A mini-review of practical interventions of renewable energy for climate change in Sub-Saharan Africa in the last decade (2010–2020): implications and perspectives

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ABSTRACT
As part of the Kyoto Protocol, several Sub-Saharan Africa countries vowed to use more renewable energy sources, and the number of Sub-Saharan Africa countries that have undertaken renewable energy initiatives has expanded considerably over the preceding decade. However, assuring demand while reducing climate change has always been one of the most significant difficulties confronting the global energy sector. This review looks at the state of practical renewable energy interventions in Sub-Saharan Africa countries over the last decade (2010–2020), focusing on infrastructure development and accessibility, decentralization, distribution, and communal acceptance, donor funding and private sector involvement, and the role of state political influence in renewable energy strategies. This study's findings suggest that renewable energy interventions in Sub-Saharan Africa are based on mature and commercialized technologies, that natural resources for energy generation have not been fully explored, and that ongoing research and development on raw material or feedstock availability will benefit regional and national projects. The findings also show that off-grid technology interventions exist in Sub-Saharan Africa. However, the adoption of a decentralized approach to renewable energy generation, particularly in rural areas, financing, and the need for integrated project design and implementation, which includes factors such as community mobilization, social, economic, institutional, and technical engagement, have all hampered the implementation of such technologies.

1. Introduction

Over the last decade, the worldwide development of renewable energy has improved and increased, owing to the huge number of countries that launched academic programs on renewable energy technology [1]. One of the biggest challenges facing the global energy sector was the security of demand while preventing climate change due to old or poor technology of energy generation [2, 3]. It was thus, critical that countries invest in efficient and cleaner technologies, on the energy sector to ensure emission are reduced as far as is reasonable. The usage of fossil fuels for energy generation has been implicated as a source of global warming dating back to the early industrialisation period [4]. The United Nations Framework Convention on Climate Change (UNFCCC) created and convened the Kyoto Protocol and Copenhagen Accord in 1995 as a tool to address climate change [5]. The Kyoto Protocol mandated that member countries make concerted efforts to reduce emissions through Clean Development Mechanism technologies that use renewable energy [6]. This was backed up by the 13th Conference of the Parties (COP13) in Bali, Indonesia, which was held for identical reasons [7]. For this reason, South Africa and other willing countries endorsed the Kyoto Protocol and signed the promise to reduce Green House Gas (GHG) emissions (Luiz 2008). Changes were visible in the energy sector as a result of the pledge, which influenced specific South African industry strategy [8].

The South African Department of Mineral Resources and Energy (DMRE) established South Africans' energy needs in the Electricity Regulation Act 4 of 2006 [2]. This gave the DMRE a tool to work with, as the Integrated Resource Plan (IRP) outlined South Africa's energy requirements as well as the methods to achieve those demands through various renewable energy sources [9]. This was done to efficiently balance supply and demand [10]. South Africa has experienced relatively high energy demand from a fossil fuel-dominated generation for the previous decade or so [3]. This will stimulate the willing inclusion of renewable energy technology in the energy generation mix.

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The recent South African IRP was promulgated by the DMRE in October 2019, thus referred to as the IRP 2019 [and the energy capacity of the country was estimated to just over 52 000MW [11]. Due to the end of life of the coal facilities, around 35000 MW of that was scheduled to be decommissioned from Eskom (South Africa’s coal-fired electricity generator) by the year 2050 [12]. As coal mine reserves threatened supply and the commitment to phase out energy supplied by burning fossil fuels, it was widely assumed that increasing inclusions of cleaner sources of energy generation would replace coal.

Other African countries have also increased their investments in renewable energy over the last decade as they shift to cleaner energy sources that are less harmful to the environment [13]. Globally, the decline in reliance on fossil fuels as a result of climate change, energy security, and natural gas reserves has necessitated research into alternative fuels. This transition was also aided by many countries’ improved understanding of the negative impacts of climate change, as well as the development of newer, more cost-effective energy producing technology [14]. This was also viewed as a possible option for energy supply in Sub-Saharan Africa, where modern energy producing technology did not previously exist [15]. This was corroborated by a research conducted by Campbell et al. [16], which found that even the wealthiest families in Zimbabwe used a variety of energy producing methods, including wood and electricity.

Due to energy constraints in the South African power system, several households, commercial, and industrial facilities generated independent electricity, a practice known as small scale energy generating (SSEG) [17]. It is estimated that it will have a maximum generation capacity of 1 MW [18]. Furthermore, the Renewable Energy Independent Power Producer Acquisition Programme (REIPPPP), established by the government in 2011 and operated by the Independent Power Producer Office (IPPO), augmented the procurement of renewable energy for the national grid [11]. Such a framework (renewable energy auction/bidding procedure) has produced and enabled the recruitment of expertise and investment in renewable energy projects in South Africa [19].

Renewable energy is undoubtedly progressing in Sub-Saharan Africa, with some mainstream renewable energy and emergent technologies growing (or maturing), while others are still in development [20]. Table 2 displays the various energy technologies and their operational features. Because of their competitiveness and appeal, renewable energy technologies such as solar photovoltaic (PV), wind technology, biofuels, concentrated solar power (CSP), and geothermal were considered as growing more reliable and mature [21].

There are also activities that are thought to be considerably more cost effective to assure cleaner energy generation from smaller communities to larger industries [22]. Interventions in community-based clean energy generation are also noticeable in African countries and are linked to the Millennium Development Goals (MDGs) [23]. These green economic reforms resulted in the creation of so-called “green jobs,” just as economic opportunities and environmental sustainability are maintained through the use of greener and cleaner energy sources [24].

Numerous corporate institutions have also supported a variety of projects in Sub-Saharan Africa countries aimed at generating clean energy for remote or impoverished communities that would otherwise have had less conventional electricity access [25].

Renewable energy improves community health and reduces household air pollution due to cleaner processes and lower greenhouse gas emissions [26]. It can also provide low-cost electricity to underprivileged communities while having considerably less negative health consequences [27], giving remote locations in Sub-Saharan Africa countries a better chance of accessing electricity. Figure 1 displays progressive forecasts of global electricity access over the next two decades as of 2010.

Eliminating energy constraints is essential for economic and social progress. In addition to significant geographic disparities (among nations and between urban and rural areas), 70% of people in Sub-Saharan Africa lack access to electricity, and this number continues to rise as electrification programs fail to keep pace with population growth [26]. Moreover, despite contributing a negligible amount to global greenhouse gas emissions, Sub-Saharan Africa is already one of the world’s regions most affected by the rising risks of climate change (droughts, floods), with grave consequences for poverty and ensuring access to affordable, sustainable, and modern energy services for all remains therefore a major concern for Africa. Additionally, despite Sub-Saharan Africa’s low contribution to CO2 emissions due to its low industrialization, the region’s energy demand is expanding rapidly.

The Paris Climate Change Conference (COP21) stressed the “shared but differentiated responsibilities” principle, which is based on voluntary
nationally determined contributions [28]. This is a crucial perspective for Sub-Saharan Africa, as it enables the intimate connection of development and climate policies in terms of energy transition. Consequently, it is essential to develop systems that simultaneously encourage the growth of the energy sector and solve global warming problems. Despite this, reconciling the goals of improving universal energy access and insisting on Sub-Saharan Africa’s pioneering role in environmental matters through a technological leapfrogging strategy can be difficult due to the financial, economic, social, political, and institutional obstacles that must be overcome. This is the impetus for this review, which aims to evaluate the recent practical interventions of renewable energy for climate change in Sub-Saharan Africa over the past decade (2010–2020) and provide perspectives.

2. Practical interventions of renewable energy for climate change

Figure 2 below indicates the global renewable energy trends and countries that were recognized for cleaner energy generation. Various renewable energy conventions and interventions by various African countries over the last decade that focused on cleaner energy generation to raise awareness of the effects of climate change caused by greenhouse gases are outlined, as are studies conducted during the same time period focusing on renewable energy generation in Africa. Table 1 summarizes key studies conducted as well as various renewable energy interventions in African countries, done in the past decade (2010–2020).

In Table 2 below, we review the objectives, outcomes and recommendations on renewable energy initiatives with regard to investment, governments political power, acceptance and policies from data collected regarding African countries in the decade 2010–2020 including Benin, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Malawi, Morocco, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Zambia. Whereas Table 3 provides a summary of advanced and commercialized renewable energy technologies as well as non-renewable energy sources in Sub-Saharan Africa countries.

3. Analysis and perspectives

The Kyoto Protocol set the tone for the global community by highlighting the critical need to commit to resolving the problem of greenhouse gas emissions and committing to emission reductions [57]. As a result, other countries developed their own policies for renewable energy adoption, with South Africa being one of the first in Sub-Saharan Africa [31]. This spurred the South African government to integrate renewable energy into resource planning and to establish a formal program for procuring energy from renewable sources [44]. As evidenced by the findings in Table 1 and Table 2, energy regulations act as a catalyst for renewable energy deployment. Kenya adopted pro-renewable energy legislation, and as a result, renewable energy accounted for up to 80% of the country’s energy mix [34]. On the other hand, other Sub-Saharan Africa governments struggle to deploy renewable energy when political interests drive renewable energy programs, and may provide little or no support to enable enterprises, as in Mozambique and Tanzania [33]. The Rwandan biogas project demonstrated that while coordination of environmental and agricultural policies, as well as an active presence of scientific and technological infrastructure, was extremely beneficial, the government’s involvement was critical in providing guidance and acting as a facilitator for renewable energy deployment [29].

The results in Table 1 and Table 2 indicate that Sub-Saharan Africa has a low level of electrical availability, with the likelihood increasing in isolated and rural locations. In Mozambique and Tanzania, less than 5% of rural residents have access to electricity [33]. In Kenya, only about 18% of the population has access to electricity, and the situation is much worse in rural areas, where just 4% of homes have electricity [34]. Sub-Saharan Africa has just 30.5% electrification due to insufficient electrification installation in the region [35]. Electricity generated in a central location was unable to reach remote and rural areas due to a lack of distribution infrastructure [31].

Financing renewable energy projects has been identified as a barrier to renewable energy technology adoption in Sub-Saharan Africa [29, 39]. While implementing such technology demands a large upfront
Table 1. A summary of renewable energy generation practical interventions in Sub-Saharan Africa countries and studies done in the past decade.

| Year | Studies conducted on renewable energy in Africa                                                                 |
|------|---------------------------------------------------------------------------------------------------------------|
| 2010 | **Renewable energy in South Africa: Potentials, barriers and options for support report - South Africa [30]** |
| 2011 | **Selection of renewable energy technologies for Africa: Eight case studies in Rwanda, Tanzania and Malawi [32].** |
| 2012 | **Energy and sustainable development in Nigeria: The way forward - Nigeria [36]**                            |
| 2013 | **Hydrokinetic power generation for rural electricity supply: Case of South Africa - South Africa [39]**       |
| 2014 | **Towards achieving energy for sustainable development in Nigeria - Nigeria [40]**                           |
| 2015 | **Can carbon finance transform household energy markets? A review of cookstove projects and programs in Kenya - Kenya [43]** |
| 2017 | **The rise of Renewable Energy implementation in South Africa - South Africa [31]**                          |
| 2018 | **Accelerating energy access through Public-Private Partnership Investment in Zambia – Zambia [47]**         |
| 2019 | **Opportunities and challenges to rural renewable energy projects in Africa: Lessons from the Esaghem Village, Cameroon solar electrification project - Cameroon [49]** |
| 2020 | **Hybrid off-grid renewable power system for sustainable rural electrification in Benin - Benin [51]**         |

**Renewable energy conventions and practical interventions by African countries in the past decade**

- **A feed-in-tariff rate was introduced to encourage the development of biogas - Kenya [29]**
- **Biogas installation targets were included in the yearly performance contracts for district authorities – Rwanda [29]**
- **National Climate Change Response Policy was approved**
- **National Development Plan (NDP) was released to commit to renewable energy - South Africa [31]**
- **Competitive bidding process for renewable energy replaced the feed-in-tariffs - South Africa [31]**
- **Establishment of small plants focused on household biogas through SNV and the Rwandan’s government support – Rwanda [32]**.
- **Biogas for schools, prisons and other institutions established through non-government aid agency - Tanzania [32]**.
- **Establishment of solar PV by shop owners through the government driven support from ProBEC – Malawi [32]**.
- **Drivers and barriers to rural electrification in Tanzania and Mozambique - grid extension, off-grid and renewable energy sources [33] - Mozambique and Tanzania**
- **Renewable energy in Kenya: Resource potential and status of exploitation [34] - Kenya**
- **The United Nations Secretary-General launched a global initiative called the Sustainability Energy for All Initiative in 2012, aimed at encouraging access to modern energy by the year 2030 – Malawi [35]**
- **The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya – Kenya [37]**
- **Investigation of the agricultural biomass agricultural potential, for decentralized energy in the rural areas - Ghana [38]**
- **Microgrid project on renewable energy decentralization for electricity generation – Senegal [38]**
- **Renewable energy resources for distributed power generation in Nigeria: A review of the potential - Nigeria [38]**
- **Over 92 independent power producers allocated 6300MW through REIPPPP - South Africa [31]**
- **The decentralization of energy was defined by the World Alliance for Decentralized Energy (WADE) organization, and several pilot projects undertaken by SERC and NCERD – Nigeria [40]**
- **South African renewable energy investment barriers: An investor perspective - South Africa [41]**
- **The South African International Renewable Energy Conference (SAIREC) to discuss and exchange their vision, experiences and solutions to accelerate the global scale-up of renewable energy - South Africa [42]**
- **The Kenya National Domestic Biogas Programme (KENDIP) embarked on a promotion drive to raise interest on biogas businesses - Kenya [29]**
- **The diffusion of a renewable energy technology and innovation system functioning - Kenya and Rwanda [29]**
- **The Scaling-Up Renewable Energy Program (SREP) that is aimed at increasing renewable energy especially in Africa, as a Climate Finance Modality that was implemented - Kenya and Ethiopia [35]**
- **The Clean Technology Fund (CTF) assisted with the implementation of projects, including the Ekom Renewable Energy Support Programme - South Africa [35]**
- **Renewable energy auctions in South Africa outline feed-in tariffs - South Africa [44]**
- **Announcement of the construction of a 40.5 MW power plant- Solar PV in Mocuba district, an agreement between Scatec and Mozambique’s national electricity company - Mozambique [45]**
- **Windaba Conference-Investment for an integrated energy transition - South Africa (SAWEA 2019) [46]**
- **Energy justice and sustainability transitions in Mozambique – Mozambique [45]**
- **6th Southern African Solar Energy Conference (SASEC) on Solar Thermal Energy Technology and Solar PV - South Africa [46]**
- **3rd North Africa Renewable Energy Summit - Morocco 2020 [50]**
- **A systematic decision-making approach for planning and assessment of hybrid renewable energy-based microgrid with techno-economic optimization: A case study on an urban community in Egypt- Egypt [52]**
Table 2. Summary of the objectives, outcomes and recommendations on renewable energy initiatives with regard to investment, government’s political power, acceptance and policies in Sub-Saharan Africa countries (2010–2020).

| References | Country | Objectives of renewable energy initiative | Conclusions and Recommendations related to renewable energy technologies |
|------------|---------|-------------------------------------------|------------------------------------------------------------------------|
| [30]       | South Africa | • To identify the relevant renewable energy investment barriers. | • Best practices of energy generation technologies,  
• Provision of support for the independent power producers,  
• Government involvement in drafting policies that include public opinions  
• Eskom to consider renewable energy as new market  
• Coherent policies that take the energy generation evolution should be adopted. |
| [32]       | Malawi, Rwanda and Tanzania | • To advance upon previous research findings, through the evaluation of eight case studies conducted in Malawi, Rwanda and Tanzania. | • Technology factors such as knowledge transfer, site selection, adoption by communities, suitable sites for pilot studies, and availability of finance must be explored and adopted.  
• Government support and environmental benefits should be advanced. |
| [33]       | Mozambique and Tanzania | • To explore the barriers and drivers of rural electrification and the solutions on off-grid. | • Political priorities are the drivers for renewable energy.  
• In government levels, there was lack of planning, which resulted to ineffective implementation.  
• The involvement of the private sector, however, very small investment is effective.  
• Issues that make renewable energy attractive in rural areas, was the outcome-based returns that investors would expect,  
• Customer based and tariffs are set on political basis.  
• The drivers of off-grid connections of renewable energy are politically prioritised.  
• The barriers are found to be the cost of diesel that is utilized in energy generation.  
• In Mozambique’s hydro plant which sells electricity cheaper.  
• Inadequate infrastructure was identified as another barrier.  
• There is heavy reliance on donor funding for renewable energy deployment in African countries. |
| [34]       | Kenya | • To assess the potential of renewable energy resources in Kenya,  
• To evaluate the status of exploitation of the renewable energy in the country. | • Kenya has formulated energy policies that are relevant and in favour of renewable energy development goals.  
• Kenya has the largest small household solar ownership in the world (at 30 000).  
• 80% of energy mix is generated from renewable energy.  
• The bigger challenge is the country’s inability to satisfy the demand of electricity.  
• 18% of Kenyan households have the conventional electricity.  
• Only 4% of rural households have access to electricity. |
| [36]       | Nigeria | • To review policy interventions that can have a big contribution to the social development, sustainability of the economy and environmental development. | • The government should intensify the establishment of programs on energy efficiency and renewable energy in order to ensure a sustainable economic development.  
• Policies that ensure integration of energy efficiency and renewable energy should be developed. |
| [37]       | Kenya | • To determine the advantages and disadvantages of renewable energy technologies as a potential reduction of poverty and climate change strategy. | • The dimensions of welfare and benefits of sustainability should be considered in the planning and implementation of the project such as mini grids.  
• There are social, economic, environmental, technical and institutional planning that must be considered for energy generation projects.  
• Energy generation project policies should promote comprehensive community mobilization.  
• The establishment of training centres through a joint technology and community engagement. |
| [39]       | South Africa | • To investigate possibility of utilizing hydrokinetic technology to supply electricity in the rural area of South Africa, where there’s water availability. | • The suitable option of power generation in rural areas was hydrokinetic power over wind, solar and diesel generators.  
• Policies should be developed and deployed, in support of the hydrokinetic power in South Africa.  
• Site identification research to locate and source suitable power generation technologies must be explored. |
| [38]       | Nigeria | • To review the potential renewable energy resources from the major sources, that is hydro, wind, solar and biomass. | • The distributed generation of electricity from the renewable energy was found to be effective, as an integrated solution for the rural areas.  
• The benefits of renewable energy offsetting the global warming potential from the conventional energy generation sources.  
• The renewable energy can reduce the deforestation of forests. |
| [40]       | Nigeria | • To examine the renewable energy and energy efficiency perspectives in Nigeria, for sustainable development. | • For sustainable development a reliable, efficient and decentralized energy system was required.  
• The adoption of decentralized energy generation, particularly in the rural areas;  
• The energy mix to incorporate diversified resources such as the renewable energy. |

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Table 2 (continued)

| References | Country            | Objectives of renewable energy initiative                                                                 | Conclusions and Recommendations related to renewable energy technologies                                                                 |
|------------|--------------------|-----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| [41]       | South Africa      | • To discover reasons for reluctance for investing in renewable energy, by some private investors.         | • Factors such as technological factors, economic factors, financial viability, social factors they significantly influence the investment in renewable energy.  
• The political landscape of the country was not conducive for renewable energy investments when there was lack of government support. |
| [43]       | Kenya             | • To analyse what the carbon finance role can be, on Kenya’s cookstove project implementation.             | • The carbon finance had a beneficial effect and had the potential to strengthen cookstove projects.                                     |
| [29]       | Kenya and Rwanda  | • To investigate the promotion of diffusion of renewable energy technologies through the role played by Technological Innovation System (TIS), with a comparative analysis on biogas TIS. | • In Rwanda the biogas project was found to be alignment to environmental and agricultural policies.                                       
• Active presence of infrastructure from science and technology was instrumental in success of the renewable energy.    
• Foreign aid organizations had an important role to play, as the bases of renewable energy initiatives. |
| [35]       | Malawi            | • To assess the distribution of renewable energy, climate change management and electrification          | • In order for Malawi to enhance the renewable energy sector, there needs to be a political will in the energy sector.                    
• The Growth and Development Strategy has been developed                                                   
• The Malawi Rural Electrification Programme (MAREP), which is a key component of the Integrated Rural Development strategy for the country was established. 
• Political influence will have an influence on the direction of MAREP; In order for Malawi to enhance the renewable energy sector, there needs to be a political will in the energy sector. |
| [44]       | South Africa      | • To evaluate the policy package details of the process of auctioning the renewable energy.               | • The advantage of the auctioning process for renewable energy process was successful when implemented over four rounds of procurement process  
• Renewable energy projects are best commissioned through the Renewable Energy Independent Power Producer Programme (REIPPPP). |
| [31]       | South Africa      | • To review the implementation of renewable energy projects.                                              | • To address the political volatility, reconciliation of the differing long-term strategies of renewable energy with regards to technologies.  
• The grid infrastructure to be improved and enable access for the rural areas                              
• Address the shortage of skills for implementation and development of renewable energy | |
| [47]       | Zambia            | • To address access to energy generation in Zambia                                                        | • To emphasise the participation of private sector in providing sustainable energy for those in need.                                    
• To highlight the policy related interventions by the governments to allow partnership of the private and public sector. |
| [46]       | Mozambique        | • To analyse the energy transition in a country that was facing access and energy generation challenges.   | • To determine ways for incorporation of the households using systems that are mobile-based.                                             
• To call for localized models of providing energy.                                                            |
| [49]       | Cameroon          | • To determine and analyse the renewable energy technology challenges and opportunities                    | • The state should find ways to reduce the renewable energy cost by implement programs for training technicians and capacity building.       
• Ensure accessibility of weather data for optimization of renewable energy technologies such as wind and solar. 
• To make provision for subsidies for communities to afford the high costs of the renewable energy and to open the energy sector market. |
| [51]       | Benin             | • The analyses of hybrid renewable energy system by conducting a techno-economic feasibility, based on rural electrification. | • Suitable technology to electrify villages was the hybrid Photovoltaic (PV)/Distributed Generation (DG)/battery system. |
| [52]       | Egypt             | • To evaluate the hybrid renewable energy system through the analysis of techno-economic optimization.      | • Hybrid system with the combination of solar PV, fuel cell, wind and diesel have the efficient performance in delivering on electricity. |

Financial expenditure, particularly for installation. Government and private sector financial support, whether in the form of subsidies or from donor funders or implementing organizations, is vital to the success of cleaner energy generation in Sub-Saharan Africa. This was supported by a research undertaken by Barry et al. [32], who concluded that a lack of financial competence can stifle the expansion of renewable energy projects due to their high capital costs. As a result, private investors are critical in accelerating the adoption of cleaner energy technology. Tigabu et al. [29] also confirmed that foreign aid groups are critical in supporting the resources required to adopt renewable energy initiatives.

The data indicate that off-grid interventions are prevalent in Sub-Saharan Africa, with technologies such as solar photovoltaic (PV), wind, and micro-hydro being used. However, adoption of such technologies has been impeded by a variety of documented barriers to renewable energy technology acceptance and dissemination [33]. African countries, on the other hand, have an abundance of renewable energy resources [47]. According to Oyedepo’s study [40], a decentralized strategy to renewable energy generation, particularly in rural parts of African countries, should be investigated. Kenyan studies found that the country has made significant progress toward integrating renewable energy into the energy mix, although capacity remains insufficient. According to a
proposals in Yadoo and Cruickshank’s study [37], Kenya should explore sustainability issues, community mobilization, and the establishment of training centers to increase awareness of cleaner renewable energy generation.

Numerous studies indicate that natural resources for energy generation in certain Sub-Saharan Africa countries have not been fully tapped. Kenya, for example, relied on hydroelectricity, but the potential of geothermal, wind, and solar energy went unexplored. Additionally, Kiplagat et al. [34] and Jain and Jain [31] claimed that while potential energy sources such as solar, wind, hydro, landfill gas, and biomass have been identified for Sub-Saharan Africa, they have not been completely utilized. A similar finding was reached by Kusakana and Vermaak [39], who discovered that hydroelectric energy generation was the best option for rural areas but was underutilized.

Due to poverty and efforts to alleviate it, African rural electrification has been prioritized, with emphasis on developing and procuring advanced technologies; as a result, no technology that is still in development has been implemented [33]. According to Mohammed et al. [38], the most effective method of adopting renewable energy technology was to distinguish between distribution and generation modes, with an integrated rural solution. The study identified several benefits, including the prospect of counteracting the potential for global warming (as a result of conventional energy producing techniques) and lowering heavy reliance on wood (to reduce deforestation). This was backed further by Oyedepo [40], who argued that it was more efficient and dependable and should be considered for rural African adoption. According to Kusakana and Vermaak’s study [39], identifying viable sites for renewable energy development requires collaboration with the landowner. This includes both land availability and access. Yadoo and Cruickshank [37] echoed the study’s findings and emphasized the necessity of project design and implementation that considers community mobilization, social, economic, institutional, and technical engagement. Barry et al. [32] studied parameters for the selection and sustainability of renewable energy technologies and discovered that one of the factors was community adoption, recommending that such establishments and community support play a critical role in ensuring the technologies’ sustainability. There were a few goals for this study. One of them was to see if previous efforts and interventions on the part of African countries in renewable energy generation had been successful in producing energy solutions that addressed climate change while also focusing on rural electrification.

Tables 1, 2, and 3 demonstrate that several interventions have taken place in different African countries over the last decade and that renewable energy has the potential to accomplish this goal through decentralization or mini-grid distribution. This was ascribed to increased support for renewable energy efforts, as evidenced by policy approvals, the installation of feed-in tariffs, and the establishment of a competitive bidding process [30, 31]. Additionally, the African countries’ participation was consistent with other programs such as biogas, solar photovoltaic (PV), and the deployment of various renewable energy schemes such as the energy for all Initiative, the Renewable Energy Independent Power Producer Procurement (REIPPP), the Kenya National Domestic Biogas Programme (KENDBIP), the Scaling up Renewable Energy Program (SREP), and the Clean Technology Fund (CTF) [30, 31, 35]. Numerous studies on the condition of renewable energy generation on the African continent have been done in order to gain a better understanding of the resources available to enable such advances [30, 34]. The majority of studies have focused on the development of more sustainable energy distribution systems for rural areas, electrification using existing energy technologies, decentralization of energy generation, funding models adopted by African states, and the political influence exercised by African leaders on renewable energy initiatives. Mozambique, Tanzania, Malawi, Rwanda, Tanzania, Kenya, Senegal, Zimbabwe, South Africa, Nigeria, Kenya, Rwanda, Malawi, Cameroon, and Benin were all represented (Table 1). Numerous studies have also examined the investment in renewable energy, sustainability, carbon financing, appropriate technology, rural community access to electricity, and green job creation (Table 2). This looked to be a sign of Africa’s progress toward sustainable energy generation and dedication to rural electrification [38, 40]. Furthermore, by merging the public and private sectors, countries such as Kenya, South Africa, and Tanzania are paving the path for more environmentally friendly solutions [41]. Zambia and Mozambique, according to research [45, 47], are on the same path. Renewable energy technologies slated for development and commercialization over the next decade have identified a variety of readily available feedstock sources throughout Africa [54]. As a result of the preceding, it is clear that a significant amount of clean energy might be used to supplement existing energy infrastructures [47]. With renewable energy solutions displaying lower greenhouse gas emissions and water consumption, this may be regarded the most likely future for Africa’s complicated energy supply problem [53]. As obtained from Tables 1 and 2, Figure 3 depicts the multiplicity of factors that have influenced renewable energy interventions in Sub-Saharan Africa during the last decade.

### 4. Future directions

The integration of sustainable development goals pertaining to energy and climate change to support the economic trajectories of emerging countries is a significant worldwide challenge. Mastering the relationship between economic growth and climate in Sub-Saharan Africa will necessitate a deeper comprehension of the factors likely to influence this relationship [58, 59, 60].

The successful deployment of renewable energy initiatives for climate change in Sub-Saharan Africa will also require a more coordinated centralized and decentralized strategy. The decentralized exploitation of renewable energies (in the form of mini-grids or individual production) makes it possible to circumvent the high investment costs of the

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**Table 3. Summary of advanced and commercialized renewable energy technologies with potential for the African continent.**

| Technology          | Feedstock origin      | Greenhouse gas emissions | Efficiency of electricity generation | Water consumption | Limitations/barriers                                                                 | References |
|---------------------|-----------------------|--------------------------|--------------------------------------|-------------------|-------------------------------------------------------------------------------------|------------|
| Coal Technology     | Plants/fossil         | 603–1250 g/kWh           | 30–45 %                              | 1.5–80 kg/kWh     | Highest carbon emissions.                                                            | [53, 54, 55]|
| Gas Technology      | Plants/animals - natural source | 533–800 g/kWh         | 45–55 %                              | 0.5–80 kg/kWh     | High carbon emissions.                                                               | [53, 54, 55]|
| Geothermal Technology | Heat - natural source | 0–400 g/kWh             | 10–25 %                              | 10–300 kg/kWh     | Geographically limited.                                                              | [53, 54]   |
| Hydro Technology    | Water - natural source | 0–450 g/kWh             | >90 %                                | 0.65–35kg/kWh     | Requires high volumes of water.                                                     | [53, 54, 55, 56]|
| Solar Photovoltaic Technology | Sun - natural source | 50–300 g/kWh           | 4–25 %                               | 1.5–10 kg/kWh     | Energy storage can be barrier                                                       | [53, 54, 55]|
| Wind Technology     | Wind - natural source | 0–100 g/kWh             | 20–55 %                              | 0.5–1 kg/kWh      | Weather dependent                                                                   | [53, 54, 55]|

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*Note: The table provides a summary of advanced and commercialized renewable energy technologies with potential for the African continent, detailing their feedstock origin, greenhouse gas emissions, efficiency of electricity generation, water consumption, and limitations or barriers.*
extension of the network in sparsely populated and remote areas, or even peri-urban areas where the network does not exist [61]. Initiating a virtuous cycle, a decentralized model can contribute to the socioeconomic development of underprivileged communities [62, 63]. To support the deployment of decentralized solutions (mini-grids or off-grids), public authorities must collaborate with multilateral/bilateral funders, non-governmental organizations, and local populations [63]. In recent years, numerous initiatives, such as solar systems, have arisen and demonstrated their positive effects on local economic growth beyond boosting energy access. The success of these initiatives relies on the combination of public and private funding and the implementation of novel economic models in order to overcome financial obstacles [62]. The energy sector in Sub-Saharan Africa has typically been managed by vertically integrated governmental monopolies. Despite the measures done in favor of increased openness to the private sector within the framework of structural adjustment, the difficulties of governance, regulation, and pricing (price below the cost of energy) have been significant impediments to investment. In the absence of more funding and a more ambitious political and strategic vision for sustainable development in Sub-Saharan Africa, it seems unlikely in the short term that the proliferation of modest efforts will have a significant impact on the improvement of energy access [64, 65].

Additionally, a sustained development of renewable energies in Sub-Saharan Africa will require the establishment of an appropriate political and institutional environment to guide and plan projects upstream, new modes of governance, especially participatory ones, to encourage and coordinate the diversity of actors, and innovative economic models to make investments profitable. In the current scenario, poverty and development issues still remain largely isolated from climate change agenda [66].

5. Conclusion

Numerous countries in Sub-Saharan Africa are interested in renewable energy, with several vowing to study ways to mitigate the consequences of climate change while simultaneously reducing greenhouse gas emissions caused by traditional energy sources. Several governments in Sub-Saharan Africa have also committed to implementing more environmentally friendly energy resources in accordance with the Kyoto Protocol, particularly through the development of necessary regulations to promote the use of renewable energy sources. This analysis has showed that by establishing legislation and formalizing renewable energy procurement through the Renewable Energy Independent Power Producer Procurement (REIPPP), a country like South Africa has been able to foster the growth of renewable energy technologies. Additionally, the findings of this study suggest that renewable energy adoption in Sub-Saharan Africa countries (including South Africa) has been based on mature and commercialized technology in the international marketplace. Numerous studies, however, indicate that natural resources for energy generation have not been fully explored, and that ongoing research and development about raw materials or feedstock availability will benefit regional and national initiatives. Additionally, the data establish the presence of off-grid technology in Sub-Saharan Africa. However, the adoption of a decentralized approach to renewable energy generation, particularly in rural areas, financing, and the requirement for integrated project design and implementation that considers community mobilization, social, economic, institutional, and technical engagement have all hampered the adoption of such technologies.

Declarations

Author contribution statement

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Additional information

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