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Review Article

The Status of Solar Energy Utilization and Development in Ethiopia

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ABSTRACT

Ethiopia is endowed with abundant solar renewable energy resources, which can meet the ambitions of nationwide electrification. However, in spite of 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; Solar renewable; Photovoltaic

INTRODUCTION

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 [1]. 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 [2].

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,

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with its year round availability in the region, is the best option for overcoming this issue *via* off grid solutions [3].

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 [4].

Africa has a high amount of solar energy, with most parts of the continent receiving annual average irradiance levels of more than 2000 kWh/m^2. 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 Photo Voltaic (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 [5]. Ethiopia, like other tropical countries, receives a lot of solar energy. The country's average solar energy potential is about 5.2 kWh/m^2 per day. This potential, however, varies by season, with the lowest being 4.55 kWh/m^2 per day and the highest being around 6.25 kWh/m^2 per day [6].

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/m^2/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. So, this study is intended to review the status of solar energy utilization, development, opportunities and challenges in Ethiopia.

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 [7].

Access to energy is among the key elements of Ethiopia's economic and social developments. 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 live 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 sources of biomass to meet the demand for fuel. 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 [8].

The 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 fuel wood and charcoal made from fuel wood. 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 fuel wood shortage.

About 5 MW installed capacity of solar electricity generating units have 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 centers with badly needed electricity services, that otherwise would not have been served.

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 [9].

Objectives of the study

General objectives of the study: The main objective of this systematic r eview 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.

Specific objectives of the study

- To examine the status of solar energy utilization in Ethiopia.
- To assess solar energy potential and development opportunities in Ethiopia.
- To identify the main challenges in utilizing solar energy in Ethiopia.

Research questions

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

- To what extent does solar energy utilization exist in Ethiopia?
- How many solar energy potential and opportunities exist in Ethiopia?
- What are the main challenges in utilizing solar energy in Ethiopia?

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.

LITERATURE REVIEW

Solar energy

Solar PV is an environmentally friendly renewable energy source that can be used in households, education, health and agriculture, social, communal, commercial and industrial sectors of the economy. Solar PV can be used for lighting, water pumping, cooking, phone charging, vaccine preservation, dairy refrigeration, egg incubation, crop and manure drying, and fish and poultry production, among other things. The paper listed the benefits of using solar PV, which included job creation, increased agricultural production and access to a large, pollution free energy source, among other things [10].

The sun is the central star of our solar system. It consists mainly of hydrogen and helium. The mass of the sun is so large that it contributes to 99.68% of the total mass of the solar system. In the center of the sun, the pressure temperature conditions are such that nuclear fusion can take place [11].

Solar electricity systems capture the sun's energy using Photovoltaic (PV) cells. The cells convert the sunlight into electricity, which can be used to run household appliances and lighting [12].

Our primary source of clean, abundant energy is the sun. The sun deposits 120,000 TW of radiation on the surface of the earth, far exceeding human needs even in the most aggressive energy demand scenarios. The sun is earth's natural power source, driving the circulation of global wind and ocean currents, the cycle of water evaporation and condensation that creates rivers and lakes, and the biological cycles of photosynthesis and life. Covering 0.16% of the land on earth with 10% efficient solar conversion systems would provide 20 TW of power, nearly twice the world's consumption rate of fossil energy and the equivalent 20,000 1-GWe nuclear fission plants. These comparisons illustrate the impressive magnitude of the solar resource, providing an energy stream far more potent than present day human technology can achieve [13].

Solar energy can also be used to produce electricity instead of heat. Photovoltaic (PV) cells employ semiconductor material to generate a flow of electricity when struck by sunlight. Though the technology is now well developed and reliable, it is also expensive compared to current energy sources, perhaps three times as expensive as fossil fuel generated electricity, depending on the specific circumstances being compared. Costs of solar PV have fallen considerably and are projected to fall further; an important issue, discussed further below, is whether and when solar costs will reach a fully competitive range. In contrast to other renewable energy sources, solar PV is sustainably available in almost infinite quantities, and in almost any location [14].

Solar radiation utilization and development

Existing solar companies are few, with less than 15 PV equipment suppliers in Ethiopia. However, only five or six companies supply 90% market. The other suppliers sell Photovoltaic (PV) systems along with many other products, with the solar business accounting for less than 5% of their annual turnover. While the private sector is the sole supplier of photovoltaic systems in the commercial market, it relies heavily on tenders from the public sector REF, Non-Government Organizations (NGOs), and foreign aid missions. Only a few companies like direct solar, Ethio-Dutch business, and ever bright sell off grid lighting products to consumers. Many other small electronic shops offer only small LED lighting products as off grid lighting technology options [15].

The social benefits of modern energy systems extend from health condition improvements to family safety and from economic improvements to a better quality of life. While the majority of the socially diverse but economically poor East African nation's population has no access to modern energy, many experiences the negative consequences of using firewood and different fossil fuels. One of the main socially devastating impacts of using wood as a source of energy in rural households is in connection with the burning of children, housewives and properties in many cases the house itself. Whereas the frequency may vary from region to region depending on the type of wood consumed, the type of stoves used, etc., the incident is rather common in many parts of the planet.

Rising concerns about climate change, the health effects of air pollution, energy security and energy access, along with volatile oil prices in recent decades, have led to the need to produce and use alternative, low carbon technology options such as renewables. Solar photovoltaic has been one of the pioneering renewable technologies over the decades. The total installed capacity of solar Photovoltaic (PV) reached 480 GW globally (excluding CSP) by the end of 2018, representing the second largest renewable electricity source after wind. Last year, solar photovoltaic again dominated total renewable and power capacity additions, adding twice as much capacity as wind and more than all fossil fuels and nuclear together, with solar Photovoltaic (PV) additions reaching around 94 GW [16,17].

Ethiopia is one of the energy deficient countries in the world with a net energy importer. The country is potentially endowed with various potential sources of renewable energy. It has the not fully exploited potential of renewable energy up to 45,000 MW from hydropower, 10,000 MW from wind, 5000 MW from geothermal and an average of 5.26 kWh per square meter per day from solar energy. Except for biomass fuel, most of the presented energy source is either untapped or not fully developed. For example, in terms of hydropower potential, Ethiopia is ranked second in Africa next to the Democratic Republic of Congo (DRC) but has exploited only <10% of its full potential. Despite limited electricity access to its citizen, Ethiopia is one of the countries in Sub-Saharan as a hub of renewable resources potential [18].

Energy use is closely linked to a range of social issues, including poverty alleviation, population growth, urbanization, and a lack of opportunities for women. Although these issues affect energy demand, the relationship is two-way: The quality and quantity of energy services, and how they are achieved, affect social issues as well. Poverty is the overriding social consideration for developing countries. Some 1.3 billion people in the developing world live on less than $1 a day. Income measurement alone, however, does not fully capture the misery and the absence of choice that poverty represents. The energy consumption patterns of poor people especially their reliance on traditional fuels in rural areas tend to keep them impoverished. Worldwide, 2 billion people are without access to electricity and an equal number continue to use traditional solid fuels for cooking. As shown in the next section, cooking with poorly vented stoves has significant health impacts. In addition, hundreds of millions of people mainly women and children spend several hours a day in the drudgery of gathering firewood and carrying water, often from considerable distances, for household needs. Because of these demands on their time and energy, women and children often miss out on opportunities for education and other productive activities. Lack of electricity usually means inadequate illumination and few labor saving appliances, as well as limited telecommunications and possibilities for commercial enterprise. Greater access to electricity and modern fuels and stoves for cooking can enable people to enjoy both short term and self-reinforcing, long-term advances in their quality of life [19].

The environmental impacts of energy use are not new. For centuries, wood burning has contributed to the deforestation of many areas. Even in the early stages of industrialization, local air, water and land pollution reached high levels. What is relatively new is an acknowledgement of energy linkages to regional and global environmental problems and their implications. Although energy's potential for enhancing human well-being is unquestionable, conventional energy production and consumption are closely linked to environmental degradation. This degradation threatens human health and quality of life and affects ecological balance and biological diversity.

Solar PV technology has advanced rapidly in recent years as a result of technological advancements, material cost reductions, and government support for renewable energy based electricity generation. Photovoltaic plays an important role in utilizing solar energy for electricity production around the world. At the moment, the PV market is expanding rapidly, with a global capacity of around 23.5 GW in 2010 and an annual growth rate of 35%-40%, making photovoltaic one of the fastest growing industries. One of the most important parameters in establishing this technology in the market is its efficiency. Currently, extensive research is being conducted to improve the efficiency of solar cells for commercial use. Year after year, the efficiency of monocrystalline silicon solar cells has improved dramatically. It begins at only 15% in the 1950's rises to 17% in the 1970's and continues to rise to 28% today [20].

The solar energy transformation rationale

The reduction of energy related CO2 emissions is central to the energy transformation. Rapidly shifting the world away from the use of fossil fuels because climate change and shifting toward cleaner renewable energy sources is critical if the world is to reach the Paris agreement on climate goals. There are many drivers behind this transformation includes, first, the cost of renewable energy is rapidly declining. In 2018, the global weighted average cost of electricity from all commercially available renewable power generation technologies fell further. Second, air quality is improving. Air pollution is a major public health problem that is primarily caused by unregulated, inefficient, and polluting energy sources (e.g., fossil fuel combustion, chemical related emissions). The transition to clean renewable energy sources would improve air quality in cities while also increasing prosperity by reducing illness and increasing productivity. With the increased use of renewables, a reduction in net energy subsidies could potentially result in lower healthcare costs due to air pollution and climate effects. The savings from reduced externalities such as air pollution and climate change, as well as avoided subsidies, outweigh the cost of the additional energy system. Third, carbon emissions must be reduced. The difference between observed emissions and the reductions required to meet internationally agreed upon climate targets.

Finally, clear policies and system regulations, updated guidelines, simple rules, professional training, and widespread dissemination are required for the energy transition. It is critical to disseminate pilot projects and interventions in which the concept of integration is not simply the juxtaposition of solar panels on an existing surface.

Potential of solar radiation in Ethiopia

The average annual solar radiation in the country is more or less uniform, and it's estimated at around 5.2 $kWh/m^2/day$ with seasonal variations. 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. In May 2016, the state owned power company Ethiopian Electric Power (EEP) initiated the Metehara project, which was Ethiopia's first solar plant tender for 100 MW.

The Ethiopian solar market is still at an early development stage with an estimated installed capacity of 5 MWp. Growth during the 1990's was under 5% but has reached 15%-20% during the last few years, primarily driven by the telecom market that constitutes 70% of installed capacity. Five or six companies supply 90% of the market and some lack a specialist focus on solar PV. The market potential is estimated at 52 MW, the majority within the Solar Home Systems (SHS) market and continued expansion in telecom sector. SHS has the greatest annual growth rate of 20% with few suppliers and driven by the extension of low cost housing and real estate developments. In the longer term, the growing inverter charger backup market combined with a feed in tariff law under revision could constitute a stepping stone to grid connected PV. For the foreseeable future, larger and in particular grid connected PV systems will face stiff competition from smaller hydro power systems, including small and micro hydro power. Donor support, the establishment of the Renewable Energy Fund (REF) and projects such as those backed by UNEP/GEF has brought opportunities for solar PV and micro hydro, and should continue to be a driving force behind commercial demand for institutional and household PV systems as well as for solar hybrid PV and village mini grids. The political environment already turned into positive: Since 14th December 2009 the Ministry of Finance and Economic Development (MoFED) lifted the import duty fees on PV modules and balance of system.

Benefits of solar energy utilization development

Sustainable development is the important gift that we can leave for our future generations. It is of vital importance to develop different types of renewable energy sources including solar, wind, hydro, biomass, geothermal and hydrogen gas to supply the energy needed for sustainable development in a country. Among these, solar energy has been identified as one of the promising renewable energy sources which have the potential to meet the future energy demand in developing countries like Ethiopia. To achieve this, solar energy can be harnessed either by generating electricity using solar panels (solar photovoltaic or PV) or directly by using solar thermal effect to generate heat.

Solar energy application, Photovoltaic (PV) power generation uses the photovoltaic effect to directly convert solar radiation energy into electric energy, which is one of the most promising renewable energy technologies to realize sustainable development and it is also a means to realize zero energy building. At the same time, PV power generation, as a solution to the increasing demand for electricity, can also minimize environmental and social problems related to fossil fuels and nuclear fuels. Driven by energy and environmental benefits, PV systems have developed rapidly in recent years, with an average annual growth rate approaching 50%, and have begun to gradually replace coal-fired power generation.

Solar energy is energy for the moment. If the environment and the ecosystem are to be preserved for today and the generations yet unborn, the clean and renewable energy that solar energy offers should be exploited and utilized because, solar energy is an everlasting, renewable, clean energy source with no potential damage to the environment, free and large source of energy that does not cause pollution and provision of a practical platform solar renewable energy resources have the attendant advantages it provides over fossil fuel.

Worldwide energy consumption is increasing every year and different technologies are used to produce electricity to compete with the energy demand. Environmental pollution is also a serious problem nowadays due to the more use of fossil fuels for energy production. Solar PV technology is growing rapidly in past decades and can play an important role to achieve the high energy demand worldwide. The huge amount of PV systems installed yearly shows the seriousness and the responsibility of every country about the issue to save the earth by using renewable energy. Promoting the use of distributed PV systems in rural areas will not only provide energy benefits and alleviate environmental issues but will also provide some economic benefits to rural farmers.

There is a reason why solar energy has become a trending topic when talking about renewables. While it has been widely criticized for being expensive or not very efficient, solar energy has now proved to be extremely beneficial, not only for the environment but also financially benefits, additionally, due to the higher demand, the technology has been improved considerably, turning into a significantly efficient source of clean energy. In summarizing, some advantages of solar energy are:

- A renewable, sustainable and environmentally friendly clean energy source that is available every day of the year, even cloudy days produce some power.
- Reduces electricity bills and can enhance the value of the homes.
- Can be installed anywhere; from a remote field location to a city building.
- Diverse applications (photovoltaic for electricity or solar thermal for heat).
- No maintenance costs as solar panels last over 30 years.
- Use batteries to store extra power for use at night.
- Provides energy reliability, energy independence and energy security.
- Technology is in constant development and safer than traditional electric current, etc.

Solar PV has been especially beneficial to rural women as an alternative source of energy because it has served as an effective substitute for environmentally unfriendly traditional fuel sources. Prior to the introduction of solar systems, poor women's firewood collection exacerbated the scale of deforestation in the areas and consumed a lot of women's time and labor. Furthermore, it occasionally exposed them to potentially lethal hazards in the bushes. The availability of PV electricity has improved the quality of life in the study areas. Access to social services such as health and education has improved; an entrepreneurial spirit has flourished, and women have begun to establish microenterprises for petty trade. Small shops, cafes, and traditional drinking establishments have provided opportunities for income diversification, albeit on a limited scale. Furthermore, the use of information and communication technologies (such as radios, televisions and telephones) has provided women with access to information, particularly about farming and agriculture in general, which is the foundation of their livelihoods.

Challenges of renewable energy production in Ethiopia

According to Ayalneh et al., lack of access to modern electricity means a lack of opportunities for social services such as water supply, health services and educational facilities for which modern energy sources are essential input. There are several challenges that mired the harnessing and development of renewable energies in Ethiopia. Generally, the main challenges of harnessing renewable energy sources in Ethiopia can be categorized as follows:

- **Technical and human capacity barriers:** There is a lack of developed and adapted energy technologies that could fit specific local conditions in the country. Reason that could cause lack of locally developed energy technologies is due to limited on job training experiences. These may, in turn, are due to a shortage of enough funding for the development of energy sectors, law level of socio-economic, a lack of technical (skilled manpower) for the maintenance of energy generation technologies, and institutional incompetence in terms of the energy sectors.
- **Economic and financial barriers:** There is limited finance for the development of renewable energy sources due to the relatively high cost of solar energy technologies.
- **Underdeveloped rural energy infrastructures and markets:** The low level of rural energy infrastructures and energy markets resulted in low participation of private energy sectors as the startup capital is intensified. One reason for this is that there is less experience in commercial operations and weak delivery systems in the country.
- **Information barriers:** There is a lack of detailed and updated energy data as well as maps for the development of renewable energy technologies in Ethiopia.
- **Political barriers:** The adverse impacts of political conflicts in the Eastern Africa region as well as internal conflicts hindered the development of renewable energy sources. For example, the Grand Ethiopian Renaissance Dam (GERD) hydropower development has been recently politicized in the East Africa region, which significantly contributes to the slowdown of renewable energy development.

The challenges of solar energy production in Ethiopia

Ayalneh, et al., also, the categories of the challenges in solar energy production in Ethiopia are as follows:

- **Insufficient technical skill:** Lack of skilled manpower (lack of maintenance and training facilities). Sustaining solar PV systems is directly connected to the long-term maintenance, repair, and replacement of batteries after they reach a regular lifespan. This is a great concern since maintaining solar PV systems requires highly technical skill and manpower.
- Lack of innovative financing mechanism to compensate for the cost of the system. This results in purchasing quality solar PV products remaining a bottleneck, especially in rural areas.
- There is no clear and coherent policy as well as the institutional capacity to ease the commercialization of the technology.
- Consumers and policymakers do not have adequate awareness of the technology.
- The association between national dealers and local retailers and technician is poor, hence importing poor quality of products.
- Undeveloped solar PV supply chains.
- Lack of well-organized research and capacity development.
- Lack of adequate logistics and transportation systems for the local solar technologies development and manufacturing.

Theoretical framework

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. The theory of metabolic rift and the more recent EMT have contrasting foundations, frameworks, and implications. While both consider the human environment relationship, they theoretically ground modernization and environmental degradation in contrasting ways. However, both can be used to examine the adoption of solar energy technology in both “developed” and “developing” societies throughout the modern world. This paper applies both theories to solar energy technology adoption and explores what the theories offer for understanding potential policies and practices that promote renewable energy technology adoption. Both theories provide unique and important insights into the structure and consequences of modern society that shape the economics and politics of renewable energy technology adoption, yet each offers only partial provided by its assumptions and foundational beginnings. While the theory of metabolic rift (and modern extensions of the basic theoretical premises from this classical foundation) is arguably more fitting for the decisions of individuals or small communities, and EMT more applicable to nation-states, both theories offer theoretical grounds for understanding the adoption of solar technologies by individuals, communities, and businesses and offer insight for potential policy tools to promote renewable energy technology adoption at multiple scales and in diverse national contexts.

By 2050 and by the end of the century, the global energy consumption is expected to more than double and triple, respectively. To meet this demand in a sustainable manner, existing energy networks cannot be improved incrementally enough. One of society's most difficult problems is finding enough renewable energy sources in the future.

About 5 MW installed capacity of solar electricity generating units have 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 centers with badly needed electricity services, that otherwise would not have been served.

However, solar energy utilization is not effectively developed in a coordinated way, it may be because, of deployment of solar PV technology is still very expensive and unaffordable to the majority of society, particularly the rural dwellers. Because the parts are imported, the parts are still expensive. When compared with diesel or petrol generators, particularly for household use, solar PV is still expensive in the short run, though overall, solar PV may cost beneficial. Financial constraints, technological incapability, and low level of public awareness absence of a comprehensive national energy policy are among the thing that makes difficult the use of solar energy.

Conceptual framework

As we can see from the conceptual framework, the government's role in solar energy development is critical. Promoting renewable energy has long-term environmental benefits as well. The future development of solar energy in Ethiopia is dependent on government policy and promotion activities in the energy sector. Rural electrification and reduced biomass consumption may help to reduce pollution and lead to more sustainable development (Figure 1).

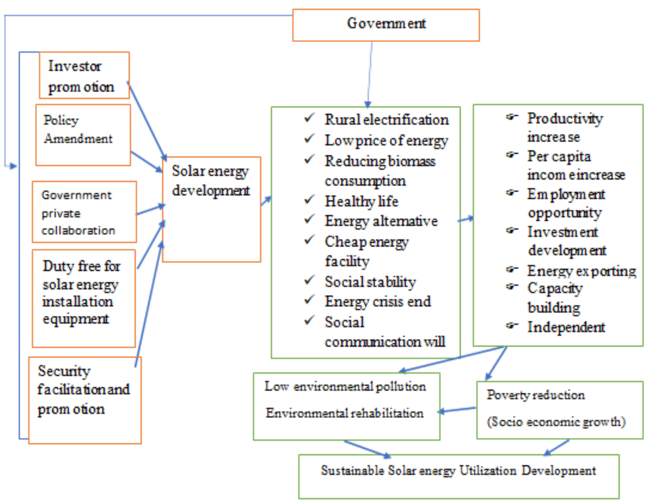

Figure 1: Conceptual framework.

METHODOLOGY

This section aims to show how journals were identified, the search strategies, 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 Nunn and Chang, 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.

Data source and study selection

Search strategy and design: 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 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 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 flow diagram was strictly applied. As is it mentioned in Figure 2 below, the issues related to the objective of the review, adequate terms, and 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 was 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.

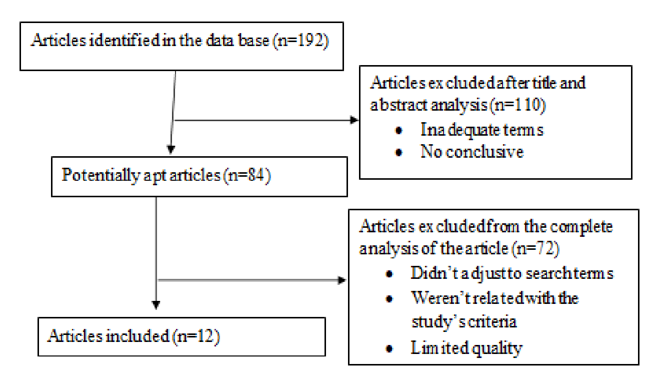

Figure 2: PRISMA 2009 flow diagram.

Method of data analysis

Conducting a periodical systematic review on 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 there by 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.

Description of the study area

Ethiopia is a landlocked country located between 3°N (Moyale) and 15°N (Bademe-the Northernmost tip of Tigray) latitudes and 33°E (Akobo) to 48°E (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.

Neighbors 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, and soil composition, and settlement patterns, population estimated at 115 million as of 2021, with an annual growth rate of 2.5%. It is the second most populous nation in Africa after Nigeria. Ethiopia has registered an average of 10.4% per annum from 2005-2019, making it one of the fastest growing economies in Africa.

Ethiopia is endowed with abundant renewable energy resources, which can meet the ambitions of nationwide electrification. However, in spite of all its available potentials the country energy sector is still in its infancy stage. The majority of Ethiopia population lives in the rural area without access to modern energy and relied solely on traditional biomass energy sources. Now-a-days Ethiopia has one of the lowest electricity consumption per capita in Africa. Recognizing that energy access and security are a crucial factor to economic growth; Ethiopia needs to cope with key challenges related to energy security and diversification of energy supply (Figure 3). Further, current state of renewable energy resources is described and existing energy policies are articulated. Various policies, that could possibly promote energy technology use in a rural Ethiopia, are proposed (Tables 1 and 2).

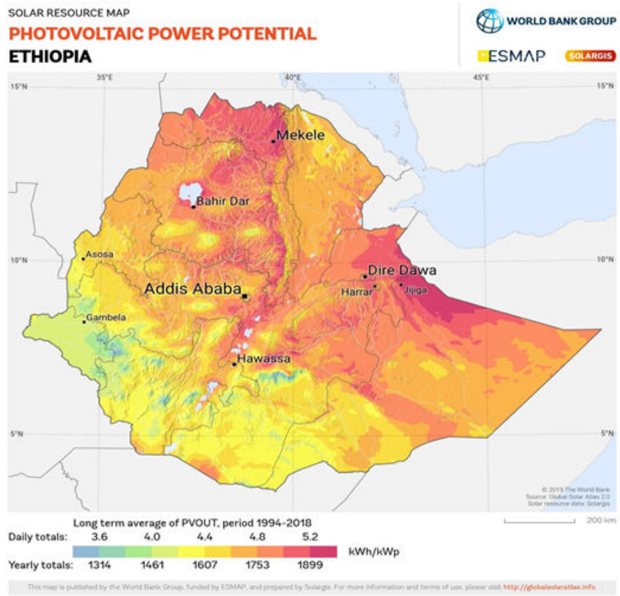

Figure 3: Solar resource map of Ethiopia.

FINDINGS OF THE STUDY

Location, study approach, objectives and methods of the studies

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 (Table 1).

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	Amhara, (Siadeber and 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 PV syst software database meteorological tool.
Ankamma Rao J, Bizuayehu Bogale, Asefa Sisay, May 2017	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	Ethiopia	Mixed approach	To analyses the current state of the art in the utilization and promotion of solar energy.	Document analysis Analyses.
Tegenu Argaw Woldegiyorgis, September 2019	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 Oromia regional state of Ethiopia.	Document analysis And literature review.
Nagesso Beker, August 2019	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 PV watt global solar atlas.
Antene Belay, January 2019	Ethiopia	Mixed approach	To review the current status, future potential and barriers to the development of renewable energy for power generations in Ethiopia.	Questionnaire, document analysis.
Seife Ayelet, Wei Shen, Tadesse Kuma, Worako, Lucy H. Baker and Samson Hadush, December 2021	Ethiopia	Mixed approach	Aims to understand the legal and institutional framework needed for a renewable energy competitive bidding programmer to be effective in Ethiopia.	Interview consultation workshop: Deskwork or document analysis
Ashebir Dingeto Hailu and Desta Kalbessa Kumsa, November 2020	Ethiopia	Mixed approach	To carry out on Ethiopia's renewable energy potentials and current state.	Document analysis And literature review.
Anshebo Getachew Alemu, Teketel Alemu, May, 2021	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	Ethiopia	Mixed approach	To provides a comprehensive assessment	Document analysis

Natei Ermias Gebrehiwet Abraham and Ramato Ashu, September 2021				of renewable energy availability, potential, opportunity and challenges in Ethiopia.	
Natei Ermias, Yedilfana Setarge Mekonnen, Ashenafi Asfaw, Mulatu Tegenu Argaw, Chernet Amente Gaffe and Abreham Berta, January 2022	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.
Engidaw Abel Hailu, Ayodeji Olalekan Salau Amache Jara Godebo, March 2021	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

The status of solar energy utilization, development opportunities and challenges in Ethiopia

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 is 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 earning and attraction of international energy company and may put the base for the development of solar energy in the country (Table 2).

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

Author(s), 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	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	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 relatively sun rich region with an average daily irradiance of more than 7000 $Wh/m^2/day$	Administrative commitments and lag approval for research and materials suppling.
Antene Belay, November 2018	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 No promotion and very low utilization of this energy snow, in such area solar energy is limited. All solar equipment will import and the investment cost is when compared to the other source.	Low market penetration and high maintenance cost.
Tegenu Argaw Woldegiyorgis, September 2019	Abundant (average) solar energy potential of 5.52 $KWh/m^2/day$. Electric load for a single household, school and clinic was	The use of the PV systems to electrify the remote sites of Ethiopia considering its long-term benefits and less cost of installation	Low government commitment, risky security around the Area and foreign currency shortage, and lack

	estimated at 313, 2064 and 2040 Wh/day respectively.	compared to national grid extension to the remote sites.	of trend human labour around the field. Low technical assistance
Nagesso Beker, 2019	Ethiopian annual solar radiation ranges from 1730 kWh/m^2 in Chencha city to 2481 kWh/m^2 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 the 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	A country has 5.5 kWh/m^2/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 Ayelet, Wei Shen, Tadesse Kuma, Worako, Lucy H. Baker and Samson, Hadush, December 2021	Ethiopia has held two solar Photovoltaic (PV) projects that led to the signing of (PPAs) and was hailed 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.	The newly established PPP framework has laid a solid foundation for the future development of (non-hydro) renewable energy projects in Ethiopia.	Overlapping roles and functions, capacity deficiencies and risk to private sector 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, powering water pumps in rural areas and water heating in major cities.	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 preferred bidder for one of the projects, located near Metehara.	Unevenly distribution of solar energy utilization, underutilization only about 14 MW solar PV have been implemented limited only used for telecom 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	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/m^2/day, respectively, and 6.30 kWh/m^2/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 Alemu, Teketel Alemu, May 2021	The Afar region is exceptional solar potential with significant AV. The solar flux of 239.9 W/m^2), AV. Annual. Density 2.102 MW/h/ m2·a, therefore the afar region is the prospective candidate for the development of PV power systems.	The PV systems have been the main pillar of solar energy in Afar region so far, it is expected that these types of systems could bring more immediate solutions for inhabitants without access to common energy 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/m^2), Amhara (240.34 W/m^2) and the Afar (239.9 W/m^2) 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	The area has a high potential for renewable energy developments, with a RE penetration rate of	Thus, this system is environmentally friendly because it contributes to the maintenance of a clean and	The largest share of energy consumption (≈87%) in Ethiopia is dominated by traditional fuels

Gebrehiwet Abrham and Ramato Ashu, September 2021	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.	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.	(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 and Abreham Berta, January 2022	PV/DG/battery Hybrid Energy System (HES) with a 7.5 kW PV, 7.3 kW DG,	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). 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.	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.

The status of solar energy potential in Ethiopia

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 practiced by generating huge power and feeding it to the national grid. Due to always blacking out people is practicing 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, creating local jobs and incomes for distrusters.

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 populations have 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.

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 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/m^2). The target value is 1,000 W/m^2. This value is typical of sunlight intensity at 12:00 noon, when the sun is highest in the sky.

The main energy policy goal is to ensure the availability, accessibility, affordability, safety and reliability of energy services to support the countries accelerated and sustainable social and economic development and transformation. 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.

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.

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.

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.

DISCUSSION

Ongoing renewables solar IPP projects

The Gad and Dicheto solar PV projects: Have the greatest potential for solar energy production in the country. ACWA hasproposed 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 years contract, with a total investment in both projects at US$180 m.

Metehara project: This project was developed as the first utility-scale solar PV plant, with 100 MW 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$120 m project is scheduled to generate approximately 280-Gigawatt-Hours (GWh) per year and to sell electricity to EEP under a 20 years PPA. The development of the project has been assisted by the United States AGENCY for International Development (USAID) power Africa programmer and the world bank (Table 3).

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

Project (energy source and region)	Capacity	Awarded project developer	Cost (US$ mil.)	Tariff (US$ in KW/h)	Project tenure
Metehara (solar, Oromia)	100 MW	Enel green power and orchid business group	120	n/a	20
Gad (solar, Somali)	125 MW	ACWA power	90	0.02526	25
Dicheto (solar, Afar)	125 MW	ACWA power	90	0.02526	25

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 the 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.

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% of Ethiopia's total population has access to electricity. Public electricity is available to nearly 85% of Ethiopia's urban population, but only 29% of the rural population.

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 for improving solar energy technology adoption and increasing installed capacity in the sector was the financial issue.

Lack of awareness is exacerbated in some rural communities by a lack of TVs 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.

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.

Consequences of low solar energy utilization

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 Hernandez, et al., 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.

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. 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.

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

Implementation barriers of solar energy technologies in Ethiopia

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 (Table 4).

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 for replication	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	Lack of a comprehensive techno economic assessment	Lack of cooperation between Institutions in the context of fragmented researches	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 super computers 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

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 her 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 Siadeber and 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 are 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.

RECOMMENDATIONS

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:

- 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.
- More research into the techno economies involving the initial and subsequent costs of solar plants and their power efficiencies should be encouraged.
- Private individuals and organizations should be encouraged by appropriate authorities to invest in solar technologies in the country.
- Government should create more awareness of the advantages derivable from Renewable Energy Technologies (RET) such as solar technologies.
- 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.
- 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.

- 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 the rural areas.

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