and exclusion criteria, information sources, assessment of quality studies and analysis of data. Thematic analysis guides a researcher to identify and analyze themes occurring in the data. According to the research [33]. A systematic review can be designed to provide an exhaustive summary of current literature relevant to a research question. Hence, this systematic review was prepared by summarizing and synthesizing the findings of empirical research results conducted in different parts of the study area. This review is composed of a comprehensive search for reliable databases on a specific topic, followed by an appraisal and synthesis of those studies according to a predetermined method.

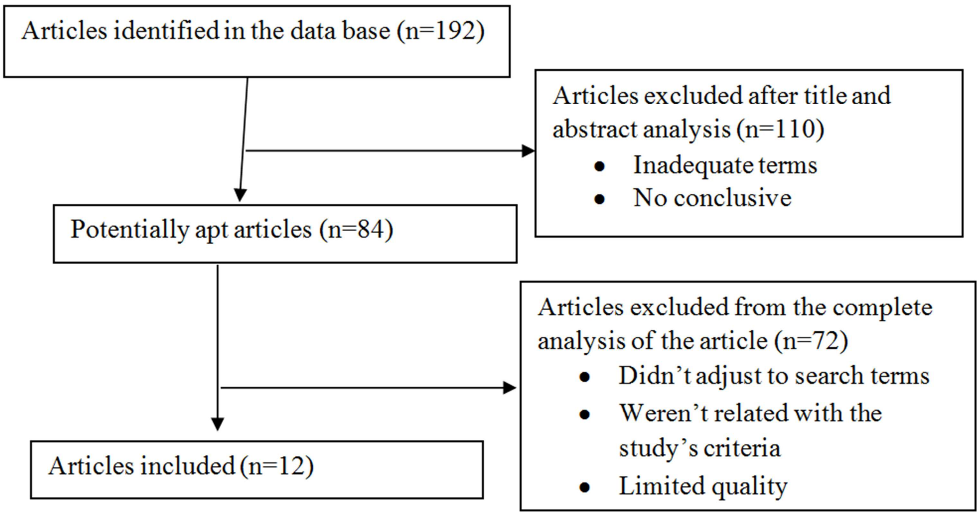
2.1. Data Source and Study Selection

To undertake this systematic review, literature was collected thoroughly from main scientific databases like the Web of Science, Journal of citation report, Scopus, Google Scholar, citation tracing and science direct. Hence, data from selected articles and journals were extracted based on criteria of inclusion and exclusion of papers; mainly based on the level of relevance with the topic under study, published year and study area. The specific key terms and phrases related to the issue under study were used to screen out studies for inclusion in the review process. Those articles dealing with the status of solar energy utilization have been considered for the selection process. *Inclusion criteria*: The criteria employed to incorporate different related studies into this systematic review were time of publication, similarity, type of publication and scope. The studies considered in the review do have the characteristics like their relation to the objective of the review, conducted within the scope of the review and published in a their-reviewed journal between 2015 and 2022 years. Moreover, an outstanding emphasis was given to the research works resulting from the scientific database consultations and even selected one from another within the same search engines based on the quality or position of the journal and its rankings.

Exclusion criteria: The studies published before 2015, conducted out of the target area, with differences in objectives with similar topics and journals which were not well recognized by the Ethiopian Ministry of Education were excluded to be part of the systematic review. Besides, the review also ignored the journals which were not peer-reviewed and had a poor-quality position in its rankings.

Data collection: Different information like author/s name and publication date, journal name, type and category of publication, study settings, methods and key findings were collected and extracted systematically from the identified studies.

Quality assurance mechanism: To promote the reliability and validity of the systematic review, the [34]. flow diagram was strictly applied. As is mentioned in the figure 1 below, the issues related to the objective of the review, adequate terms, conclusiveness, inclusion/exclusion criteria, method of data analysis and concrete data presentation were strictly checked and controlled. Hence, taking into account all the aforementioned key procedures and criteria, from the total of 192 articles assessed, only 12 were identified for this systematic review. To promote the validity of the findings of the study and to strengthen the triangulation of the data obtained, research conducted in the different parts of Ethiopia was fairly entertained. Most of the articles included in the study were case studies and mixed studies. But for the study, mixed studies aspects were selected to synthesize using the thematic analysis.



Source: PRISMA 2009 flow diagram.

Figure 1. *PRISMA 2009 flow diagram.*

2.2. Method of Data Analysis

Conducting a periodical systematic review of a given field of study enables us to comprehend the conceptual development of a discipline. This review is, therefore, executed to systematically analyze solar energy research articles published in the previous 7 years and thereby reassess the past, understand the present and envisage the future of solar energy utilization and development. Thematic and summative content analyses were employed to examine the contents of each publication. The current study provides up-to-date insight into the solar energy utilization and development literature by highlighting the main themes and trends of solar energy utilization and development research over the last seven years.

2.3. Description of the Study Area

Ethiopia is a landlocked country located between 3oN (Moyale) and 15oN (Bademe - the northernmost tip of Tigray) latitudes and 33oE (Akobo) to 48oE (the tip of Ogaden in the east) longitudes. The east-west distance (150) is longer than the north-south distance (120) within the area of 1,106000 km^2 [30].

Neighbours are Kenya, South Sudan, Sudan, Eritrea, Djibouti and Somalia. Relies on Djibouti as its main port. Features diverse terrains – from cold highlands (Ethiopian Highlands) to extremely hot depressions (e.g., Danakil depression). Therefore, it has distinct regional variations in climate, vegetation, soil composition, and settlement patterns, Populations estimated at 115 million as of 2021, with an annual growth rate of 2.5 percent. It is the second most populous nation in Africa after Nigeria. Ethiopia has registered an average of 10.4 percent per annum from 2005-2019, making it one of the fastest-growing economies in Africa [4].

Ethiopia is endowed with abundant renewable energy resources, which can meet the ambitions of nationwide electrification. However, despite all its available potential the country's energy sector is still in its infancy stage. The majority of the Ethiopian population lives in rural areas without access to modern energy and relied solely on traditional biomass energy sources. Nowadays Ethiopia has one of the lowest electricity consumption per capita in Africa. Recognizing that energy access and security are crucial factors in economic growth; Ethiopia needs to cope with key challenges related to energy security and diversification of the energy supply. Further ethe current state of renewable energy resources are described and existing energy policies are articulated [7].

3. Findings of the Study

3.1. Location, Study Approach, Objectives and Methods of the Studies

Table 1. *Location, Study approach, Objectives and methods of the studies.*

Author (s) Year of publication	Location, Setting	Study approach	Main objectives	Methods
Misrak Girma Abebayehu Assefa and Marta Molinas (June 2015) [21]	Amhara, (Siadeberand Wayu) Oromia (Wolmera) and Tigray (Enderta) Ethiopia	Mixed approach	To study the feasibility of a solar photovoltaic water pumping system for drinking water supply to three selected rural areas in Ethiopia.	NASA-SSE satellite data PVsyst software database meteorological tool.
Ankamma Rao J, Bizuayehu Bogale, Asefa Sisay May – 2017 [35]	Afar, Samara University, Ethiopia	Mixed approach	To design a system to extract solar power using a PV array, to supply power for Samara University as backup power to the main power supply.	Document Analysis Practical, World Atlas
Antene Belay November 2018 [13]	Ethiopia	Mixed approach	To analyse the current state of the art in the utilization and promotion of solar energy	Document analysis Analyses.
Tegenu Argaw Woldegiyorgis September 2019 [42]	Boke Village, near, Nekemte city Oromia Regional State, Ethiopia	Mixed Approach	To assess the potential of a solar PV power system to provide the required electricity for a rural community Boke village, near Nekemte city in the Oromia regional state of Ethiopia.	Document analysis And literature review
Nagesso Beker August 2019 [12]	Ethiopia	Mixed approach	To evaluate solar energy's potential as a power generation and financial feasibility for selected locations in rural areas of the country.	Simulation Analysis PVGIS and PVWatt Global Solar Atlas
Antene Belay January 2019 [14]	Ethiopia	Mixed approach	To review the current status, future potential and barriers to the development of renewable energy for power generation in Ethiopia.	The questionnaire, Document analysis
Seife Ayele, Wei Shen, Tadesse Kuma, Worako, Lucy H. Baker and Samson Hadush (December 2021) [2]	Ethiopia	Mixed approach	Aims to understand the legal and institutional framework needed for a renewable energy competitive bidding programme to be effective in Ethiopia.	Interview consultation workshop: Deskwork or document analysis
Ashebir Dingeto Hailu and Desta Kalbessa Kumsa November 2020 [6]	Ethiopia	Mixed approach	To carry out Ethiopia's renewable energy potential and current state.	Document analysis And Literature review
Anshebo Getachew Alemu1, Teketel Alemu (May 26, 2021) [24]	Afar Region, Ethiopia	Mixed approach	To provide scientific information on the solar potential of the Afar region, for photovoltaic (PV) solar energy industry sectors.	Solar shortwave radiation transfer model.
Girum Ayalneh Abreham Tesfaye Yedilfana Setarge Natei Ermias Gebrehiwet Abraham and Ramato Ashu (September 2021) [1]	Ethiopia	Mixed approach	To provide a comprehensive assessment of renewable energy availability, potential, opportunity, and challenges in Ethiopia.	Document analysis
Natei Ermias, Yedilfana Setarge Mekonnen, Ashenafi Asfaw, Mulatu Tegenu Argaw, Chernet Amente Gaffe & Abreham Berta (Jan, 2022) [19]	Wolaita Zone of Southern Ethiopia,	Mixed approach	Techno-economic analysis of solar energy system for electrification of a rural school in Southern Ethiopia	Field observation, Document analysis

Author (s) Year of publication	Location, Setting	Study approach	Main objectives	Methods
Engidaw Abel Hailu1, Ayodeji Olalekan Salau Amache Jara Godebo (March 20201) [3]	East Gojjam Zone, Oromia regional state, Ethiopia	Mixed approach	To the assessment of the solar energy potential of the East Gojjam Zone in Ethiopia	Angstrom-Prescott (AP) Model

Source: (Owen review data 2022).

3.2. The Status of Solar Energy Utilization, Development Opportunities and Challenges in Ethiopia

Table 2. *The status of solar energy utilization, development opportunities and challenges in Ethiopia.*

Author Year of publication	Findings of the studies/The selected articles		
	Status/development level solar energy in Ethiopia	Potentials and Opportunity	Challenges/ and Limitations
Misrak Girma Abebayehu Assefa and Marta Molinas (June, 2015) [21]	The life cycle cost analysis of pumping water shows that the SPV water pumping system is more economical and feasible compared to the Diesel system.	The results of this study are encouraging the use of the PV system for drinking water supply in remote areas of the country.	Cloudy days and summer time Minimizing the solar energy captured. Governments' commitments toward solar energy sector development
Ankamma Rao J, Bizuayehu Bogale, Asefa Sisay May – 2017 [35]	No Actually in practice. It is an approach/ scenario for designing a solar power plant to supply power to all classrooms of buildings of Samara University.	The geographical location of Samara University, camera, Ethiopia makes it a relatively sun-rich region with an average daily irradiance of more than 7000Wh/m2/day	Administrative commitments and Lag Approval for research And Materials supplying
Antene Belay November 2018 [14]	increase the use of solar energy Proved technology available and local production proficiency creating jobs for the young technicians	80% of the people are living in rural areas in this area we will find those consumers. The rise of oil prices shifted to the development of solar energy Solar energy is environmentally friendly	Low market penetration and No promotion and very low utilization of this energy snow, in such areas solar energy is limited. All solar equipment will import and the investment cost is when compared to the other source High maintenance cost,
Tegenu Argaw Woldegiyorgis September 2019 [42]	Abundant (average) solar energy potential of 5.52 KWh/m2/day. Electric load for a single household, school, and clinic was estimated at 313, 2064, and 2040 Wh/day respectively.	The use of PV systems to electrify the remote sites of Ethiopia considering its long-term benefits and less cost of installation compared to national grid extension to the remote sites.	Low government commitment, risky security around the Area and foreign currency shortage, and lack of trend human labour around the field. Low technical assistance
Nagesso Beker 2019 [12]	Ethiopian annual solar radiation ranges from 1730kWh/m2 in Chencha city to 2481kWh/m2 in Asaita city. The annual PV energy was found to be 1686.579 kWh, 5059.95 kWh, and 83832 kWh respectively.	The financial evaluation shows that system solar energy is economically feasible.	Low investment in solar energy Low promotion for government and actors Stakeholders need high capital
Antene Belay (January 2019) [14]	a country has 5.5 kWh/m2/Day of solar radiation which can be benefited from solar energy. The solar is utilized in different forms. solar energy is exploited by small off-grid components under rural electrification programs installed for schools, social institutions health institutions and Tele-com towers.	Environmentally friend and sustainable utilization is the most important opportunity and benefits of solar energy	In the country, there are no big solar farms Yet, the development of this renewable energy was hindered by different barriers
Seife Ayele, Wei Shen, Tadesse Kuma, Worako, (2021) [9]	Ethiopia has held two solar photovoltaic (PV) projects that led to the signing of (PPAs) and were hailed	The newly established PPP The framework has laid a solid foundation for the future development of (non-	Overlapping roles and functions, capacity deficiencies, and risk to the private sector
Lucy H. Baker and Samson Hadush (December 2021) [10]	as one of the cheapest tariff rates in sub-Saharan Africa, at 2.526 cents/kilowatt hour (kWh) over 25 years. However, none of the projects has yet become operational.	hydro) renewable energy projects in Ethiopia.	investment. Weak and fragmented IPP governance Weak policy support for the nascent domestic private sector Security risks and Access to land/project sites
Ashebir Dingeto Hailu* and Desta Kalbessa Kumsa November 2020	Even though, abundant solar energy resources were available in the country only about 14 MW of solar PV have been used for telecom service, lighting,	Ethiopia has launched the first tender to build, own and operate three 100 MW solar PV projects and ENEL Green Power (EGP) was selected as the	Unevenly distribution of solar energy utilization and underutilization of only about 14 MW of solar PV have been implemented limited only used for telecom

Author Year of publication	Findings of the studies/The selected articles		
	Status/development level solar energy in Ethiopia	**Potentials and Opportunity**	**Challenges/ and Limitations**
[6]	powering water pumps in rural areas and water heating in major cities	preferred bidder for one of the projects, located near Metehara.	service, lighting, powering water pumps in rural areas and water heating in major cities
Engidaw Abel Hailu, Ayodeji Olalekan Salau Amache Jara Godebo March 2021 [3]	The annual mean daily global horizontal radiation for Debre Markos, Debrewerk, Mota, and Yetnora is 5.88, 6.52, 6.28, and 6.31 kWh/m2/day, respectively, and 6.30kWh/m2/day for East Gojjam	East, Gojjam Zone, which is a very good solar energy potential.	Solar energy fluctuation because of the season Low studies and implementation of solar energy in the region
Anshebo Getachew Alemu1, Teketel Alemu (May 26, 2021) [24]	The Afar region is exceptional solar potential with significant AV. The solar flux of 239.9W/m2), AV. Annual. Density 2.102 MW/h/m2·a, therefore, the afar region is the A prospective candidate for the development of PV power systems.	PV systems have been the main pillar of solar energy in Afar region so far, it is expected that these types of systems could bring more immediate solutions for inhabitants without access to common energy sources in Afar region hydroelectric energy.	Average solar radiation power and average annual total solar energy of unit area are higher in Tigray (246.48 W/m2), Amhara (240.34 W/m2) and the Afar (239.9 W/m2) respectively. In comparison to other regions and total solar radiation, the afar region cover third rank next to Tiger and Amara region
Girum Ayalneh Abreham Tesfaye Yedilfana Setarge Natei Ermias Gebrehiwet Abrham and Ramato Ashu (September, 2021) [1]	The area has a high potential for renewable energy developments, with a RE penetration rate of 92.855 %, which has reduced the operating hours and fuel consumption of the diesel plants to 340 hours per year and 303 L of fuel	Thus, this system is environmentally friendly because it contributes to the maintenance of a clean and safe atmosphere through the use of low-pollutant fuels. The solar PV off-grid hybrid system is believed to be the optimal option for electrifying Ethiopia's remote rural communities	The largest share of energy consumption (≈87%) in Ethiopia is dominated by traditional fuels (charcoal, fuel wood, dung cakes, and agricultural residues) which pose various health and environmental risks.
Natei Ermias, Yedilfana Setarge Mekonnen, Ashenafi Asfaw, Mulatu Tegenu Argaw, Chernet Amente Gaffe & Abreham Berta (Jan 2022) [19]	PV/DG/battery hybrid energy system (HES) with a 7.5 kW PV, 7.3 kW DG, 6.60 kW converter, and 11 units of batteries (case I) is the most feasible, optimized, cost-effective and environmentally friendly system among the systems considered.	This system has a Net Present Cost (NPC) of $32,019 and a Cost of Energy (COE) of $0.254/kWh, as computed using current equipment values. The optimized system is also environmentally benign, emitting 793 kg of carbon dioxide per year, about 91% less than the PV/diesel combination (worst case IV).	Policymakers can't create the necessary investment environment; such projects can be a viable alternative to rural electrification. Weak policy support for the nascent domestic private sector

Source: (Owen review data 2022).

3.3. The Status of Solar Energy Potential in Ethiopia

As is depicted in the aforementioned two tables, this systematic review was made employing eight research articles which were undertaken in the different corners of the Ethiopian regional states. Amhara regional state Siadeberand Wayu and Eastern Gojjam, Oromia Regional state Wolmera, Tigray regional state Enderta, South nations and nationalities of Ethiopia, Wolaita Zone Ethiopia, and Afar Region Samara. The results of these selected studies acknowledged that the region possesses high potential for solar energy possession of renewable Solar energy resources which have a central role in its future economic growth with great environmental benefits by reducing biomass and fossil fuel consumption in the country. It further articulated that Ethiopia has high solar energy potential related to its position and gifted 13th-month sunshine. The solar energy potential of the country may result because of the existence of the country in low latitude makes with high annual solar energy region in the world and maybe the future of Ethiopia's energy source next to hydroelectric power may cause foreign currency earnings and attraction of international energy company and may put the base for the development of solar energy in the country.

Besides, different study results stated that Ethiopia is famous for its high solar energy potation in Africa. In Ethiopia, solar PV is utilized for off-grid areas and grid-connected areas. The off-grid application of lighting and income generation activity. Solar PV for off-grid areas to lighting social institutes like (health centres, schools and farmer training centres), Households (including run TV, and radio), telecom towers (network towers) and town water supply (water pumping). Currently is not practised by generating huge power and feeding it to the national grid. Due to always blacking out people are practising using small-scale solar for household light and charging mobiles. In Ethiopia, people are using solar energy in off-grid areas due to the following reasons: scattered population, low investment cost, reliable power, and creating local jobs and incomes for distrusters [13].

To provide rural communities with low-cost electricity, innovative off-grid renewable energy-producing techniques have emerged. The International Energy Agency estimates that around 45% of Ethiopia's total population has access to electricity. Nearly 85% of Ethiopia's urban population has access to public electricity, but this figure is only 29% for the rural population [19].

3.4. Actual Status of Solar Energy Site in Ethiopia

In the solar energy industry, calculations are made using the amount of sun energy provided by the sun over the period of a day. The intensity (brightness) of the sun is referred to as solar insolation. When the sun is at its brightest during the day the light intensity is measured using an irradiance meter (or pyranometer) and measured in Watt per meter squared (W/m2). The target value is 1,000W/m2. This value is typical of sunlight intensity at noon when the sun is highest in the sky [23].

The main energy policy goal is to ensure the availability, accessibility, affordability, safety and reliability of energy services to support accelerated and sustainable social and economic development and transformation of the country. With seeks to meet: Improve the security and reliability of energy supply and be a regional hub for renewable energy, Increase access to affordable modern energy. Promote efficient, cleaner, and appropriate energy technologies and conservation measures. Strengthen energy sector governance and build strong energy institutions, ensure environmental and social safety and sustainability of energy supply and utilization and Strengthen Energy Sector Financing [8].

While the markets for off-grid lanterns and solar household systems have grown, the technical services infrastructure – including capacity for design, manufacture and assembly, as well as installation and service provision – has not grown along with the rapid increase of sub-standard solar products on the market. As a consequence, customers have had to deal with faulty installations, encountering technical problems with their devices and problems with poor quality. Investment barriers Too many organizations are involved in the business licensing, quality verification and taxation processes for off-grid solar products. The process involves numerous actors, ranging from ministries to banks and agencies working together in a system that is not streamlined. This has led to delays and increased transaction costs for enterprises. In addition, it has made the off-grid business unattractive for investors and made higher-wattage off-grid equipment unaffordable for most end-users, thereby decreasing the penetration rate of off-grid solar equipment [29].

The involvement of various agencies in the importation process has also created communication gaps that inconvenience enterprises involved in the import and distribution of solar products. This is compounded by unclear jurisdiction in terms of which agency is in charge of verifying and approving quality certificates for solar products when they arrive at customs. It appears that the Ministry of Water, Irrigation and Electricity, the Ethiopian Energy Authority, the Ethiopian Revenues and Customs Authority, the Ministry of Trade, and the Ethiopian Conformity Assessment Enterprise all assume some responsibility, depending on various factors that are neither clearly defined nor effectively communicated to importers. Presently, solar equipment that is imported into the country takes about 47 days to be fully tested. Testing is conducted without unloading the goods from the truck, which brings about high demurrage expenses for the importer. Financial constraints and the limited availability of foreign currency requires importers to wait up to three months or longer to access the foreign exchange needed to purchase solar products [29].

Coupled with high-interest rates for solar products, have depressed demand and made solar products unaffordable for many. Enterprises are required by multilateral financial institutions to deposit 10% of the value of the products being imported. Multilateral financial institutions also charge interest rates of 15– 20%. Similarly, commercial banks provide loan guarantees to solar enterprises to access a loan facility from the Development Bank of Ethiopia. While the Bank charges 12% interest, commercial banks add 4% to secure the loan guarantee, increasing the total interest to 16%, which is directly accrued by the end-user – increasing costs further [29].

3.5. Ongoing Renewables Solar IPP Projects

3.5.1. The Gad and Dicheto Solar PV Projects

Have the greatest potential for solar energy production in the country. ACWA has proposed the most attractive selling rate at US$0.02526 per kW/h, one of the lowest tariffs on the continent. ACWA Power won a 25-year contract, with a total investment in both projects of US$180m [8].

3.5.2. Metehara Project

This project was developed as the first utility-scale solar PV plant, with 100MW installed capacity in the Oromia region. The tendering process was launched by EEP in May 2016, and among five shortlisted consortiums, the Italian energy company Enel's renewable energy subsidiary Enel Green Power (EGP) was selected in 2017 as the preferred bidder. This US$120m project is scheduled to generate approximately 280-gigawatt hours (GWh) per year and to sell electricity to EEP under a 20-year PPA. The development of the project has been assisted by the United States Agency for International Development (USAID) Power Africa programme and the World Bank [29].

Table 3. *Non-hydro renewable energy IPPs under implementation in Ethiopia (as of 2021).*

Project (energy source & region)	Capacity	Awarded project developer	Cost (US$ mil.)	Tariff (US$ in KW/h)	Project tenure
Metehara (solar, Oromia)	100MW	Enel Green Power & Orchid Business Group	120	n/a	20
Gad (solar, Somali)	125MW	ACWA Power	90	0.02526	25
Dicheto (Solar, Afar)	125MW	ACWA Power	90	0.02526	25

Source: (Owen review data 2022).

3.6. The Cause for Underutilization of Solar Radiation Energy in Ethiopia

Ethiopia is located in the tropics, which means it has an abundance of solar energy. However, solar energy is underutilized, and the energy sector is the least developed because solar radiation is measured using ground instruments at meteorological stations. Instrument installations that directly measure global solar radiation are quite costly, so the spatial density of instruments is low. In Ethiopia, for example, there is only one Pyranometer, which is currently inoperable. Furthermore, unlike rainfall and temperature, solar radiation cannot be confidently extrapolated to other areas based on a few sample measurements. This is primarily because solar intensity is heavily influenced by topography and surface features. Digital Elevation Models (DEMs) are essential for determining these topographic features that influence the amount of incoming solar radiation. Estimation of solar resources in complex topography and inaccessible areas, where measurements are not available and/or expensive to measure over large areas, is fast, cost-effectively, and reliable using DEM [40].

Innovative off-grid renewable energy-producing techniques have emerged to provide low-cost electricity to rural communities. According to the International Energy Agency, approximately 45 percent of Ethiopia's total population has access to electricity. Public electricity is available to nearly 85 percent of Ethiopia's urban population, but only 29 percent of the rural population [19].

The main reason for low solar energy utilization in Ethiopia is that the country's feed-in tariff law has not been improved to encourage investors to invest in the rural energy development market. Another bottleneck in improving solar energy technology adoption and increasing installed capacity in the sector was the financial issue [12].

Lack of awareness is exacerbated in some rural communities by a lack of TV and radio stations, making those advertising channels inaccessible. Furthermore, market actors, particularly solar panel and system suppliers, are experiencing a lack of assistance in marketing and promoting rural energy technologies. Additionally, Irradiation, shading, sorting, array orientation, array asymmetry angle, array angle, roof structure and condition, system location balance, and latitude are all factors that influence PV system performance [43].

Because of the solar resource's day/night variation, the practical use of solar energy faces two overarching technological challenges: economically converting sunlight into useful energy and storing and delivering that converted energy to end users in an economical, convenient form. Solar electricity and any other solar energy conversion system will require tightly integrated storage and distribution technology to provide energy to end users on demand. Furthermore, there must be a cost-effective way to convert this energy into forms suitable for transportation, residential, and industrial applications [39].

3.7. Consequences of Low Solar Energy Utilization

Solar energy is one source of energy that is harnessed today to provide electricity [15]. The utility level of solar energy systems is growing in popularity around the world, driven by technological advancements, policy changes, and the urgent need to reduce our reliance on carbon-intensive energy sources as well as greenhouse gas emissions into the atmosphere [27]. Solar PV capacity in Ethiopia has almost tripled in the past five years. However, 14 MW of solar PV systems has been installed up to now, counting for 0.3% of the Nation's total energy capacity. Ethiopia's solar capacity is expected to increase in the coming years with the number of ongoing solar PV projects. Most of this installed 14 MW solar PV capacity is used for telecom systems, both mobile and landline network stations [18].

A significant portion of the global economy is reliant on fossil fuels. Not only the ubiquitous plastic, but also various types of moving, transporting, heating, and running electric devices rely to varying degrees on oil, coal, and gas usage and energy retrieval. The use of these energies comes with some inherent risks. Power plants, distribution networks, and storage facilities are vulnerable to both natural disasters and human-caused destruction (Beck, 2018). On a more practical level, as fossil fuels, most notably crude oil, become more expensive and scarcer, solar energy is likely to become very useful in providing for more localized communities. It is debatable how much time we have left in the free distribution of fossil energy, oil, gas, and coal, as well as uranium for nuclear power, to be replaced by new and alternative technologies, such as solar energy [36].

Currently, the main energy source used in rural areas of Ethiopia for cooking and heating is unprocessed biomass and fossil fuel such as kerosene, paraffin and petrol/diesel. These energy sources generate a large volume of indoor air pollution that increases the risk of chronic diseases. Solar energy is the most practical and economical way of bringing power to poor and remote communities in the long term and Ethiopia is strategically located in a maximum sun shines hours zone [42].

The future impact of climatic change on Ethiopia's energy production is highly unknown. It's debatable whether climate change has any effects. In the highlands of Ethiopia, precipitation may rise rather than decrease, potentially resulting in more water being available for the production of hydroelectric power. However, since water shortage typically develops during the dry season, if precipitation increases only take place during the rainy season, this may not convert to increased hydroelectric energy output. Therefore, unless it happens during the dry season, greater precipitation may not always help hydropower generation. As precipitation intensity rises, there may be a greater chance of floods, siltation, and sedimentation, all of which have a direct impact on the capacity of hydroelectric reservoirs. Large hydroelectric projects are now being constructed in Ethiopia. The adage "Don't put all of your eggs in one basket" applies to investments. As practically total reliance on huge hydroelectric reservoirs may involve enormous energy security hazards, growing risk or financial loss also pertains to energy security. There may be numerous adaptation strategies available to deal with drought or climate change like solar energy utilization at a national level [16].

3.8. Implementation Barriers of Solar Energy Technologies in Ethiopia

Table 4. *Implementation barriers of Solar Energy Technology in Ethiopia.*

Technical	Capacity	Information	Economic	Institutional	Policy
Lack of local content development	Inadequate technology development	Inadequate dissemination efforts	Lack of affordability due to high levels of poverty reflected by the low GDP per capita	Institutional inadequacies at all levels in terms of research facilities and research outputs: patents, publications in the context of translating invention to innovation	The policies are outdated, especially the Energy Policy document from 1994
Lack of training facilities	Lack of technical expertise in the context of the STEM fields	Inadequate feedback mechanism	High-interest rates	Lack of a laboratory inventory between various Institutions	Lack of updated electricity master plans
Lack of maintenance facilities	Tripartite structure of Government, Academia, and Industry not fully realized	Lack of awareness	High payback period	Lack of capacity-building programs at the various Institutions	Lack of appropriate Feed-in Tariff mechanisms
Lack of standards for solar and wind energy	Outsourcing and brain drain	Lack of a common database of data for replication	Lack of a comprehensive techno-economic assessment	Lack of cooperation between Institutions in the context of fragmented research	Lack of roadmaps and standards for solar technologies for embedded generation
Lack of a structured know-how exchange	Lack of state-of-the-art manufacturing companies in solar/wind	Lack of quality assurance and control mechanisms	Lack of innovative and cost-efficient technologies	Lack of appropriate technology	Lack of an energization plan
Lack of qualified and competent engineers	Lack of solar and wind test stations and facilities	Fragmented coordination including weak linkages	High product cost due to lack of scale	Lack of supercomputers and advanced facilities	Lack of comprehensive wind/solar resource maps
Lack of frugal engineering practices	Lack of pilot projects for replication	Lack of modern ICT facilities	Substandard imported products	Lack of manufacturing of solar cells and wind turbine blades	Top-down approach applied

Source: (Hameer and Ejigu, 2020)

4. Conclusion and Policy Recommendations

4.1. Conclusion

This paper has confirmed the huge potential of solar energy in Ethiopia. It has also confirmed that Ethiopia has enough solar radiation to solve its energy needs. With the many areas of utilization of solar PV cutting across the household, education, health, agriculture, and commercial, to mention just but a few, as well as the multi-faceted benefits derivable from exploitation and utilization of solar PV, there is no doubt that solar PV holds the key to bail Ethiopia out of her perennial energy crises. Ethiopia needs to invest in relatively cheap renewable energy resources in pursuit of green energy development, poverty alleviation, and energy security; however, such an effort is hindered due to the high capital costs of alternative energy resources. Technological and efficiency innovations are expected to have important roles in future energy investment pathways in Ethiopia. Policy measures could directly target innovation through the development of local skills and technical capacity. In the world of constrained resource availability technological and efficiency, innovations can be an engine of growth. This reflects the economic benefits of technological and efficiency innovations due to their role in reducing resource scarcity. Such policies would contribute to all four dimensions of energy security: affordability, accessibility, availability, and acceptability of clean energy to both rural and urban populations, and also offer green growth opportunities for Ethiopia. Different studies are conducted in different parts of the county such as Amhara regional state Siadeberand Wayu and Eastern Gojjam, Oromia Regional state Wolmera, Tigray regional state Enderta, South nations and nationalities of Ethiopia, Wolaita Zone Ethiopia, and Afar Region Samara. The results of these selected studies approved that the region possesses high potential for solar energy possession of renewable Solar energy resources which have a central role in its future economic growth with great environmental benefits by reducing biomass and fossil fuel consumption in the country. There is also, ongoing solar energy utilization, like Metehara, in Oromia, gad in Somali and Dicheto in Afar regional states. Generally, Solar radiation utilization status in Ethiopia is very low because its' installation material is imported from abroad and needs huge amounts of foreign currency.

4.2. Recommendations and Policy Implications

Ethiopia needs to invest in relatively expensive renewable energy resources in pursuit of green energy development, poverty alleviation, and energy security; however, such an effort is hindered due to the high capital costs of alternative energy resources. Technological and efficiency innovations are expected to have important roles in future energy investment pathways. For effective and efficient utilization of solar energy in Ethiopia, the following recommendations and policy implications will be useful:

1) Government should subsidize the cost of importation of Renewable Energy Technologies (RET) most especially solar PV to bring down the high cost in Ethiopia and make it affordable.
2) More research into the techno-economies involving the initial and subsequent costs of solar plants and their power efficiencies should be encouraged.
3) Private individuals and organizations should be encouraged by appropriate authorities to invest in solar technologies in the country.
4) Government should create more awareness of the advantages derivable from Renewable Energy Technologies (RET) such as solar technologies.
5) Government can also consider placing restrictions on the importation of diesel and petrol engine generators because of their adverse effects on the environment even as the global community gear toward clean (green) energies.
6) Funding for solar technology research and development initiatives in Ethiopia Universities, Polytechnics and Research Institutes to develop solar PVs with increased efficiency that will be adaptable to our environment is advocated as is obtainable in developing countries.
7) At last, PV electricity is the most viable option for power supply in areas where grid electricity is not reachable due to difficult topography, poor infrastructure and the resultant inaccessibility. Private investors and NGOs need to be encouraged to participate in the process of expanding PV-based off-grid power into rural areas.

References

[1] Ayalneh Tesfaye et al. (2021). Opportunities and Challenges of Renewable Energy Production in Ethiopia. Sustainability, https://doi.org/10.3390/.

[2] Ayele and Shen. (2021). Renewable Energy Procurement by Private Suppliers in Ethiopia. Addis Ababa: ids.ac.UK.

[3] Abel et al. (2021). Assessment of Solar Energy Potential of East Gojjam Zone Ethiopia Using Angstrom-Prescott Model. Article in International Journal of Engineering Research in Africa, 10.

[4] ADBG. (2020). African development bank group report.

[5] Ankamma Rao J et al. (2017). Standalone Solar Power Generation to Supply Backup Power for Samara University in Ethiopia. International Journal of Engineering Research & Technology (IJERT), 5.

[6] A. D. Hailu* and D. K. Kumsa (2020). Ethiopia's renewable energy potentials and current state. See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/346192887.

[7] Ashebir. (2020). Ethiopia's renewable energy potentials and current state. See discussions, stats, and author profiles for this publication.at: https://www.researchgate.net/publication/346192887.

[8] Ayalneh Tesfaye et al. (2021). Opportunities and Challenges of Renewable Energy. Sustainability, 25.

[9] Ayele, Shen, et al. (2021). Renewable Energy Procurement in Ethiopia: Overcoming Obstacles in Procurement from Independent Power Producers. Addis Ababa: ids.ac.UK.

[10] Baker and Hadush (2021) Procurement, finance and the energy transition: Between global processes and territorial realities. Environment and Planning E Nature and Space. DOI: 10.1177/2514848621991121.

[11] Beck, V. E. (2012). Utilization of Solar Energy in Liljeholmskajen. Stockholm: KTH.

[12] Beker, (2019). Evaluation of solar energy potential in Ethiopia as power generation source: a case study at 100 selected.

[13] Belay, A. (2018). The Study on the SWOT Analysis of Solar Energy in Ethiopia. Journal of Environmental Pollution and Management, 5.

[14] Belay, A. (2019). Current Status, Future Potential and Barriers for Renewable Energy Development in Ethiopia. https://www.researchgate.net/publication/343600889, 7.

[15] David and Ayodeji. (2014). Conceptual Framework for Sustainable Energy Development in Africa. Quest Journal of Electronics and Communication Engineering Research**.** *Volume1 ~ Issue1 (2013) pp: 10-19.*

[16] Diriba and Jan. (2015). Solar Power System: A Viable Renewable Energy Source for Nigeria.

[17] Dingeto and Kalbessa. (2020). Ethiopia's renewable energy potential and current state. http://www.aimspress.com/journal/energy, 14.

[18] Erkan Dursun (2021) Solar Energy Potential in the Horn of Africa: Journal of Electrical and Computer Engineering A Comparative Study Using Matlab/Simulink.

[19] Ermias et al. (2022). Techno-economic analysis of solar energy system. ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaen20, 22.

[20] Folasade Dahunsi (2013) Conceptual framework for sustainable energy development in Africa. Conference Paper DOI: 10.1109/NIGERCON.2013.6715661.

[21] Girma et al (2015) Feasibility study of a solar photovoltaic water pumping system for rural Ethiopia. DOI: 10.3934/environsci.2015.3.697.

[22] H F Ummah et al 2021 IOP Conf. Ser.: Earth Environ. Sci. 780 012007.

[23] Franklin, E. (2019). Calculations for a Grid-Connected Solar Energy System. Cooperative Extension, 8.

[24] Getachew and Alemu (2021). Solar Energy Potential and Future Prospects in Afar Region, Ethiopia. American Journal of Modern Energy, 6.

[25] Hameer and Ejigu, (2020) https://www.semanticscholar.org/paper/A-prospective-review-of-renewable-energy-in-Hameer-Ejigu/80454db0f8b8d090f52c41ecc9ac39fde42ab354

[26] Hailu, D. (2010). Ethiopian Energy Systems Potentials, Opportunities and Sustainable Utilization. ID: 126808393

[27] Hernandez et al. (2014). Environmental impacts of utility-scale solar energy. Renewable and Sustainable Energy Reviews, 1-15.

[28] IRENA. (2019). Future of solar photovoltaic Deployment, investment, technology, grid integration and socio-economic aspects. Abu Dhabi: International Renewable Energy.

[29] Lakew, Hailu et al. (2017). Climate for solar power: Solutions for Ethiopia's energy poverty.

[30] Mekonnen et al. (2019). Geography of Ethiopia and the Horn. Addis Ababa: Ministry of Education.

[31] MWE. (2012). Scaling-Up Renewable Energy Program the Federal Democratic Republic of Ethiopia.

[32] MWE. (2013). Ethiopian national energy policy (2nd draft). Addis Ababa.

[33] Nunn and Chang. (2020). What is a systematic review? Article in Wiki Journal of Medicine, 12.

[34] PRISMA. (2009). The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions:

[35] Rao J et al. (2017). Standalone Solar Power Generation to Supply as. International Journal of Engineering Research & Technology (IJERT), 5.

[36] Rhodes, C. (2010). Solar Energy: Principles and Possibilities. Caversham, United Kingdom: DOI: 10.3184/003685010X12626410325807.

[37] Saeed et al. (2006). Solar Power and Sustainability in Developing Countries. Proceedings of the International Conference on Renewable Energy for Developing Countries-2006, (p. 13).

[38] Schelly, C. (2015). Frameworks for Understanding and Promoting Solar Energy Technology Development. www.mdpi.com/journal/resources, 15.

[39] S. Lewis. (2005). Basic research needs for solar energy utilization. Washington: Renée M. Nault, Argonne National Laboratory.

[40] Teshome, F. (2014). Modelling solar radiation and GIS-based multi-criteria analysis. Trondheim.

[41] Tyagi et al. (2013). Progress in solar PV technology: Research and achievement. n Renewable and Sustainable Energy Reviews, Kuala Lumpur.

[42] Woldegiyorgis, T. A. (2019). Journal of Modern Materials, 1-10.

[43] Worku, A. (2021). Study Solar Energy Usage and Evaluation Activities around Bahir Dar, Ethiopia. https://doi.org/10.21203/rs.3.rs-665802/v1, 1-13.

[44] World Bank. (2020). Global photovoltaic power potential by country. 1818 H St NW.