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Review

Overview of Energy Systems in Africa: A Comprehensive Review

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Abstract: Africa has abundant solar resources but only 2% of its current capacity is generated from renewable sources. Photovoltaics (PV) offer sustainable, decentralized electricity access to meet development needs. This review synthesizes the recent literature on PV in Africa, with a focus on Mozambique. The 10 most cited studies highlight the optimization of technical components, such as storage and bifacial modules, and challenges in integrating large-scale PV. Case studies demonstrated Mozambique's potential for PV applications in water heating, irrigation, and rural electrification. These benefits include reduced emissions and energy access. However, barriers, such as high costs, lack of infrastructure, and training, exist. While solar cookers are insufficient, thermal systems have unrealized potential. Mozambique's urban and rural electrification rates are 57% and 13%, respectively, despite its energy resources. Targeted policies, financing, and community engagement are essential for promoting adoption. While PV can sustainably expand electricity access, coordinated efforts must address costs, infrastructure, maintenance, and social factors for successful implementation. Mozambique has immense solar potential, but strategic planning and support are critical to unlocking these benefits. This review provides insights into optimizing PV systems and policy frameworks for a clean and inclusive energy production future in Africa, to synthesize the 10 most cited studies on photovoltaic solar energy in Africa, and to deeply reflect upon the current energy needs in Mozambique, the benefits of employing PV and solar thermal systems, and the challenges of implementing such systems within the Mozambican context.

Keywords: photovoltaics; solar thermal systems; solar energy; Africa; Mozambique

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1. Introduction

In recent years, solar energy has emerged as a pivotal solution to the pressing energy challenges faced by Africa. With abundant sunlight year-round, Africa has immense potential for solar energy generation. Photovoltaic (PV) systems, which convert sunlight directly into electricity, are particularly well suited for this context. These systems offer a sustainable, renewable, and clean energy source that can help mitigate energy poverty, affecting a significant portion of the population. In addition, PV systems can play a vital role in reducing the dependence on fossil fuels, lowering energy-related emissions, and fostering energy security and resilience. Therefore, understanding the applications, benefits, and challenges of photovoltaic systems in Africa is of paramount importance [1,2].

Africa is considered to have the highest potential for solar energy systems worldwide, accounting for 60% of the world's best solar resources [3,4]. Despite its potential, Africa has only 1% of its installed solar energy capacity [4,5]. The lack of energy access is considered the most significant barrier to African economic development [4]. However, solar PV is already the cheapest source of power in many parts of Africa, and by 2030, it is predicted to outcompete all other sources [5]. Renewables, including solar, wind, hydropower, and geothermal, are expected to account for over 80% of the new power generation capacity by 2030 in the Sub-Saharan Africa region, which demonstrates that solar energy systems are leading the way in Africa's energy sector [5].

The off-grid model transformed the access to solar power in rural Africa. Small-scale modular solar power installations are being implemented at village and household levels [6,7]. Solar energy systems can support irrigating and fertilizing farms, providing a new way to help 791 million Africans without electricity [6]. However, challenges such as financial, technological, human resource, and environmental issues complicate the implementation of solar energy systems in Africa [8]. To overcome these challenges and exploit Africa's abundant natural and renewable resources, the adoption of efficient renewable energy technologies is essential for future sustainability [8].

The growth of solar energy in Africa serves as a live example of how this technology can benefit the continent economically and environmentally, potentially boosting its economy [8,9].

African leaders are committed to bringing solar power to rural homes, and have created numerous growth platforms for companies operating in small-scale residential solar or storage markets. However, the implementation of solar energy systems in Africa remains challenging. One major challenge is the lack of infrastructure in rural areas, which hinders electrification efforts in these regions [7]. Moreover, traditional energy sources, such as wood or other biomass, are still dominant for cooking in Africa, presenting another challenge for implementing solar energy systems [10]. Despite these challenges, the pay-as-you-go solar power model, also known as PayGo, has been a consistent approach for overcoming these barriers. This model leverages mobile money technology to receive payments from customers in rural areas, and offers credit to enable poor customers to invest in infrastructure for their homes [7]. The PayGo system has gained 500,000 new users in East Africa since 2015 [9].

Furthermore, many African countries have established special funds to support consumer credit for solar energy systems [10]. Private sales initially dominated the solar market in South Africa, but the government initiated a substantial off-grid effort that is now fully active [10]. Improved energy storage is increasingly balancing the power supply in microgrids at lower costs, creating opportunities for companies operating in small-scale residential solar or storage markets [9]. Remote solar facilities can provide power to construction projects, farms, and safari lodges in Africa, thereby offering solutions to power outages in the region [4]. Although most Africans still rely on less efficient traditional energy sources, solar power offers compelling advantages for Africa, including faster electrification for the population and reduced environmental damage caused by cutting down trees for fuel [7,10].

Photovoltaic (PV) and solar thermal systems are two distinct types of solar energy technologies. While PV systems directly convert sunlight into electricity, solar thermal systems use the sun's energy to heat a fluid, which then generates electricity [11].

There are two main types of solar energy systems: photovoltaic and solar energy. Photovoltaic systems convert sunlight directly into electricity using solar panels, whereas solar thermal systems employ mirrors or lenses to concentrate the heat of the sun, which, in turn, creates steam to generate electricity. Africa is emerging as a leader in solar energy, although increased investment is necessary to maximize its potential for clean energy generation [3,7]. Photovoltaic systems are widely used in Africa and have proven successful in powering homes, clinics, and communities in remote areas. For instance, off-grid solar energy solutions, such as solar home systems, provide affordable and reliable electricity in areas without access to centralized power grids [6].

However, solar thermal systems are not as common in Africa as photovoltaic systems. However, they hold significant potential for large-scale power generation because they can generate steam to drive turbines and produce electricity on a larger scale. The use of solar thermal systems is more prevalent in countries with high levels of direct sunlight and large flat areas available for installation, such as Morocco and Egypt [12]. With 60% of the world's prime solar resources, Africa has the potential to become a leader in both photovoltaic and solar thermal technologies. However, at present, only approximately 2% of Africa's electricity is generated from renewable sources, including solar power [9]. Despite this, the continent is progressing towards a future that prioritizes renewable energy sources for example. By 2030, renewables, including solar power, are projected to account for more than 80% of the new power generation capacity in South Africa [5]. This underscores Africa's potential to play a significant role in the global transition to clean energy sources.

In conclusion, Africa holds immense potential for solar energy development, which could be the key to solving the energy poverty problem. While challenges such as a lack of infrastructure and financial barriers exist, innovative solutions, such as the PayGo model, are paving the way for extensive solar energy deployment across the continent.

In a recent study conducted by Papazis [13], valuable insights that can be adapted and applied to the African context and an innovative integrated approach to EDC optimization for thermal systems were introduced. This study not only advances previous knowledge by presenting an integrated model grounded in exact matrix mathematics and solutions but also provides a valuable resource for researchers in the techno-economic domain to address EDC challenges specific to thermal system generators. One of its main strengths lies in its capacity to optimize costs for hybrid energy systems, particularly those with a large number of power units, varied operating conditions, different fuels, and differing unit prices.

The implementation of solar energy in Africa requires a thorough analysis of both the technical and economic aspects. Computer simulations have shed light on the performance and cost-effectiveness of different solar thermal power plant designs, such as parabolic trough and non-tracked systems. Furthermore, building-integrated PV technology can be synergized with solar energy sources in structures to satisfy their energy requirements [14].

2. Materials and Methods

This article is situated within the context of a larger study titled 'Proposal for a Methodology for Sustainable Rehabilitation Strategies of the Existing Building Stock—The Ponte Gêa Neighborhood' [15]. The present review aims to answer specific questions posited as justifications for this article.

2.1. Definition of Keywords

The keywords "photovoltaics" and "Africa" were used to conduct the literature search. These keywords were chosen to focus on the search for photovoltaic technologies applied within the African context.

2.2. Time Period

The review was limited to articles published between 2012 and 2024. This period was selected to capture the recent trends and significant developments in the field.

2.3. Databases

The Scopus database was used for the search because of its extensive coverage of the scientific literature across various disciplines.

2.4. Selection Criteria

Initially, the 10 most cited articles were selected from 261 articles identified using the keywords search. After reviewing the abstracts of these 261 articles, 5 additional articles were selected that were deemed relevant to this review based on their content, quality, and relevance to the context of African countries.

2.5. Research Date

The search was conducted on 4 August 2023.

2.6. Selection Process

The article selection process was conducted in several stages:

- Phase 1: Identification of articles using the specified keywords in the Scopus database;
- Phase 2: Application of filters, such as the time period (2012–2024) and limitations of articles written in English;
- Phase 3: Selection of the 10 most cited articles from the 261 found using Scopus' citation analysis tool;
- Phase 4: Review the abstracts of these ten articles to confirm their relevance;
- Phase 5: Five additional articles were selected after reviewing the abstracts based on their relevance to the research questions.

Exclusion Criteria: Articles that did not focus on photovoltaic systems or the African context were also excluded.

2.7. Additional References

From the 5 additional articles selected in phase 5, 15 more relevant references were identified and added to this review.

2.8. Analysis of Articles

The selected articles, including the initial 10 most-cited, 5 additional articles, and the 8 references identified within them, were analyzed according to the following topics, which are aligned with the research questions of this study:

- Current energy needs in Mozambique: Identification and synthesis of relevant information found in articles about the current energy needs of Mozambique;
- Benefits of using photovoltaic and solar thermal systems in Mozambique: Extraction and summarization of the benefits identified in the selected articles;
- Challenges in implementing photovoltaic and solar thermal systems in Mozambique: Identification and summary of the challenges reported in the selected articles.

Each article was carefully read and its content was categorized according to the topics above. The main conclusions of each article are summarized and compared to identify patterns, contradictions, and gaps in the existing literature.

2.9. Identification of New Studies via Other Methods

The websites of relevant organizations and institutions were searched for additional publications. A total of 12 websites were consulted, 9 of which were selected for further review, contained in the references.

2.10. Report Assessed for Eligibility

A total of 281 articles, reports, and websites were assessed for eligibility after the initial search and application of the selection criteria. This included 261 articles identified through a database search and 15 additional references identified within the 5 selected articles and 12 websites of relevant institutions.

2.11. Final Number of Included Studies/Articles in This Review

After a thorough assessment and application of the exclusion criteria, a total of 39 articles/reports/websites were deemed relevant and included in this review for a detailed analysis.

3. Results and Discussion

In this section, we provide a detailed analysis of key studies and current conditions related to photovoltaic solar energy in Africa, with a specific focus on Mozambique. In Section 3.1, we present a synthesis of the ten most cited studies on photovoltaic solar energy in Africa, highlighting the significant contributions and findings of these influential works. Section 3.2 narrows the focus to Mozambique, summarizing the five most relevant studies on photovoltaic solar energy in this country. To provide a comprehensive context, Section 3.3 outlines the current energy needs in Mozambique, offering insights into the demand and challenges the country faces in meeting its energy requirements. Section 3.4 explores the potential benefits of employing photovoltaic and solar thermal systems in Mozambique, emphasizing the positive impacts these technologies could have on the country's energy landscape. Finally, Section 3.5 discusses the challenges associated with implementing photovoltaic and solar thermal systems in Mozambique, shedding light on the obstacles that need to be addressed for the successful and sustainable adoption of these technologies.

3.1. Synthesis of the 10 Most Cited Studies on Photovoltaic Solar Energy in Africa

The analyzed articles (Table 1) explore different aspects related to solar energy and other forms of renewable energy, ranging from the assessment of costs of photovoltaic (PV) systems with energy storage [16] to incentive policies for the use of wind energy in the European Union. The first group of studies (Orders 1–5) focus on the technical aspects and potential implementation of solar energy technologies in various global contexts. The second group (Orders 6–10) addresses the dimensions of the development and integration of renewable energies, with an emphasis on solar energy systems and incentive policies.

Table 1. Top 10 Most Cited Articles for the Keywords 'photovoltaics' and 'Africa', Searched in the Scopus Database, Time Period of 2012–2024.

Order	Title	Year	Citations	Objective	Refs.
1	Levelized Cost of Electricity for Solar Photovoltaic and Electrical Energy Storage	2017	310	Develop methods to calculate levelized costs for photovoltaic systems with electrical energy storage	[16]
2	Global Analysis of Photovoltaic Energy Output Enhanced by Phase Change Material Cooling	2014	171	Analyze potential improvements in PV panels using PCMs	[17]
3	Optimization and Performance of Bifacial Solar Modules: A Global Perspective	2018	169	Analyze and optimize the performance of bifacial solar modules from a global perspective	[18]
4	Hybrid Off-grid Renewable Power System for Sustainable Rural Electrification in Benin	2020	166	Analyze the technical and economic feasibility of hybrid renewable energy systems (HRESs) for rural electrification in Benin	[19]
5	Solar Power Potential of Tanzania: Identifying CSP and PV Hot Spots through a GIS Multicriteria Decision Making Analysis	2017	155	Investigate the spatial suitability for large-scale solar power installations in Tanzania	[20]
6	Review of advanced grid requirements for the integration of large scale photovoltaic power plants in the transmission system	2016	135	Review the development of grid codes for large-scale PV integration and compare requirements across different countries	[21]
7	Global applicability of solar desalination	2016	127	Analyze effectiveness of renewable energy policies in promoting wind power across EU countries	[22]

Table 1. *Cont.*

Order	Title	Year	Citations	Objective	Refs.
8	GIS-based assessment of photovoltaic (PV) and concentrated solar power (CSP) generation potential in West Africa	2018	126	Evaluate the potential for solar electricity generation in rural areas of West Africa	[23]
9	Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?	2016	120	Review the feasibility of off-grid solar PV systems for rural electrification in Sub-Saharan Africa	[24]
10	Sustainable energy planning: Leapfrogging the energy poverty gap in Africa	2013	118	Review of renewable energy policies and their effectiveness in promoting renewable energy growth	[25]

In the discussion on PV systems with energy storage, the first study highlighted the advantages of vanadium flow batteries over lithium-ion batteries in terms of the levelized cost of electricity [16]. The potential of phase change materials (PCMs) to improve the performance of solar panels, especially in tropical regions, has been emphasized, although a cost–benefit analysis still requires further investigation [17]. Bifacial solar modules, under ideal conditions, can significantly increase energy gain, but these gains are generally below 10% in typical configurations [18]. The fourth study highlights the technical and economic feasibility of hybrid renewable energy systems for rural electrification in Benin, demonstrating the sustainability of these systems compared with diesel-based options [19]. The fifth study used a quantitative and spatial approach to identify favorable areas for large-scale solar installations in Tanzania, which may be useful in guiding energy policies in Tanzania [20].

In the context of renewable energy integration, studies highlight the complexity and challenges associated with adopting these technologies. The importance of rigorous grid codes for the integration of large-scale photovoltaic (PV) plants is emphasized by comparing the requirements of various countries [21]. Incentive policies, such as feed-in tariffs and green certificates, have played a crucial role in promoting renewable energy in the European Union, but their results vary between countries [22,25]. The research of Order 8 emphasizes that although West Africa has a high technical potential for solar energy generation, the effective development of this capacity depends on more integrated analyses, considering grid planning, economic factors, and local conditions [23]. In the context of Sub-Saharan Africa, despite the high solar potential, the current high costs of off-grid PV systems are a significant obstacle to rural electrification, indicating the need for innovative financing strategies and perhaps the consideration of other electrification options [24].

Together, these studies reinforce the importance of ongoing research to optimize the efficiency and implementation of solar energy technologies and other renewables in various global contexts. They also underline the need for well-designed and locally adapted policies to promote effective and sustainable integration of these technologies into energy grids.

3.2. Synthesis of the Five Most Relevant Studies on Photovoltaic Solar Energy in Mozambique

The five papers (Table 2) analyzed the use of solar photovoltaic energy in various applications in Mozambique, exploring technical, economic, environmental, and social factors.

Table 2. Five Selected Articles from the Scopus Database Search on the Use of Photovoltaic Solar Energy in Mozambique: Technical, Economic, Environmental, and Social Factors (Period 2012–2024).

Order	Title	Year	Citations	Objective	Refs.
1	Comparison of two dynamic approaches to modelling solar thermal systems for domestic hot water	2018	18	To compare two dynamic approaches to modeling solar thermal systems for domestic hot water: an hourly model (Model A) developed by the authors and Polysun simulation software (version 9.2, Switzerland) (Model B).	[26]
2	Domestic hot water technology transition for solar thermal systems: An assessment for the urban areas of Maputo city, Mozambique	2020	9	To survey domestic hot water (DHW) usage in Maputo, Mozambique, and model the effects of transitioning to solar thermal systems (STSs).	[27]
3	The greenest decision on photovoltaic system allocation	2017	25	To analyze the life cycle CO_2 emissions of three PV technologies in 138 countries and understand the importance of installation location.	[28]
4	Feasibility of Utilizing Photovoltaics for Irrigation Purposes in Moamba, Mozambique	2021	5	To assess the feasibility of using photovoltaics (PV) for irrigation pumping in Moamba, Mozambique.	[29]
5	Multicriteria Decision-Making Approach for Optimum Site Selection for Off-Grid Solar Photovoltaic Microgrids in Mozambique	2023	2	To analyze the feasibility of solar photovoltaic (PV) mini-grids for rural electrification in Mozambique.	[30]

In technical terms, studies have shown that Mozambique has a high solar potential that can be harnessed for power generation. The technical analyses of photovoltaic systems in the studied applications (water heating [26,27], irrigation [28], and rural electrification [29]) demonstrate feasibility and good efficiency levels.

Economically, transitioning to solar photovoltaic energy in the analyzed applications presents benefits, reducing costs for end users compared to options such as diesel and grid electricity [26–30]. However, the initial investment remains a barrier [27,28].

Environmentally, solar energy significantly reduces CO_2 emissions compared to fossil fuel alternatives [26,27,29]. However, these papers highlight the importance of considering the full life cycle in an environmental analysis [26,30].

Socially, these studies emphasize the need to engage local communities and consider social factors for successful implementation [28,30]. Maintenance, user education, and business models were identified as critical aspects [28,29].

Artur et al. [26] compares two dynamic approaches to modeling solar thermal systems for domestic hot water: an hourly Model A (Model A) developed by the authors and Polysun simulation software (Model B). Model A performs an energy balance calculation at the level of the hot water tank and is useful for the sensitivity analysis and pre-sizing of systems. In contrast, Model B provides detailed modeling of the system components, including stratification in the tank, but tends to over/undersize the tank because of the temperature control layers. Despite the differences in auxiliary energy estimation, both models align well in terms of solar energy delivered to consumers.

Artur et al. [27] presented a survey of 700 households in Maputo, Mozambique, to understand domestic hot water (DHW) usage and technologies. The findings suggest that transitioning to solar thermal systems (STSs) could significantly reduce electricity demand (by 65.7%) and CO_2 emissions (by 78.7%). However, the study also highlights the need for load management policies owing to potential increases in peak load with 100% STS adoption.

Serrano-Luján et al. [28] employed a life cycle assessment to analyze three PV technologies in 138 countries, focusing on CO_2 emissions avoided by replacing the grid electricity. The study emphasizes the importance of the optimal location for PV installation, as avoided emissions can vary significantly based on the installation country owing to factors such as grid emissions and irradiation.

Mindú et al. [29] explored the feasibility of using photovoltaics (PV) for irrigation pumping in Moamba, Mozambique. The study found that solar PV irrigation is technically and economically feasible based on solar potential, water resources, and farmer needs. However, it also emphasizes the importance of considering social factors, such as maintenance and community engagement, when implementing new technology.

Tafula et al. [30] analyzed the feasibility of solar photovoltaic (PV) mini-grids for rural electrification in Mozambique. This study demonstrates that PV mini-grids can be a technically and economically viable solution for rural electrification in Mozambique, particularly for villages with over 100 households within 100 km of the grid. However, the study also identifies challenges that need to be addressed, such as load management, theft, and long-term maintenance.

In summary, these studies collectively highlight the potential of solar energy systems in various applications in Mozambique. They emphasized the importance of detailed modeling and analyses in optimizing these systems, the significant potential for reducing electricity demand and emissions, and the need for comprehensive planning that considers technical, economic, and social factors. The papers also underscore the necessity of supportive policies to address challenges, such as load management, theft, and maintenance, which are critical for the successful implementation and sustainability of these systems [26–30].

3.3. Current Energy Needs in Mozambique

Mozambique is facing an energy crisis, with low access rates to electricity in both urban and rural areas. Despite having a significant potential for power generation, only 57% of urban areas and 13% of rural areas have access to electricity [31]. Solar cookers have been identified as a valuable tool for public health facilities in Mozambique, particularly for cooking and sterilizing medical instruments. However, there is limited information on solar cooking activities in the country and there are no data on institutional solar cooking activities [32]. The lack of knowledge regarding the installation and proper operation of PV systems has hindered the use of solar PV systems in solving the energy crisis [33]. Social and economic factors have created barriers to the implementation of solar power systems in the Maputo region, despite the significant potential for solar power generation [33]. The government has made efforts to increase energy access in Maputo, which has resulted in significant progress. However, there is still a lack of knowledge regarding the potential of solar power systems in this region [33]. In Mozambique, there are significant differences in electricity access rates between urban and rural areas, with rural electrification rates being below 5% in many places [32]. The UNIDO project introduced solar-powered water pumping and small irrigation systems to enhance the production capacity, highlighting the need for sustainable energy in Mozambique [34].

In a study by Tafula et al. [30] (Figure 1), the current energy landscape of Mozambique is described in detailed. After consolidating data from the first half of 2022, which include an online map from FUNAE showing ongoing mini-grid projects, records from EDM, and various statistics, solar-powered mini-grids (ranging from 4 kW to 550 kW) and three major solar facilities (from 30 MW to 41 MW) were confirmed.

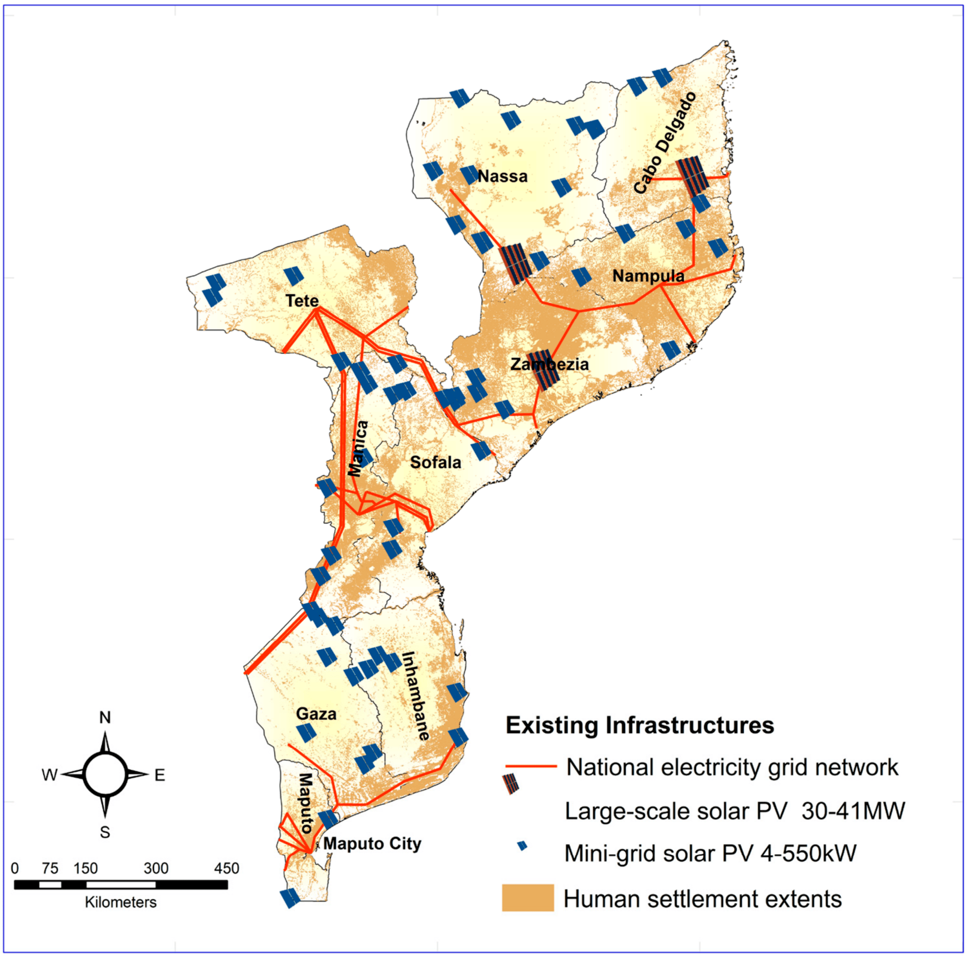

Figure 1. Current energy setup in Mozambique highlights solar energy plants, established networks, and areas of human habitation (Source: [30]).

3.4. Benefits of Using Photovoltaics and Solar Thermal Systems in Mozambique

In Mozambique, the integration of standalone solar PV systems has notably amplified energy access in rural locales where it is predominantly limited. Yet, determining the appropriate dimension and positioning of these solar PV units remains an obstacle in the country [33]. To address this, tools like HOMER [35], the hybrid optimization of multiple energy resources (HOMER), a hybrid energy resource optimization solution, have been employed to pinpoint the best system dimension. Concurrently, the SAM [36] (system advisor model) tool helped in identifying the perfect module inclination and orientation [34], whereas it also tracked the module's best slope and azimuth angle installation.

The study further probed the significance of the distance between the PV module and its support structure as well as the thermal effects on the panel's rear in Mozambique [33]. It is critical to ensure suitable ventilation at the back of the solar PV panel in Mozambique because heightened temperatures can undermine the module's efficacy [33]. For areas within the Maputo region, the recommended tilt was discovered to be approximately $23 \pm 2°$, with the optimal direction being close to $11 \pm 1°$ [33]. The incorporation of solar PV methods has played a role in mitigating the stress on the national electricity infrastructure, responding to escalating power needs, and fostering a deeper appreciation of sustainable energy approaches [33,34]. Educational sessions have highlighted the value of transitioning to green technologies, both for environmental stewardship and augmenting agricultural yields in Mozambique [34].

On the other hand, The Energy Fund (FUNAE) in Mozambique places significant emphasis on the implementation of photovoltaic (PV) systems. PV systems, which efficiently convert sunlight directly into electricity, present a cost-effective avenue for generating renewable energy [33]. Notably, FUNAE has been a pivotal player in introducing solar PV systems to the rural economy, primarily looking for systems under 100 W. Such systems are tailored for purchases by households and small businesses to meet their energy needs [37]. By championing PV systems, FUNAE plays a crucial role in expanding electricity access throughout Mozambique, particularly in rural regions where grid connectivity remains sparse. Nonetheless, although FUNAE is actively involved in various solar-related initiatives, many of these projects adhere to standard configurations. This led us to categorize their sociotechnical setups as either fixed or adaptable. FUNAE takes a top-down approach in not only funding but also designing and rolling out these projects, often with limited or even superficial consultations with beneficiaries. Additionally, they dominate the provision of maintenance services and spare parts in these systems. End users are rarely empowered to modify or adapt projects to better suit their needs. Local involvement in shaping electrification projects, being grid-connected or off-grid, usually stems from non-state actors rather than allowing the local population to proactively shape projects [38].

3.5. Challenges in Implementing Photovoltaics and Solar Thermal Systems in Mozambique

While the implementation of solar PV systems in Mozambique has increased access to electricity and helps ease the pressure on the national power grid, solar PV panels face challenges in producing sufficient levels of power required for cooking. Most solar PV systems in Mozambique produce an output of up to 45 W, which is insufficient for cooking [32]. Moreover, solar PV systems do not help overcome the 'cooking crisis' that exists in Sub-Saharan Africa [32]. This is because solar PV systems cannot generate the required amount of energy for cooking, which is one of the most significant energy requirements in the region. It is essential to note that in Mozambique, cooking primarily relies on biomass, which is responsible for environmental degradation and deforestation. Therefore, to overcome the 'cooking crisis', it is necessary to develop and implement alternative renewable energy technologies, such as solar thermal systems, that can produce the required amount of energy for cooking [32]. However, the implementation of solar thermal systems could also face challenges such as a lack of awareness and funding. Therefore, it is essential to create awareness and provide funding to increase the adoption of renewable energy technologies in Mozambique.

4. Conclusions

This review article provides a comprehensive analysis of the current state of photovoltaic solar energy in Africa, with a specific focus on Mozambique. The synthesis of the most cited studies on photovoltaics in Africa highlights key technical aspects such as optimizing system components and integrating large-scale plants into grids. It also emphasizes the importance of incentive policies and financing models in promoting adoption.

The analysis of studies focused on Mozambique demonstrates the significant potential of photovoltaics in applications such as water heating, irrigation, and rural electrification. However, it also reveals challenges related to the lack of infrastructure, high upfront costs, and the need for maintenance and training.

Mozambique faces a severe electricity access deficit, with only 13% rural electrification. Photovoltaics play a vital role in sustainably expanding access. The identified benefits include reduced reliance on diesel, lower emissions, and minimization of the grid pressure. Solar thermal systems have untapped potential.

However, barriers exist, such as insufficient power for cooking needs and lack of funding and awareness. Targeted policies and financing mechanisms are essential for promoting adoption. Comprehensive planning and analyses are needed to integrate technical, economic, and social factors.

Mozambique, with FUNAE's support, is tapping into this potential, especially using photovoltaic (PV) systems to enhance electricity access in challenging rural areas. However, while FUNAE leads in solar promotion, its approach can limit local adaptability. Despite solar energy's cost-effectiveness, challenges persist, requiring local integration, strong policies, and community engagement to address them.

This review underscores Mozambique's immense solar potential. Although photovoltaics can provide clean, decentralized electricity access, challenges related to costs, infrastructure, and maintenance must be addressed. Policies and community engagement are crucial to unlock the benefits of solar energy and make progress towards universal energy access. Further research can help optimize the systems and frameworks for sustainable implementation.

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