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Research paper

Climate action: Prospects of solar energy in Africa

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ABSTRACT

Solar energy has become crucial in providing the world with an opportunity to reduce its carbon footprint, as well as fighting the consequences of climate change. Furthermore, Africa is at the forefront of the regions affected by climate change with a future expectancy of worsening consequences, in addition to being a region with various electricity complications, energy demands, and global greenhouse emissions contributions. Therefore, not only is Africa in major need of adopting efficient renewable energy technologies for their apparent future concerns but also Africa is already considered a region that has significant solar energy potential due to its abundant natural and renewable resources. Solar energy's potential in Africa could not only be a solution to many of the continent's complications, but it could also help the continent's economy thrive The potential of solar energy in Africa as well as techniques to efficiently implement it has piqued literary interest a lot recently however, this paper aims to highlight through literature not only the potential and the technologies available for adoption but also the challenges complicating the implementation. This paper is split into four literary sections, first section puts forward the challenges facing Africa in the uptake of solar energy technologies including financial, technological, human resources, and environmental challenges. Then, in-depth discussions of the various solar energy technologies for potential adoption. Third, the biggest solar energy projects implemented in Africa are put forward. Finally, a thorough study of the aforementioned challenges, their current state, and the actions required to overcome them is presented in order to fully realize the potential of solar energy deployment across the continent.

1. Introduction

Renewable energy (RE) is globally gathering steam as a viable alternative to traditional fossil fuels in developed as well as developing regions like Africa (de Vries et al., 2007). Whereas, RE plays a critical role in assisting both developing and developed countries in achieving many of the UN's 2030 Sustainable Development Goals (SDGs) (World Bank Group, 2020). The 2030 Agenda requires countries to adapt their policies, governance, and commitments to be able to implement the SDGs plan (United Nations, 2015). Thus, most countries have made national development strategies that align with the SDGs. Considering Africa's abundant natural resources, several types of RE can supply practical and efficient energy solutions that will benefit the continent's future sustainable development plans and economic growth by 2030 (IRENA, 2015; Seada and Hatem, 2022). Solar energy stands out as the most abundant natural resource in Africa (Adenle, 2020).

Solar energy provides regions with an opportunity of boosting their economies and minimize their global carbon footprint and greenhouse emissions (Mutombo and Numbi, 2019). Exploiting Africa's solar energy-generating potential, on the other hand, is today more of a necessity than an opportunity as the continent is increasingly facing numerous electrical challenges. Despite this necessity, there are factors that can complicate the implementation of renewable energy projects. Major aspects that affect the renewable energy market in Africa will be discussed with an aim to combine different solutions and initiatives for all the challenges to allow the reader to get an overview of how the development could be achieved. The strategies proposed will help African governments develop their energy sector. In addition, it will help promote economic growth, reduce poverty, and achieve sustainable development.

1.1. Electrical challenges across Africa

Africa owns 40% of the globe's potential for solar power yet it only inhabits 1.48% of the total global capacity for electricity generation of solar energy (IRENA "Renewable Capacity Statistics", 2021). While Africa as a continent generally faces major electricity issues, Sub-Saharan Africa is the one region that suffers most

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from these issues, as Sub-Saharan Africa is presently home to more than two-thirds of the world's population who do not have access to electricity (IEA "Africa Energy Outlook", 2019). In comparison to other developing countries, inhabitants in Sub-Saharan Africa have the lowest per capita access to modern energy (Brew-Hammond, 2010). It is estimated that in Sub-Saharan Africa 0.6 billion people (out of the 1.14 billion) do not have access to electricity (O'Neill, 2022; Corfee, 2019); this represents about 53% of the total population. In addition, due to inadequate maintenance, around 15% of the installed capacity in Sub-Saharan Africa is not functioning. Moreover, it is estimated that about 0.7 billion people of the entire African population still rely on traditional biomass for power generation since access to the national power grid can be costly (Adenle, 2020).

Another major issue is the expected population growth in Africa. Whereas, Sub-Saharan Africa's population alone is predicted to reach 2.0 billion by 2050; influencing the increase of energy demands, which are expected to dramatically rise by 3% annually (Schwerhof and Sy, 2020). Moreover, due to growing energy prices and the increased need for climate change mitigation measures, more challenges may arise (Maji et al., 2019). As a result, using renewable energy resources and up-taking solar power generation to power Africa is a viable choice (Huard and Fremaux, 2020). Not only will the deployment of renewables provide solutions for the challenges facing Africa in terms of climate change, energy demands, and electricity issues, but also environmental, health and economic benefits will also be reinforced. In addition to an increase in job opportunities (IRENA "Renewable Energy and Jobs", 2020).

1.2. Solar energy potential in africa by region

The potential of solar energy is enormous all over Africa; due to a variety of factors such as the proximity to the equator and the frequent dry bright days (IRENA "The solar revolution in Africa", 2017). However, solar potential tends to stand out in North and South Africa. Fig. 1 below shows PV solar power potential across Africa.

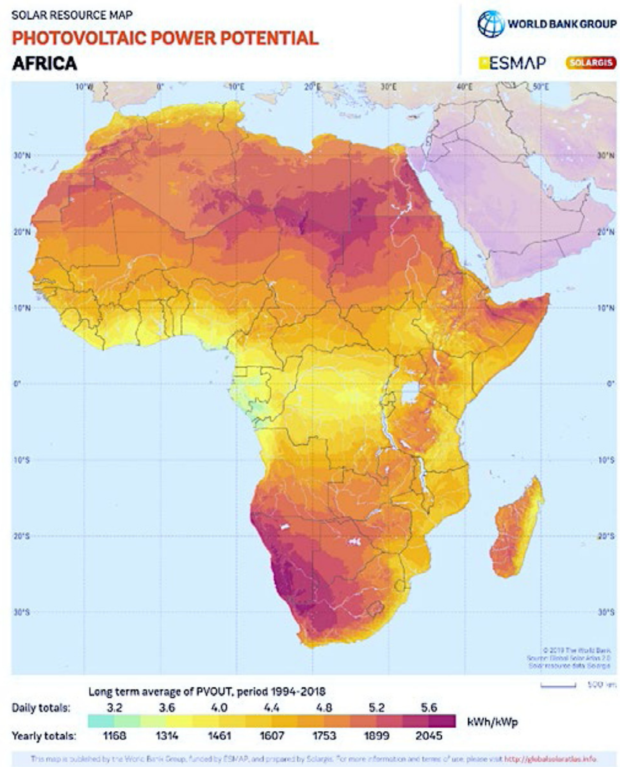

Fig. 1. Photovoltaic power potential in Africa.

For instance, South Africa has the potential for concentrating solar power of 43,275 TWh/year and potential for solar photovoltaic of 42,243 TWh/year (Adenle, 2020). Most regions in South Africa may encounter more than 2500 h of sunshine with average solar irradiation of 220 W/m^2 (Ayodele and Munda, 2019). In the case of North Africa, a solar farm spanning just 0.3% of North Africa could meet the whole European Union's electricity consumption, which accounts for the double of Africa, according to the German Aerospace Centre, a leading expert on renewable energy engineering ("The solar revolution in Africa", 2017). Because of its ideal location in the Sunbelt region, Northern Africa has an abundance of solar energy as shown in Fig. 2. This is witnessed in the high annual solar irradiation, for example Algeria, Morocco, Egypt, and Tunisia have total annual solar irradiance of 2700 KWh/m^2, 2600 KWh/m^2, 2800 KWh/m^2, 2300 KWh/m^2 respectively (Zhao et al., 2018).

With the huge potential for achieving significant change in the deployment of renewable resources and solar energy technologies across the continent, the need to analyze the complications as well as the current status of the energy market in Africa is a necessity. Accordingly, this literary research paper discusses all the major aspects that affect the renewable energy market in Africa. The paper aims to highlight available solar energy technologies for potential adoption, as well as combine different solutions and initiatives already taken for all the challenges that will be discussed further through the paper to allow the reader to get an overview of how the development could be achieved. The strategies proposed will help African governments, as well as similar developing countries, develop their energy sector, whereas these strategies can promote economic growth, reduce poverty, and achieve sustainable development.

The paper is organized into four main sections respectively. Section 2 discusses thoroughly the challenges facing the adoption of solar energy technologies in Africa as mentioned collectively in previous literature. Section 3 focuses on two energy-efficient solar technologies that could be adopted in Africa; Photovoltaics (PV) and Concentrating Solar Power (CSP). Section 4 highlights notable solar energy initiatives in Africa, through in-depth discussions of the biggest solar projects installed across the continent. Sections 5–7 are divided to showcase the current status of each of these challenges: Financial (Section 5), Policies (Section 6), and Human Resources (Section 7) while noting any initiatives taken to address those problems, as well as recommended remedies to overcome the challenges discussed so that Africa's future solar energy adoption targets can be met efficiently. Section 8 will conclude all the topics that were discussed in the previous sections.

2. Challenges facing the adoption of solar energy technologies in Africa

Despite the apparent huge potential of solar energy and solar PV in Africa, there are still significant challenges to the widespread adoption of the technologies which are not at all linked to a scarcity of resources (Dagnachew et al., 2020). Financial, human resource, environmental, and technology challenges are all prevalent. As a result, a thorough understanding of the challenges associated with solar technology adoption is crucial.

2.1. Financial challenges

Implementing renewable energy technologies requires a variety of finance and funding solutions (Mazzucato and Semieniuk,

Country	Algeria	Egypt	Libya	Morocco	South Africa
• PVOUT:	• 4.19- 5.50	• 4.76- 5.74	• 4.76- 5.57	• 4.33- 5.54	• 4.00- 5.66
• DNI:	• 4.41- 6.97	• 5.25- 7.85	• 5.31- 6.82	• 4.52- 7.20	• 4.19- 8.50

- Specific photovoltaic power output (PVOUT) in kWh/kWp
- Direct normal irradiation (DNI) in kWh/m²

Fig. 2. Specific Photovoltaic power and direct normal irradiation per day in 5 African countries according to Solargis.

2016). This might be a substantial obstacle to adoption plans, as it may be difficult to find suitable candidates and secure adequate funding. Furthermore, Renewable energy technologies are more prone to escalating financial costs than conventional energy sources, which further complicates the funding issue. The financial condition of Africa today makes the cost of solar PV more expensive than other conventional energy sources, such as coal. Moreover, the national economy may encounter a significant obstacle in the shape of foreign currency and technology importation, both of which can be costly and difficult (Ogbulezie et al., 2020). Furthermore, after the CoViD-19 pandemic, a global financial recession took place. Funding solar energy projects has become more challenging since funds have been mostly diverted to fight the pandemic. There is also a challenge due to the depreciation in African currencies on the ground that most of the solar energy projects components are usually paid for in hard currencies and most power purchase agreement is signed in dollars. This poses additional risks as the African governments purchase electricity from independent power producers in dollars and provide it in their local currency to the rest of the population (Chanchangi et al., 2020).

2.2. Human resources challenges

The photovoltaic market requires experts and technicians to utilize, design, and maintain the technologies. This can be a concern since skilled personnel and staff are scarce, which may lead to system failure and malfunction. Furthermore, personnel in the renewable energy sector must possess specific skills, which will necessitate further training for present professionals as well as an extension of the educational system to meet the PV market's demand. This process can be quite difficult to implement (Ogbulezie et al., 2020; Niyibizi, 2015). The pandemic also contributed to more significant challenges within the work environment as many workers were dismissed due to security reasons. Therefore, this caused complications in the installation and maintenance of energy systems (Gebreslassie, 2021).

2.3. Environmental challenges

The climate in Africa is known to be both dusty and warm with high levels of ultraviolet radiation. The dust in the atmosphere can result in soiling; this is a process in which dust particles accumulate on the solar cell's surface. Soiling can decrease the PV cells' efficiency because the solar irradiance can be optically disturbed while being transmitted to the PV cells, and the solar rays can be both absorbed and scattered (Chanchangi et al., 2020; Othman and Hatem, 2022). Moreover, the high temperature of the atmosphere can affect the efficiency of the PV cell. The efficiency of the PV cells decreases by about 0.40–0.50% with every one-degree rise in temperature (Ogbulezie et al., 2020; Razak et al., 2016). In addition, high solar radiation can lower the PV cells' efficiency.

2.4. Technological challenges

PV technologies are not often localized in Africa; as a result, the lack of supporting industries makes solar energy technology adoption more problematic. Moreover, since there are no manufacturing companies, service parts, or technical expertise in the area, access to such technology cannot be achieved locally (Jadhav et al., 2017). Hence, solar energy technologies are usually imported from other countries; whereas the imported technologies can be costly and of low quality, both of which are major disadvantages. To efficiently address this problem, research institutes specializing in localized solar cell technologies should be established. For instance, a research institute for solar technologies has been developed in South Africa to implement local technologies (Jain and Jain, 2017). Furthermore, following the pandemic, Africa has faced considerable challenges because it had previously relied on importing solar energy technologies from other countries. Importing technologies from the United States of America and China, which are the main technology importers, has been more challenging due to the lockdown and the halted aviation (Shen and Ayele, 2020) (see Table 1).

A thorough understanding of the aforementioned challenges is the first crucial step to being able to set effective solutions to implement solar energy technologies, but an understanding of the technologies themselves is also critical. Thus, the following section discusses two solar energy technologies that could be both keys to exploiting Africa's solar energy potential.

3. Solar energy technologies

There are two vital active solar technologies by which solar energy is harnessed; Photovoltaics (PV), which directly convert light to electricity, and Concentrating Solar Power (CSP), which uses heat reflected from mirrors that are directed to the sun (thermal energy) to drive heat engines.

3.1. Photovoltaic cells (PV)

Photovoltaic cells use solar radiation and directly convert them to electricity. The production of PV cells has drastically increased, and their costs have significantly dropped in the past decades. Different types of PV cells vary in prices, efficiencies, and production processes. The three most common types of PV cells include mono-crystalline, poly-crystalline, and thin films whose efficiencies range from 8% to 20% in most cases (Ameur et al., 2021); however, the efficiency can sometimes reach 25% with high-quality solar panels. According to research conducted by some of the authors, after testing the three PV types in environmental conditions like that near Cairo in different months, the most yield was found to be in the summer months for mono-crystalline and poly-crystalline cells as shown in Fig. 3.

Table 1
Literature summary of the types of challenges facing Africa's solar energy market.

Financial challenges (Mazzucato and Semieniuk, 2016) (Ogbulezie et al., 2020) (Chanchangi et al., 2020)	Human resources challenges (Niyibizi, 2015) (Gebreslassie, 2021)	Environmental challenges (Othman and Hatem, 2022) (Razak et al., 2016)	Technological challenges (Jadhav et al., 2017) (Jain and Jain, 2017) (Shen and Ayele, 2020)
• RE more prone to escalating costs. • RE more expensive than conventional energy. • Challenges of paying in foreign currencies. • Depreciation in African currencies.	• Scarcity of skilled personnel and staff. • Workers need to possess specific skills. • Dismissal of workers during Covid-19.	• Dust particles accumulate on the solar cell's surface. • High temperature affects the efficiency of the PV cell.	• Technologies not localized in Africa. • Technologies are usually imported from other countries. • Challenge in importation during Covid-19.

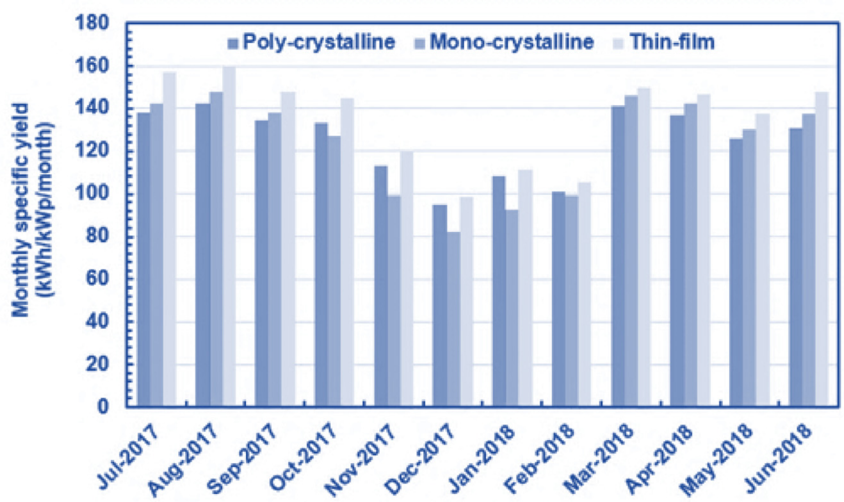

Fig. 3. Monthly specific yield in KWh/KWp from study on three different PV modules in weather conditions similar to Cairo (Othman and Hatem, 2022).

In this study, fast deterioration in PV cells efficiencies especially thin films have been witnessed. The efficiency of mono-crystalline cells is reduced because of the dissipation caused by the radiation's longer wavelengths that result in overheating the cells. Although mono-crystalline has higher efficiency than poly-crystalline, poly-crystalline is preferable because of its lower production costs. It also has the advantage of having fewer flaws in metal contamination and crystal structure (Parida et al., 2011). As a result of the weather's negative effect on the photovoltaic cells, multi-junction PV cells have been invented. Multi-junction has an advantage as it can withstand harsh weather conditions and high solar radiation without lowering output or affecting the efficiency of the cell. The efficiency of the cell can reach up to 47%; this is relatively high compared to the 17% of the other technology cells. The main problem with multi-junction cells is the expensive costs of raw materials and the complex production processes of the cell (Salah et al., 2017).

The Photovoltaic Thermal system (PV/T) is another way to improve the efficiency of PV modules. The PV/T depends on cooling the PV modules to allow them to recover some of the power dissipated as heat. The output and the thermal efficiency can be increased by using Nanofluids as coolants for the PV panels. Nanofluids are produced by getting Nanoparticles into fluids like water, ethanol, or oil. They have good cooling properties due to their high thermal conductivity and heat transfer characteristics. The decreased temperature of the PV module allows it to have greater electrical efficiency. The heated fluid from the PV module can be used in low and medium heat applications like domestic space and water heating which will maximize the output from the solar energy (Al-Waeli et al., 2017; Sangeetha et al., 2021)

Concentrated Photovoltaic cells is another technology derived from PV cells. The primary and essential objective of the Concentrated Photovoltaic cells is to concentrate the sunlight with an average of 200 to 1000 times by using developed mirrors or lenses. The Concentrated Photovoltaic cells depend on the solar flow concentration. Concentrated PV cells require much fewer layers than most of the solar energy generation and storage technologies that are currently available in the field of solar energy. Concentrated PV cells are considered to be the ultimate solution to any solar power inefficiency as they use highly efficient multi-junction solar cell technologies to obtain the required concentration of solar energy.

The majority of the Concentrated PV cells convert about 42% of the energy present in the sunlight into electricity. The multi-junction cells used in the Concentrated PV cells allow the solar cells to absorb different colors of the sunlight because they contain three semiconductor layers instead of using a single semiconductor layer. The Concentrated PV technology can be used in tough conditions. It also can work for long intervals during the day, so it is preferred to be used in hot areas.

The cost of the Concentrated PV cells is deemed low in comparison to the cost of the ordinary PV cells because the materials used in the production of the semiconducting layers of the PV cells are inexpensive, which can make the process of adding more layers smooth and affordable. In comparison to regular Photovoltaic cells, the expense and complexity of Concentrated Photovoltaic cells are regarded as a major barrier to using the technology on a broad scale. According to many studies, the Concentrated PV cells are going to be used widely in the next few years which will result in declination in their cost, so this technology will compete with the PV cells. Moreover, Egypt for example has an exceptional opportunity to participate in the field of manufacturing solar electricity production systems either for domestic use or for export (ESMAP, 2015)

3.2. Concentrated Solar Power plant (CSP)

The technology of concentrated solar power (CSP) shares numerous characteristics with the concentrated photovoltaic cells technology. However, the single major difference between them is that the CSP uses a technology that concentrates sun rays onto a small region to generate extreme temperatures ranging from 100 to 400 degrees Celsius. After that, the thermal energy produced from extreme temperatures is transformed into electricity by either gas turbines or steam (Zhou et al., 2019). The use of concentrated solar power cell technology has a number of advantages. The superior capacity to store thermal energy is one of these advantages; this ability to store energy allows the energy to be used in power production for lengthy and consistent periods throughout the day. Another significant benefit of this technology is its ability to operate efficiently and reliably in high-temperature environments (IEA, 2010). As a result, the Concentrated Solar Power plant is best placed in deserts. The global CSP potential has surpassed 3,000,000 TWh/m^2 annually, which is 166 times greater than global energy consumption.

Before settling on a location for the CSP plant, some issues such as geography, politics, and economics should be examined. Starting with the geographical factors, the land should be flat, unpopulated, and unused. Large quantities of water should also be accessible as it will be utilized for cooling. Finally, distance to the electricity grid and access to the road should be provided. Other aspects to examine include political and economic concerns, as well as the political stability of the region where the CSP will be built, land rental costs, investment freedom, the availability of a power purchase agreement, and ultimately, the existence of government incentive schemes. There are four major CSP technologies which are the parabolic trough, solar tower or power tower, linear Fresnel, and parabolic dish. The parabolic trough has a higher overall capacity than the other methods since its efficiency has been proven commercially and is regarded as the most effective CSP technique. Despite being the most efficient in solar energy production, this technology has a significant disadvantage; this technology is currently somewhat expensive compared to PV and CPVs. This system also necessitates the use of steam turbines, which makes small-scale energy generation more difficult.

These turbines add up to the complexity of the solar plant along with the duration of implementation, cost of design, and maintenance. From a technological standpoint, CPVs bridge the gap between traditional thermal plants like those found in Egypt and concentrated solar thermal plants, where tracking systems and concentrates (the major components of solar thermal concentrators) are developed (Alalewi, 2014).

4. Current status of utilizing solar energy in Africa

Africa has a huge problem when it comes to electricity. In sub-Saharan Africa, almost half of its population does not have access to electricity (see Fig. 4). In addition, people who have access to electricity must pay about twice the amount that any other consumer might pay anywhere else in the world (Schwerhof and Sy, 2020).

Moreover, Sub-Saharan Africa experiences several shutdowns annually which is about 56 days due to the shortage of electricity. It costs the continent from 2% to 4% of the GDP per year because of the electricity shortages (Schwerhof and Sy, 2020). However, to achieve widespread electricity by 2030, Sub-Saharan Africa should spend more than 30 billion USD in investments. Senegal, on the other hand, promised to have about 30% of solar energy for the country's energy requirement (Ogbulezie et al., 2020; Chanchangi et al., 2020). To get an overview of the amount of energy that will be required by Sub-Saharan Africa in the future, a simplified mathematical model is created. The model aims to give the future energy consumption approximation such that the right measures to electrify the region's households are taken. It is important to realize that this model uses approximations and average values. These values are expected to slightly change over the years. Thus, exact values will not be obtained using this model.

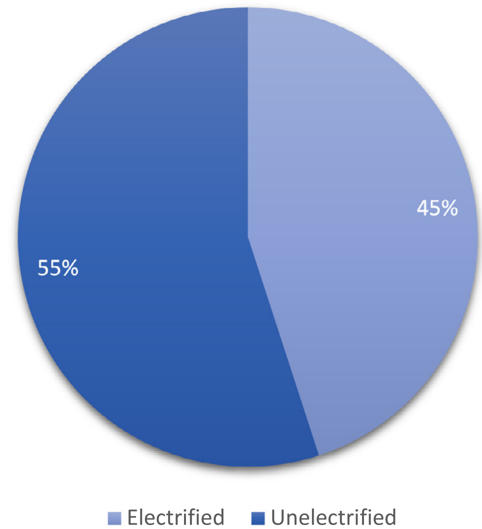

Fig. 4. Percentage of Electrified and Unelectrified Houses in Sub-Saharan Africa in 2019.

The important parameters that will help in formulating the model are as follows:

- Urban household energy consumption in Sub-Saharan Africa = 2600 KWh/yr
- Rural household energy consumption in Sub-Saharan Africa = 600 KWh/yr
- The ratio of urbanized to rural households in Sub-Saharan Africa = 52:48
- The population growth rate in Sub-Saharan Africa = 2.6%
- The population size of Sub-Saharan Africa in 2022 = 1.14 billion
- Average household members in Sub-Saharan Africa = 7

In order to get the energy consumption for a specific year, the population at that point should be calculated by using the following equation

$$P = 1.14\,(1.026)^{y-2022}$$

where 'P' is the population in the year 'y'

The energy consumption in year 'y' can be calculated using the following equation

$$E = \frac{P}{7}\,(1640)$$

Using the equations above, the residential energy consumption in the year 2040 can be approximated to be 424 billion KWh/yr. Although the approximated value is very small compared to other developed regions, it is very significant in Sub-Saharan Africa and will require energy generation measures to be taken. It is essential that the energy generated has minimal emissions to comply with different acts and protocols such as the Kyoto protocol. Hence, given the huge potential for solar energy in Africa, a considerable amount of the energy demanded can be met using solar energy.

Table 2
10 biggest solar projects in Africa in 2021.

NO.	Name	Place	Capacity (MW)
1	Noor Ouarzazate	Morocco	580
2	Benban Solar Project	Egypt	180
3	Solar Capital De Aar	South Africa	175
4	kaXu Solar One	South Africa	100
5	Xina Solar One	South Africa	100
6	Ilanga-1 CSP Plant	South Africa	100
7	Kathu Solar Park	South Africa	100
8	Jasper Solar Power Project	South Africa	96
9	Mulilo-Sonnedix-Prieska PV Project	South Africa	86
10	Kalkbult Solar Plant	South Africa	75
11	Lesedi	South Africa	75

4.1. Solar energy projects in Africa

Despite the urgent need for major investments in solar energy projects to meet the continent's growing electricity demands, some significant solar projects have already been implemented across the continent. Table 2 lists the largest solar projects in Africa, the majority of which are located in South Africa.

The first project "Noor Ouarzazate" is considered the largest CSP plant project in the world which is in morocco, and its capacity is about 580 MW. The second project "Benban Solar Project" in Egypt powers up to 80,000 houses, and its investment is around 190 million USD. The third project "Solar Capital De Aar" project powers up to 100,000 houses in South Africa and its capacity is 175 MW. The fourth project "KaXu Solar One" is considered the first commercially functioned solar thermal concentrator in South Africa. Furthermore, "Xina Solar One" is a CSP plant project that needed 880 million USD as an investment. Moreover, "Ilanga-1 CSP Plant" provides 100,000 houses with electricity annually as its capacity is 100 MW. Moving on to "Kathu Solar Park", the project provides electricity to 179,000 houses during the peak demand period. Also, "Jasper Solar Power Project" lights up about 80,000 houses and functions 180 GWh annually. Additionally, during the 20-life span, "Mulilo-Sonnedix-Prieska" PV Project lighted up to 40,000 households, while "Kalkbult Solar Plant" in South Africa contains about 312,000 PV cells on about 105ha of land. Also, the solar project generates about 135 GWh annually with a capacity of 75 MW. Finally, "Lesedi Solar PV Project" is located near the city of Kimberly in South Africa where it provides electricity to almost 65,000 households in South Africa, and it consists of 277,632 PV cells (Niyibizi, 2015; Goosen, 2021).

4.2. Renewable Energy and solar energy goals across Africa

The high potential for renewable energies allows African countries to set future visions and goals for energy generation. For example, Egypt has a goal of supplying 42% of its energy from a few other renewable resources in addition to solar energy as shown in Fig. 5 below: 22% PV, 14% Wind, 4% CSP, 2% Hydro (IRENA "Renewable Energy Outlook Egypt", 2018).

In addition, the total energy outline plan in 2030 for South Africa is 74,798 MW including 7958 MW for solar energy which is about 11% of the total energy. Considering the challenges that might face solar energy, PV cells will not work efficiently in unsuitable weather conditions. However, this challenge can be solved by adding storage systems to the PV cells to use the stored energy when the weather is not ideal.

4.3. Solar capacity in Africa

Initially, the solar capacity in Africa did not begin at an appropriate standard, but over time, it started to gain huge success. The

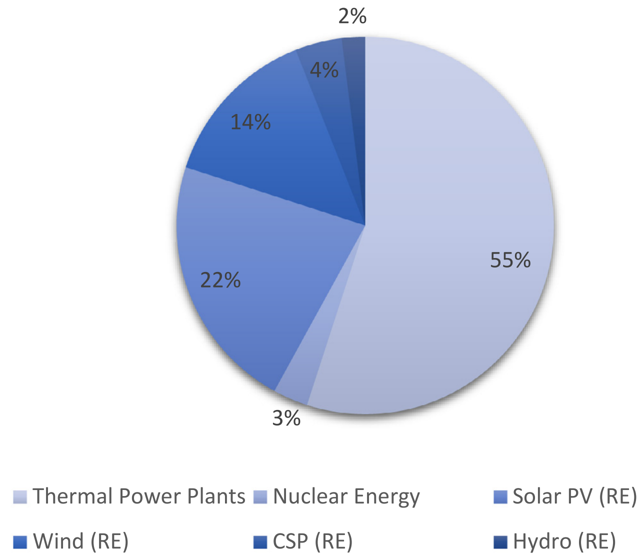

Fig. 5. Egypt's Vision 2035 for different RE technologies percentage share.

potential target of the Africa-EU Energy Partnership (AEEP) was adding a capacity of 500 MW by 2020, and the target was reached in 2010 which is 4 years after the baseline was set. In addition, the scenario of the AEEP suggested that in 2020 more than 7.7 GW of solar capacity will be installed. Fig. 6 shows the increase in solar capacity in Africa between the years 2010–2020. Fig. 7 and 8 show solar capacity percentage in comparison to other renewable energy resources in both 2010 and 2020 (see Fig. 8).

Moreover, the Independent Power Producers (IPPs) increase the generation of solar energy in 4 countries which are Ghana, Nigeria, and Senegal. In East Africa, Uganda, Rwanda, Madagascar, and Ethiopia were to have enough improvements that makes them reach the solar capacity of 500 MW in 2020 (Marks et al., 2017).

5. Financial status of solar projects in Africa

Funding and financing are major aspects that challenge the PV market in Africa. There is a major risk associated with renewable energy projects, which makes it more difficult to attract investors. It is difficult to secure funds for these both knowledge deficit, as well as economic constraints. Renewable energy projects require a huge initial investment; this necessitates unique funding arrangements and offers a major risk to investors if the project fails at an early stage. The higher investment risk for renewable energy projects in Africa causes investors to demand a greater rate of return to be able to accommodate these risks (Adewuyi et al., 2020). Currently, investments in fossil-fuel plants are easier than investments in renewable energy power plants (Schwerhoff and Sy, 2017). The poor knowledge and lack of experience in these kinds of projects make banks more reluctant on financing them Yang and Yang (2017). The improvement in the continent's economies and financial markets will reduce country-specific risks. As a result, there will be a greater number of foreign investors; they could also require a lower interest rate (Sweerts et al., 2019). According to a report by REN21, investments in renewable energy in Africa accounted for 0.8% of the global investments in 2000–2009; the percentage increased to 2.4% in 2010–2020. The annual investments in renewable energy peaked in 2018 at a value of 10.3 billion USD. This increase is an account of investments in solar PV, solar thermal, and wind projects. In the period between 2019 and 2020, the 10.3 billion USD dropped

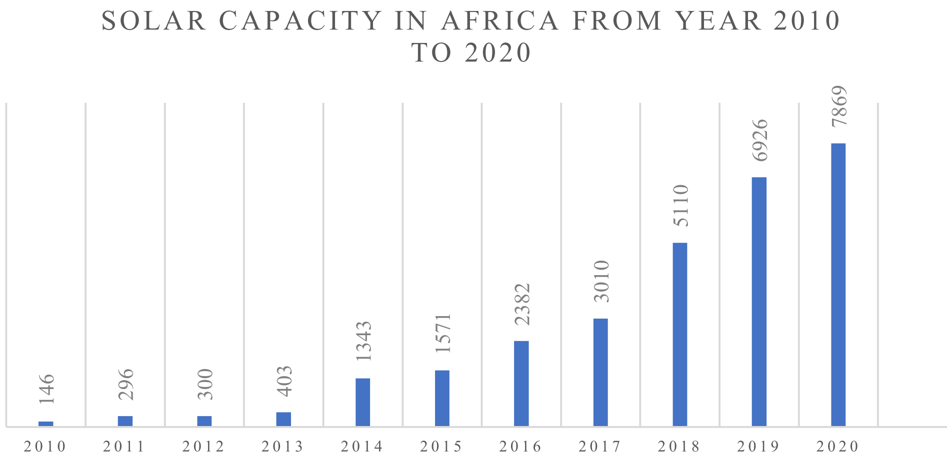

Fig. 6. Information about installed solar capacity from the year 2010 to 2020 in MW (Detollenaere et al., 2019; "Power Africa Annual Report", 2017, 2019).

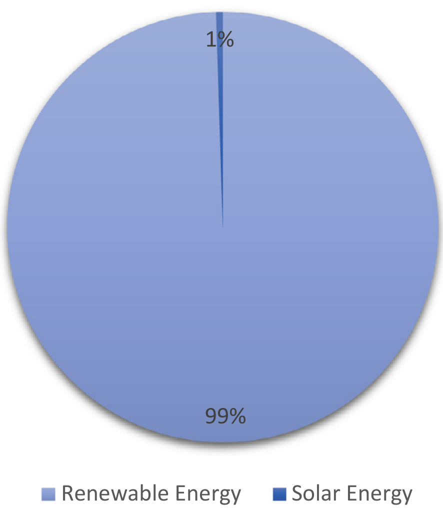

Fig. 7. Percentage of the capacity of Solar Energy to other RE projects in Africa in Year 2010.

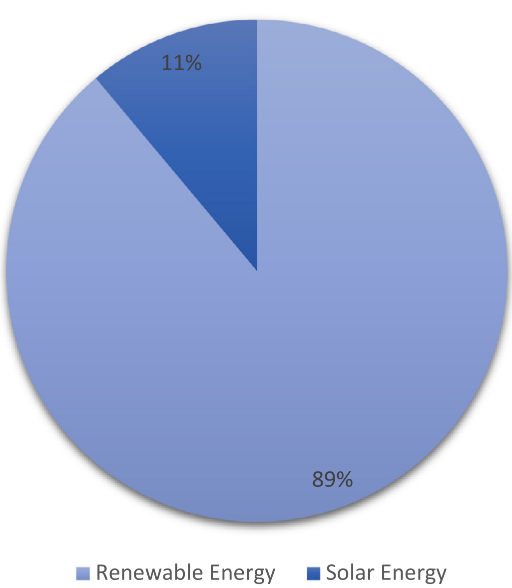

Fig. 8. Africa-EU energy partnership's goal for solar energy in Africa in 2020.

back to 3.1 billion USD. This drop was particularly noticeable in countries with previous large investments like South Africa, Egypt, Morocco, and Kenya ("Global trends in renewable energy investment 2020", 2020). Although the decrease was normal, it was further affected by the pandemic. Overall, the solar energy market has shown a significant decrease in costs which will be better for implementing solar energy projects in Africa. Globally, the Levelized Cost of Electricity (LCOE) of photovoltaics fell by 82% between 2010 and 2019. This decrease also appears in Africa where the LCOE of PV was decreased by about 49% in South Africa between 2013 and 2019 ("Renewable Power Generation Costs in 2019", 2020).

5.1. Funding techniques

The main funding technique for renewable energy projects in Africa grants. Only 14 African countries got various financing methods out of the entire continent. This is due to the fact that grants do not need a well-developed financial sector and may be used for small-scale initiatives. Most large-scale renewable energy projects are financed by subsidized forms of borrowing. Concessional loans are one type of subsidized borrowing that is provided by regional development banks. Another type is green bonds which are provided by The World Bank and The African Development Bank. There are also Public–Private Partnerships (PPPs) which leverage public funds and protect private investors from governance-related risks (Schwerhoff and Sy, 2017). The percentages of different types of funds used in African renewable energy projects are shown in Fig. 9.

5.2. Financial de-risking

Financial de-risking can help investors in solar energy projects overcome their financial issues. Financial de-risking is any form of external financial support that can reduce the risks occurring with investments. When financial de-risking reduces the risks of the projects, the investment costs are expected to decrease. There are international banks that provide financial and technical support for African countries for example Development Finance Institutions (DFIs) and Climate funds (Schwerhoff and Sy, 2017; Sweerts et al., 2019). The World Bank is one of the institutions that lend for climate change mitigation. Thus, the World Bank funds renewable energy projects in Africa. In fact, it has approved about 2 billion dollars per year for renewable energy projects in Africa. Second, the African Development Bank provides a variety of financial choices for investors looking to fund a project in

Africa. The most direct is the annual portfolio, which has surpassed 2 billion dollars in support for African sustainable energy projects. It also provides about 625 million dollars annually for the Climate Investment Funds. The African Development Bank provides two different types of indirect assistance. For starters, it can give the region's countries access to funds such as the Global Environment Fund and the Green Facility for Africa. Second, the African Development Bank and the African Development Fund have created two risk guarantee products to encourage private investors to fund renewable energy projects in Africa. There are two examples of multilateral donors which include the Global Environment Facility Trust Fund (GEFTF) and the Global Energy Efficiency and Renewable Energy Fund (GEEREF). The GEFTF is financed by 39 donor countries that aim at supporting and helping developing countries to achieve the United Nations Framework Convention goal on climate change mitigation. The GEEREF provides finance from the European Union countries. It provides equity to small and medium-sized projects by working as a Public–Private Partnership. For example, it has provided two private equity funds of 26.96 million dollars for Sub-Saharan Africa (Schwerhoff and Sy, 2017).

In addition, the European Investment bank (EIB), which finances energy projects around the world, contributes significantly to energy projects in Africa. About 15% of the investments made in 2017 were aimed at Sub-Saharan Africa. It uses different funding and risk-bearing methods including funding in local currency, equity, quasi-equity, senior debt, interest rate subsidies, access to European Development Funds, and donor funds for blending and technical assistance. Scaling Solar Zambia is one of the successful projects implemented by the EIB. Hence, it will be implemented in other African countries as well including Ethiopia and Madagascar. Since public finance is not sufficient, EIB and other donor funding develop investment vehicles and products that contribute to catalyzing private sector investments. To gain access to international funds, countries need to have their requirements clearly defined. Also, having future visions and goals can increase their chances of accessing funds (Energy Finance in Sub-Saharan Africa, 2018).

Figs. 10 and 11 illustrate the increase in investments across Africa over the years.

5.3. Off-grid technologies

Moreover, different private investment models increase the feasibility of PV solar cells in terms of finance. These are usually off-grid technologies (Meyer and Overen, 2021), and they are cheaper than on-grid technologies. First, there is a financial model and technology used in Tanzania by an energy service company called Devergy. Devergy installs off-grid power distribution networks with solar PV towers. The major cost of capital investment in this model is the power transmission cable that links households. The surplus in electricity from any household can be transmitted to neighboring households. Customers only need to pay the tariffs when they use electricity. This can be beneficial to customers as it lowers investment risks. This financial model can be implemented in the rest of Africa for the rural areas. Second, there is a financing business model called PAYG which has been used by various private companies. The client usually pays around 10% of the total capital cost of the solar kit. After that the client can pay daily installments; this becomes more affordable for clients. The PAYG model is considered very effective. It is expected that most of the rural communities in Kenya, Uganda, and Tanzania are going to use this financial model by 2030 (Yang and Yang, 2017). Africa accounted for 70% of the global investments in the off-grid sector from 2010 to 2020 as shown in Fig. 12. Despite the circumstances of the pandemic, the off-grid sector increased by 40% in the period between 2019 and 2020.

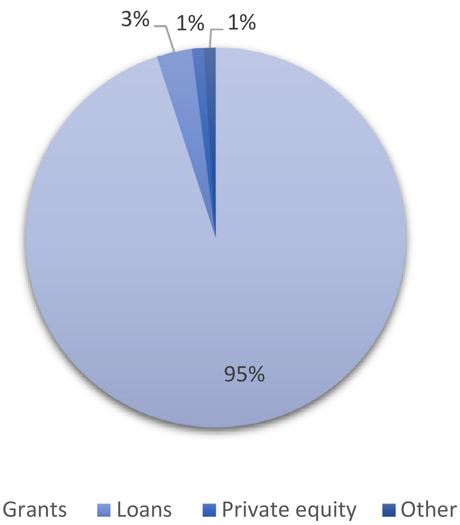

Fig. 9. Different methods of climate funds and their percentage share in African RE projects.

Table 3
Global average localized cost of electricity for different RE technologies.

Average LCOE for different Renewable energy technologies in 2010 and 2019		
Technology	2010	2019
Biomass	0.076 USD/KWh	0.066 USD/KWh
Geothermal	0.049 USD/KWh	0.073 USD/KWh
Hydropower	0.037 USD/KWh	0.047 USD/KWh
Solar PV	0.378 USD/KWh	0.068 USD/KWh
CSP	0.346 USD/KWh	0.182 USD/KWh
Off-shore wind	0.161 USD/KWh	0.115 USD/KWh
On-shore wind	0.086 USD/KWh	0.053 USD/KWh

The financial aspect of adopting solar projects in Africa is improving as shown in Fig. 13 and Table 3, however more action is needed to be able to tackle the different financial difficulties that the region still faces in terms of investments. Fig. 14 presents the suggested requirements that could potentially finance setbacks in solar energy projects' investments.

6. Policies status in Africa

Over 169 countries around the world set national goals for renewable energy shares from all accessible energy sources in 2018 (Brandt, 2019). In addition to that, 41 African countries had planned at least on achieving one target for one source of renewable energy (Marks et al., 2017). For these targets to be acquired successfully, the availability of renewable energy sources must be constantly increasing. The placement of these sources can only be successful by placing an integration policy to place regulations and protocols that the process of deployment should follow (Ayamolowo et al., 2022). Photovoltaic grid systems policies regulate the legal issues and processes that connect these systems to the national grid. These policies must also imitate the national goal of the country while also making sure that they can adapt to the changing nature of the energy market.

6.1. PV grid systems

There are two main procedures containing four different systems to link a photovoltaic system to the grid as shown in Fig. 15. The first methodology is called Power purchase agreement (PPA),

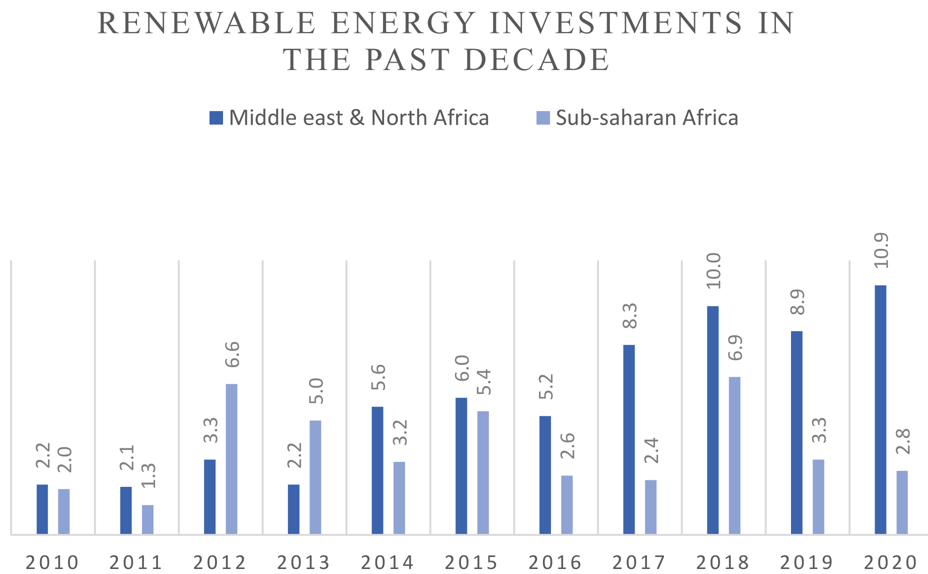

Fig. 10. Investment in RE in MENA region and Sub-Saharan Africa in Billion USD over the past decade.

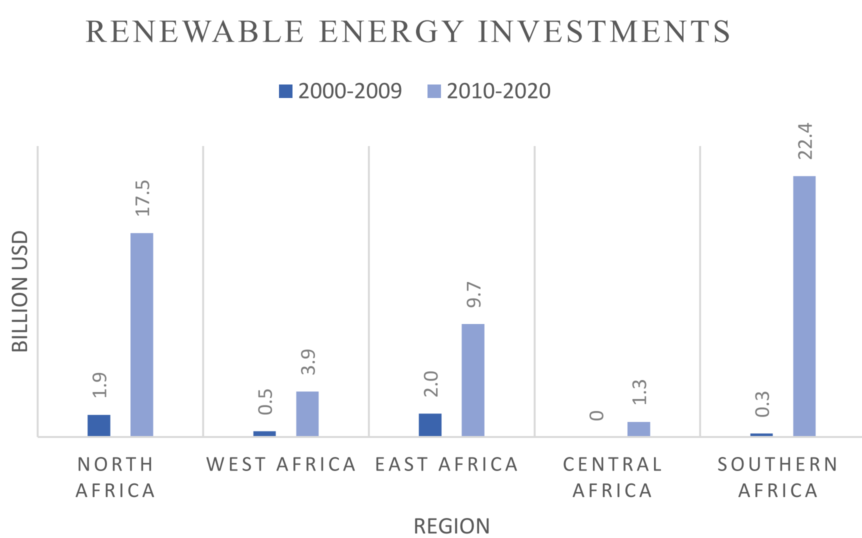

Fig. 11. Investments in RE in different regions in Africa in billion USD over the past two decades.

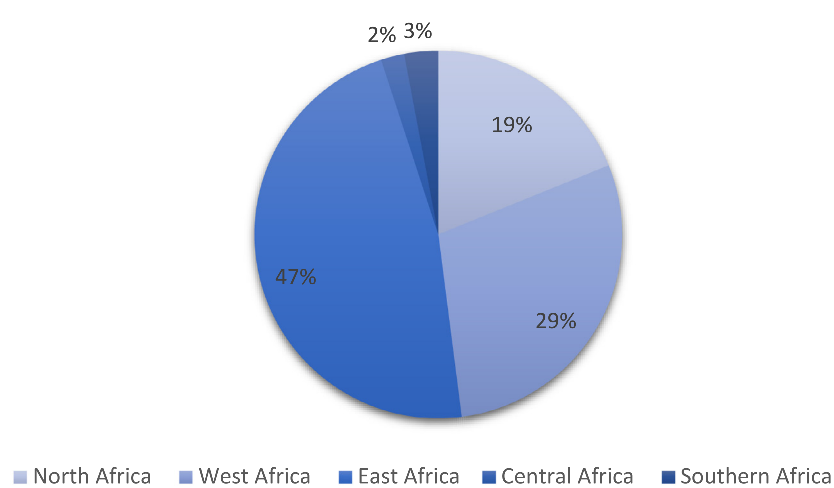

Fig. 12. Percentage of off-grid RE investments in different regions in Africa.

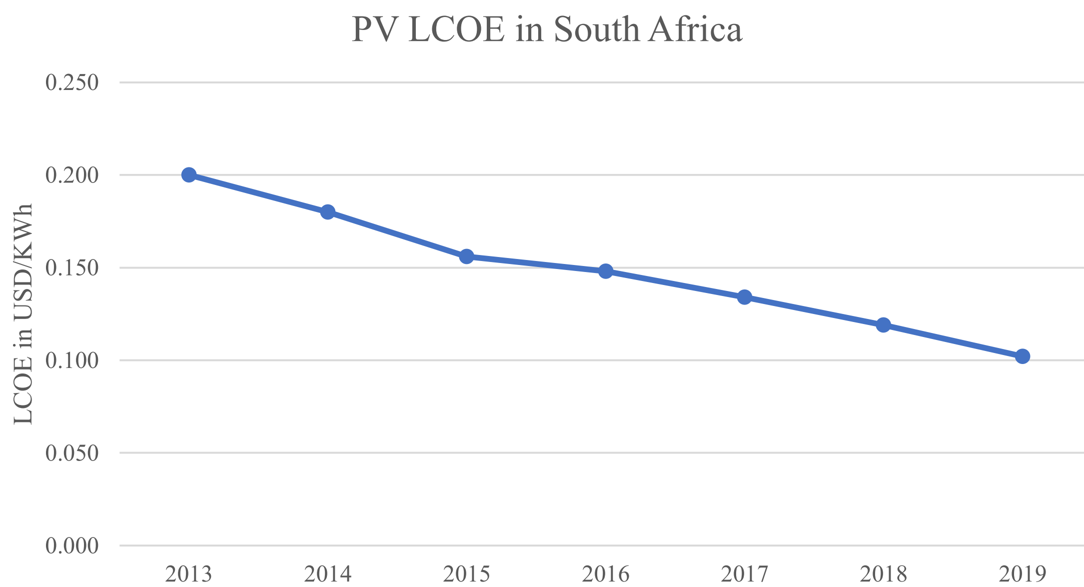

Fig. 13. The Levelized Cost of Electricity of PV in South Africa decrease over the years.

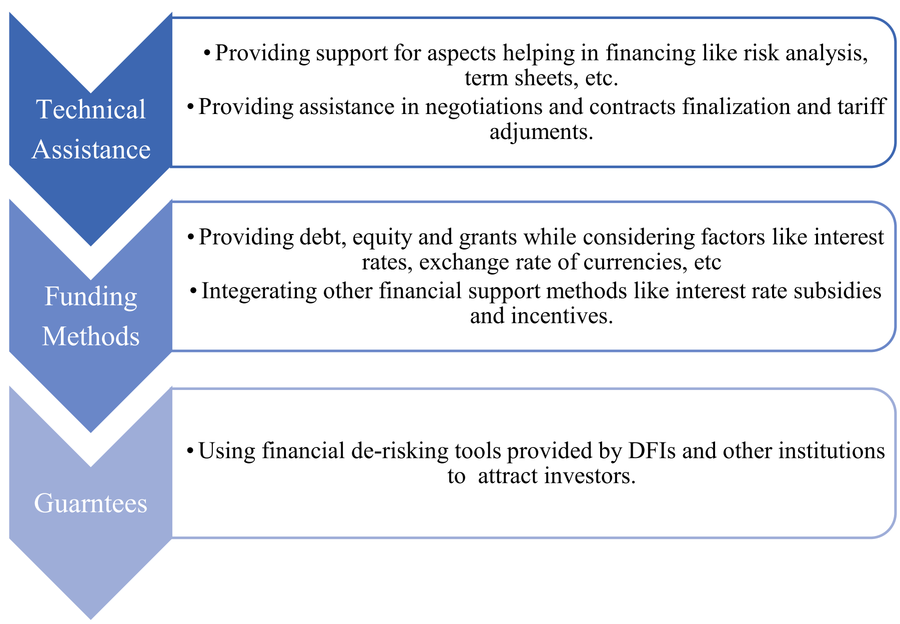

Fig. 14. Different requirements to improve RE project financing problem in Africa.

which includes 3 branches under the name of Feed-in-tariff (FiT), Feed-in-premium (FiP), and finally Auctions. The second and final methodology is defined as Net metering.

6.1.1. Power Purchase Agreement (PPA)

This agreement proved to be the most common policy for grid-connected photovoltaic systems throughout the world. It is a financial arrangement between the user and the photovoltaic plant investor. In this agreement, the government places a contract with the investor in order to buy the energy produced by the photovoltaic plant ("Understanding Third-Party Ownership Financing Structures for Renewable Energy", 2021).

A. Feed-in-Tariff (FiT)

In this type, the user buys with a given cost the energy produced from the photovoltaic plant. Also, the contract's duration can last for a long time (10 years for example). The most valuable advantage of the Feed-in-Tariff (FiT) policy is that it relieves the

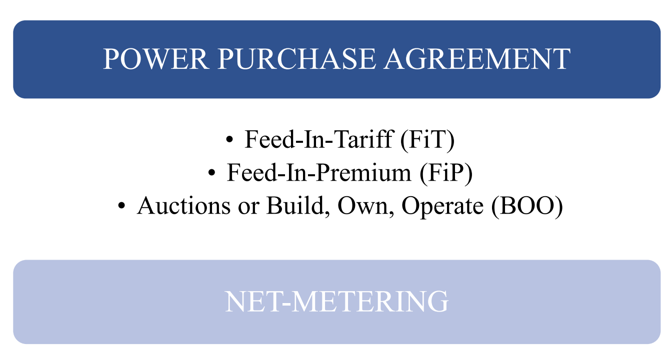

Fig. 15. Policy systems to link PV cells to a grid.

investors from concern about price fluctuations and instabilities as it conveys a constant price if the contract is valid. As a result, the FiT policy is considered one of the most outstanding economic mechanisms that encourage renewable energy technologies in Africa. The FiT policy is introduced in several countries in Africa such as Alegria, Kenya, Uganda, and Tanzania, and is done in others such as Botswana, Namibia, and Ghana. Most FiT systems in Africa are supposed to work poorly because of unlikeable institutional design, inadequate FiT rates, or difficulties in the implementation process. Shortcomings in FiT scheme design and implementation can be clarified by conflicting policy objectives such as reasonable prices of energy and network stability, but also time-wasting discussions in Power Purchase Agreements can be happened because of the indistinct distribution of property rights support which is necessary as a minor number of renewable power plants in Africa indicates that a fast spreading of the solar plant technologies is unpredictable from market power forces alone. In conclusion, the FiT's major goal is to enlarge and expand the power supply in African countries. It is preferred to be funded by international investors. In the meanwhile, increasing the prices of PV energy massively should be avoided. To gain international investors' attention, a constant cost for the PV energy should be chosen, and it is preferred to be in US dollars, but Algeria is considered one of the exceptions that offer premiums on the PV market price (Meyer-Renschhausen, 2017; Bouznit et al., 2020).

B. Feed-in-Premium (FiP)

In this scheme, the end-user (ex: government) purchases the energy produced by photovoltaic plants. In this contract, the electricity selling price is not fixed or constant like FiT, but it depends on the market prices. As a result of that, the investor takes the risk of fluctuations in market electricity prices. In addition to that, there are usually a few incentives that are provided by this contract to compensate for the high risks of market price fluctuations (Winkler, 2005).

C. Auctions

It has another name which is Build, Own, Operate. (BOO) is considered as an abbreviation for it. To submit the bidders' proposal, in BOO, for the offering charge of the renewable energy resources, the end-user offers an auction for bidders. The victor is determined by the lowest price or the number of points earned. The winner of the auction is the bidder who gained the highest points (IRENA "Renewable Energy Auctions in Developing Countries", 2013). The major obstacle concerning the auctions is that they are very effective only on large-scale projects, so any small, medium and even residential scale projects might be irritated from installing PV projects without the availability of FiT or FiP. In Egypt, for example, the New and Renewable Energy Authority (NREA) provides the land for certain projects for a selected period. After deactivating the project, the land returns to NREA, and contracts of 20 years for wind and 25 years for solar technologies will be awarded to the winners of the auction ("Egypt Renewable Energy Tenders (build-own-operate BOO contracts)", 2017).

6.1.2. Net-metering

The customer in net metering pays only for the value difference between the consumption and the production of the solar plant. Net metering has a problem with attracting investors financially against any of the PPA schemes.

FiT and FiP are considered the most common PV policy schemes. On the other hand, the governments started to reduce using FiT and FiP policies recently or started to shift to the auctions policy to offer to the end-user more competitive prices and let the investors have a risk-free feature ("Renewable Energy Auctions in Developing Countries", 2013).

In 2015, 14 African countries adopted policies of which about 7 of them adopted either the FiT or the FiP policy scheme, about 10 countries adopted the auction policy scheme, and about 5 adopted the net-metering policy scheme (Marks et al., 2017).

For example, in 2014 both FiT and auction policy schemes were adopted by Egypt. After that, in 2016 the FiT's values kept on changing until it was stopped in 2017, and now in Egypt, all the renewable energy projects are either in auctions or in net metering schemes.

7. Human resources status in the PV market

When it comes to implementing new technology, a region's human capacity is a crucial issue to consider. This can assist mitigate risks associated with various difficulties and lessen the likelihood of project failure. The lack of awareness of policymakers, project planners, and potential users can pose serious threats to developing new technologies (Hawila et al., 2014; Kimuli et al., 2017)

7.1. Current state of the human capacity in Africa

Across much of Africa, the workforce lacks awareness, necessitating the development of renewable energy capacity-building programs for decision-makers, engineers, technicians, and others. Furthermore, Africa's renewable energy consulting services are lacking, as the majority of professionals are not experts in the subject. For example, Egypt scored 4.66 on a scale of 7 on the capacity-building indicator. The African region also suffers from poor efficacy in the labor market. African countries are failing to make the most use of their resources in order to increase production and growth. Tunisia is the most efficient labor market in Northern Africa, earning 4.0 out of 7 on the measure. Africa also falls behind in terms of adopting existing technologies and developing new ones, owing to a lack of innovation and R&D investment in the region. Furthermore, due to inadequate PV module maintenance and the high likelihood of deterioration, the reliance on them for electricity is reduced (Hawila et al., 2014).

7.2. Awareness issue

Assessing the underlying problem, which is a lack of awareness, and suggesting possible remedies are the first steps in addressing human resource challenges. There are major differences between renewable energy technologies and conventional energy technologies. This makes most professionals unqualified to work in the renewable energy sector (Jenkins et al., 2014). They should attain additional skills to be able to fulfill the requirements of the new technologies. The skill gap can be reduced by training current professionals to expand their expertise to fit the requirements (Clancy and Feenstra, 2019; Odoom, 2015). This is done by providing professionals with different training programs in different fields to make them suited to work with Renewable energy projects. For example, Renewable Energy Solutions for Africa Foundation, Enel, and The European Investment Bank provide advanced courses that help participants attain technical, economical, and practical skills to be able to integrate renewable energy projects into their electricity market. The African Development Bank also offers training programs that strengthen professionals' skills and knowledge of getting funds for renewable energy projects and IRENA provides workshops for energy transition planning. In addition to training current professionals, fully specialized degrees should be developed instead of incorporating courses in the traditional engineering degrees. This is because most of the incorporated modules are superficial and do not acknowledge specific details. All renewable energy technologies are often discussed broadly. Renewable energy courses are scarce globally; whereas, Africa has a substantially lower percentage of these courses than the rest of the world, accounting for only 6.3 percent of all courses. This places it as the second least educated region in terms of renewable energy. (Hawila et al., 2014).

Fig. 16. Training in different fields is needed to develop the RE market.

7.2.1. Training needed to increase awareness and expertise

To be effective, the implementation of new technology necessitates a variety of workers and expertise. Several trainings must be completed in order for present professionals to be qualified for the role. The following are the compulsory trainings which are then summarized in Fig. 16:

A. Technicians and artisans should be trained to maintain the system in a trouble-free manner. They are supposed to handle errors properly to prevent the system from failing or malfunctioning. They should study the maintenance and repair procedures for the technology they will be working with in-depth (Jain et al., 2002).
B. Professionals and supervisors should be trained to build and create systems that are appropriate for the various conditions that their respective country faces. They should continue to improve their leadership abilities in order to preserve their effectiveness in leading and directing employees (Jain et al., 2002).
C. Decision-makers should be taught how to appraise a product and assess its practicality in the location where it will be implemented. They must examine a variety of factors, including technological, economic, environmental, and social consequences (Jain et al., 2002).
D. The research and development (R&D) sector must d since this will aid in the adaptation of existing technologies and the development of new technologies that are more compatible with the region's environment (Qadir et al., 2021). Furthermore, this can aid professionals in developing new technologies and systems that will have a significant impact on the renewable energy sector in the future (Jain et al., 2002).
E. To obtain the desired results, even the trainers need to be trained. Trainers should be given a thorough and complete education. They should learn how to promote awareness among trainees and the general public, as well as how to explain new technologies and their features to them (Jain et al., 2002).

Another initiative to be taken is incorporating renewable energy courses starting from the elementary education level. This can help improve the situation of Africa in the future in terms of human capital for renewables. The main objective of this initiative is to raise the awareness of the students about different types of energies and the challenges facing them. The aim is to teach students from a young age about conventional and non-conventional energy sources and the possibility of harnessing them. This can help prepare students for a future where renewable energy can be harnessed easily with little challenges that can be easily solved (Danquah and Amankwah-Amoah, 2017; Lucas et al., 2018). Moreover, African countries are encouraged to promote higher education and research as a way to achieve economic growth and sustainable development. The national development policy documents of different African countries strongly focus on improving higher education and enhancing research and innovation outcomes. For instance, Uganda's vision 2040 and Kenya's vision 2030 put a strong focus on improving their human capital in Science, Technology, and innovation to achieve economic growth and eradicate poverty. In addition, South Africa's National Development Plan aims to develop research in science and technology fields, increase university enrollments by 70% by 2030, and have more than 5000 doctoral program students graduate per year.

7.2.2. Features of renewable energy courses

Following are the specific features needed to be included in renewable energy courses for them to be effective:

A. All or most of the renewable energy resources should be acknowledged in the curriculum. Resources that satisfy local demands with the fewest hurdles and impediments can be emphasized even more (Kandpal and Broman, 2014).
B. All aspects of the technology and its implementation should be covered in the courses. For example, giving a reliable assessment of the resources, manufacturing and maintaining the system, financing and funding the system, and so on are all critical considerations (Kandpal and Broman, 2014).
C. The courses should also equip students with the necessary practical skills to work in the field. To attain the best results, they should have hands-on skill instruction, experiments, and theoretical demonstrations (Kandpal and Broman, 2014; Walz et al., 2016).
D. The courses should be adaptable to future developments and technological advancements (Kandpal and Broman, 2014).
E. After the students have completed the courses, there should be opportunities available to them. Students may be drawn to the renewables major because of the high employment chances (Kandpal and Broman, 2014).
F. When appropriate, the training should be delivered in the local language. This will allow everyone who is interested to study without being hindered by a linguistic barrier. To make things easier, the resources used could be translated into the local languages. Finally, these resources must be provided at a reasonable cost to appeal to a wide range of people (Kandpal and Broman, 2014).

7.3. Gender issues in the PV market employment

In Africa, there are gender issues in the PV market that need addressing; women face major challenges in joining the workforce in the renewables and PV market. Only a few women have roles in the market, such as technologists, decision-makers, and so on. (Rojas, 2019). The percentage of women in different positions in the field can be seen in Figs. 17, 18, and 19.

7.3.1. Action needed to achieve a gender-balanced market

Women's opportunities in the PV market are hampered by a number of gender-based obstacles. The PV and renewable energy markets in Africa have few to no women planning, implementing, researching, developing, and maintaining systems, posing serious problems to Africa's human capital. The following are some possible solutions to this issue:

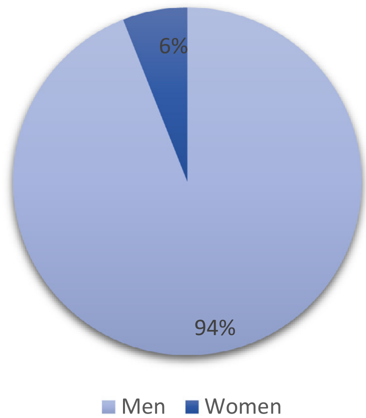

Fig. 17. Percentage of women to men in executive leadership positions in Africa.

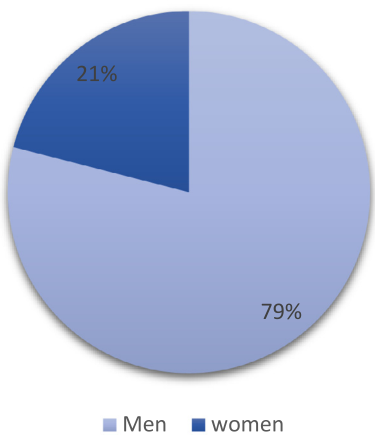

Fig. 18. Percentage of women to men in board positions in Africa.

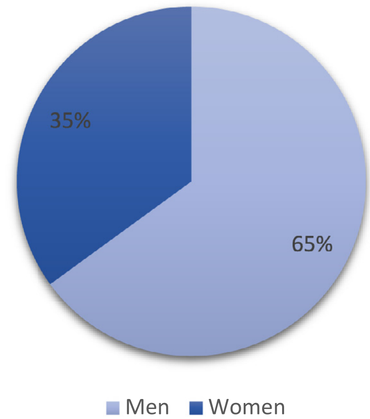

Fig. 19. Percentage of women to men in utility workforces in RE market in Africa.

A. Gender-balanced policies, projects, programs, and investments should all be non-discriminatory. This will allow women to engage in the energy market and achieve gender equality (Maduekwe et al., 2019; Clancy, 2000).
B. Workforce participation for women should be encouraged. Equal opportunities for both men and women can help them climb up the employment ladder. Women's employability in the energy sector will improve if they have the opportunity to specialize in science and engineering subjects (Maduekwe et al., 2019).
C. Gender equality in the energy industry should be supported and promoted through public campaigns and educational systems. This will help to balance the energy sector and lessen the impact of human resources on technological adoption (Maduekwe et al., 2019).

8. Conclusion

Renewable energy is the key to eliminating significant issues facing the continent of Africa including poverty, poor electrification quality, electricity blackouts, and climate change consequences. About 53% of the African population does not have access to electricity. As a result, it was essential to introduce new solutions to produce electricity and solve this problem. Due to the continent's strategic location, renewable energy has quite an enormous potential. Solar energy is the form of renewable energy that has the most significant potential in Africa due to a variety of reasons. The potential of solar energy in Africa represents 40% of the total global potential for solar power. However, the solar power market in Africa faces significant obstacles that make project implementation more challenging. Challenges vary, from financial challenges that usually occur due to the inability and difficulty in attracting investors to fund the projects while suiting local policies. Other challenges include human resources, as there is a significant deficit in trained manpower to implement renewable energy projects. Moreover, there are environmental challenges faced due to the hot and dusty climate that can lower the efficiency of the solar cells. Finally, there are technological challenges that due to Africa's incapacity to localize and execute renewable energy technology. However, applying the SDG plan helps governments take the right decisions toward sustainable development. Despite the various challenges that face the solar energy market in Africa, several projects have been undertaken across the continent. There are several solar projects in Africa with high electricity generation such as Noor Ouarzazate solar power plant in Morocco which generates almost 580 MW each year. The development of new projects and implementations have been increasing over the years to enhance the continent's electricity complications, fulfill its growing energy demands, and satisfy Africa's vision for 2030 by increasing the electricity generated from solar projects by 11%. However, starting new solar projects is challenging due to the high initial cost of investments and lack of labor experience, the capacity investments have also increased in the past decade. Improving the continent's economy will encourage investors to invest and will lower the values of the initial costs required for implementation. Applying and introducing new policies will make it easier for the investors to start new projects such as the policies that were already introduced as the PPA and net metering. Furthermore, for future potential implementations, a few suggestions could be of great use. For instance, when some de-risking and policy adjustments are undertaken, renewable energy deployment becomes more accessible. Moreover, human capital is a very essential asset when it comes to the solar energy market. Therefore, experience and knowledge must be enhanced to supply sufficient staff who will support new technologies without causing system faults. In conclusion, Africa has various future visions for achieving some of the Sustainable Development Goals by 2030; whereas these goals may be readily realized through Africa's enormous potential for renewable energy specifically solar energy, those visions may only be efficiently achieved if appropriate legislative, financial, technological, and human resource strategies are implemented.

CRediT authorship contribution statement

Maryam K. Abdelrazik: Data curation, Investigation, Formal analysis, Methodology, Software, Visualization, Analysis, Validation, Writing – original draft, Writing – review & editing. **Sara E. Abdelaziz:** Data curation, Investigation, Formal analysis, Methodology, Software, Formal analysis, Visualization, Analysis, Validation, Writing – original draft, Writing – review & editing. **Mariam F. Hassan:** Data curation, Validation, Methodology, Project administration, Visualization, Writing – review & editing. **Tarek M. Hatem:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Visualization, Supervision, Roles/Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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