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The status and potential of regional integrated energy systems in sub-Saharan Africa: An Investigation of the feasibility and implications for sustainable energy development

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ABSTRACT

Sub-Saharan Africa (SSA) is experiencing rapid economic growth and rising demand for energy, accompanied by significant low energy access and sustainability challenges. Globally, to address similar issues and unlock a region's energy potential, regional integrated energy systems have gained traction, and initiatives such as establishing power pools for regional electricity markets, cross-border power exchanges, and integrating renewable energy resources are being promoted. This paper describes the status of regional integrated energy systems in Sub-Saharan Africa. We analyze the energy growth achieved through effective strategies and policies that support regional integrated energy systems in developed and developing regions (the United Kingdom and China). Our findings show that challenges, including limited access to financing, regulatory barriers, lack of effective energy planning model, inadequate supporting policies, and fragmented institutional frameworks, hinder the region's widespread deployment of regional integrated energy systems. Taking lessons from the case studies, addressing SSA's energy challenges requires concerted efforts from governments, international organizations, and the private sector to create enabling policy environments, mobilize investments, and build technical capacity and supporting infrastructures. Regional integrated energy systems can enhance energy security by diversifying energy sources, fostering economic development, and stimulating cross-border energy trade. In the United Kingdom, the implementation of integrated energy systems has contributed to a 25% reduction in carbon emissions and a 15% increase in energy efficiency over the past decade. Similarly, in China, the integration of renewable energy sources into regional energy systems has led to a 30% increase in renewable energy capacity and a 20% decrease in coal consumption since 2010. China owns 32% of global renewable energy market, alongside an installed capacity of about 1.26 TW in the first quarter of 2023. Our findings from the power pools indicate that three out of the four pools possess significant hydro energy resources. Specifically, within the CAPP region, 7 out of 10 countries heavily rely on hydro energy, while in EAPP, 6 out of 11 countries exhibit a similar dependency. Moreover, within SAPP, 9 out of 12 countries and within WAPP, 5 out of 14 countries rely significantly on hydro energy.

1. Introduction

A key factor in achieving global net-zero carbon objective and ensuring inexpensive, reliable, sustainable, and contemporary energy to all is Sub-Saharan Africa's (SSA) transition to clean energy, given the increasingly high population of the continent [1]. SSA encompasses a substantial portion of the continent of Africa located southernmost region of the Sahara Desert, with forty-two (42) countries on its mainland and six (6) island countries. With a projected growth rate of 2.3%, SSA has great economic potential but with accompanying countless

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challenges caused by its inability to manage the increasing demand for modern energy [2,3]. The region has abundant natural resources, including coal, oil, gas, hydro energy, geothermal, wind, and solar, distributed across different countries [4]. Its solar, hydro, wind, and geothermal energy potential is estimated as 6,500 TWh/yr, 350 TW, 109 GW, and 15 GW, respectively. This is in addition to possessing approximately 21 trillion cubic meters of gas and 115 billion oil barrels respectively; the major energy generation resource in the area is fossil fuels [5]. Despite the enormous potential, its energy access rate is less than 50% due to poor and dilapidated commercial energy infrastructures, poverty, reliance on fossil fuels, imports of inefficient resources, low per capita consumption, low investment in modern energy technologies, lack of and/or unrealistic energy policies, and political instability [6,7]. Thus, hindering poverty eradication, industry innovation, sustainable communities, and quality education. For instance, the popularly known giant of Africa, Nigeria, located in the west of SSA, has a population of over 240 million having a total generating capacity of about 12,522 MW leaving most of its people with no electricity access.

Over the years, SSA has made efforts to address these issues and unlock the region's energy potential by creating several regional integrated energy initiatives to increase energy access, support energy transition, and accelerate growth [8–10]. This is dated back to 1995, when the region's first power pool was created to enhance generation capacity and transmission facilities to allow for more cross-border energy trading [11]. It is vital to highlight that the notion of regional integrated energy systems referred to in this context is the interconnection and coordination of energy infrastructure, resources, and markets across multiple countries within a region [12]. This approach efficiently utilizes diverse energy sources, including renewable energy, and facilitates cross-border trade and cooperation. By pooling resources and infrastructure, regional integration can improve energy access, enhance reliability, and promote sustainable energy development. Presently, there are four regional power pools in SSA, as shown in Fig. 1, with twelve member nations in the South Africa Power Pool, fifteen member nations in the West Africa Power Pool while the East Africa Power Pool and Central Africa Power Pool consist of eleven and ten member countries respectively [13]. These initiative aims to develop regional electricity markets, facilitate cross-border power exchanges, and promote the integration of renewable energy resources.

Recent regional developments were aided by the United Nations Sustainable Development Goal Seven (SDG7) on obtaining clean, secure, and affordable energy for all and the Paris Agreement for net zero emissions by 2050. This has fostered renewable energy resources as an off-grid system for rural electrification, domestic and commercial purposes in numerous locations around the globe [14,15]. Several countries in SSA have recognized the benefits of integrated energy systems and have taken steps in that direction, from developing small-scale microgrids for powering rural communities to large-scale renewable energy projects integrated into the national grid. Notable examples include Kenya's Lake Turkana Wind Power Project, South Africa's Renewable Energy Independent Power Producer Procurement Program (REIPPPP), and off-grid solar solutions. Despite these positive developments, low energy access is still a prevailing and significant challenge in SSA. The 2022 International Energy Agency (IEA) report shows that Africa's contribution to global energy use is less than 6% but has 18% of the global population [16]. Likewise, recent adverse effects of Covid-19 and the Ukraine and Russia war on the economy globally has disrupted the progress made in many countries in SSA due to the resulting financial crisis, high energy prices, and climate change concerns [8].

Consequently, most of the region's nations remain significantly reliant on fossil fuels and with less than 25% access to electricity. Besides, renewable energy resources are unevenly distributed across different countries, and their intermittent nature and cost implications are drawbacks to large grid integration. Therefore, further application of modern innovative, efficient, and clean energy technologies is required to reduce dependence on fossil fuels and imports of fuel. Minimizing inefficient energy systems, reducing energy costs, and controlling demand growth can ensure sustainability and achieve environmental

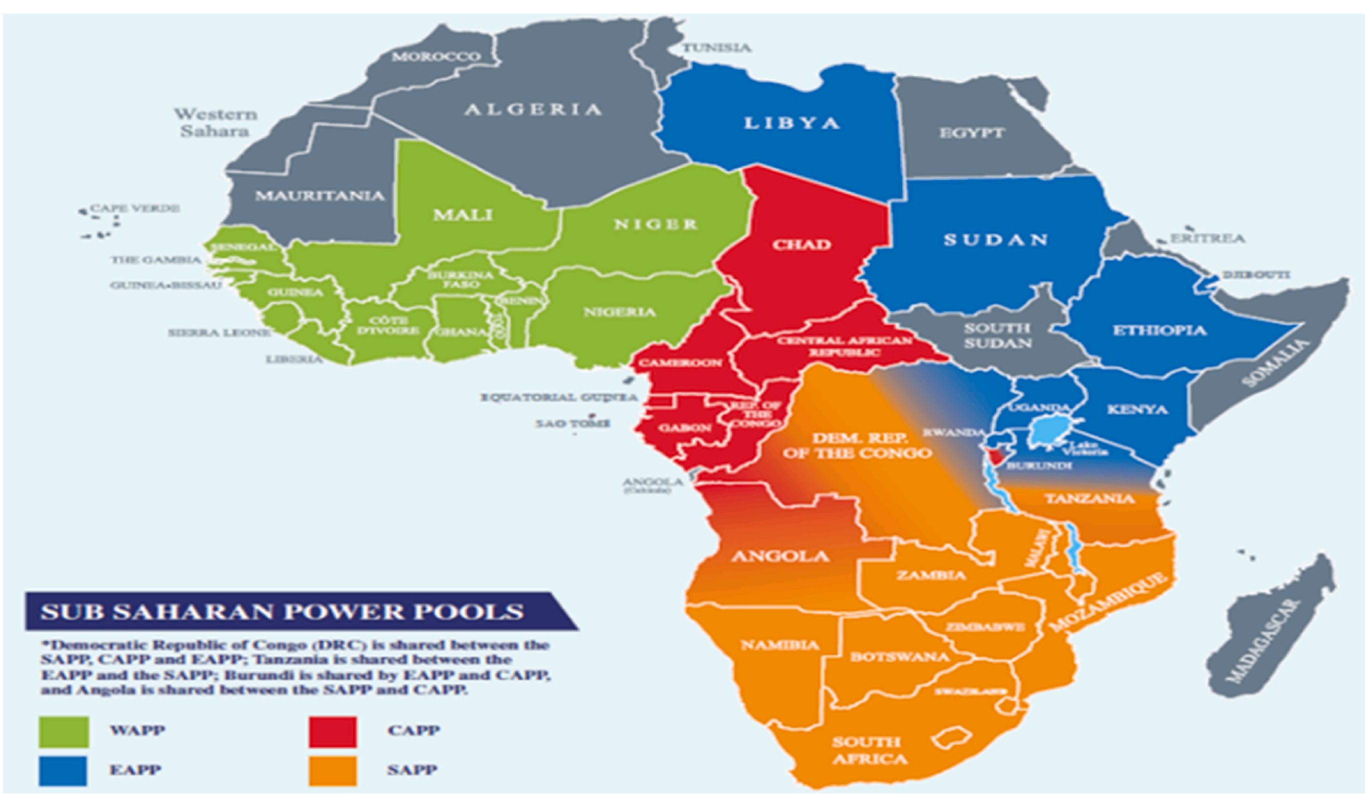

Fig. 1. Sub-Sharan Africa Power Pools and their member countries.
Source: Power pools enabling SSA's transmission corridors - ESI-Africa.com

targets [8,17]. Specifically, a wider promotion and application of RIES within countries in SSA is necessary to bridge the energy gap.

1.1. Global status of regional integrated energy System

Many other regions across the world in Europe, Asia, and the United States, have invested greatly in research, modern energy infrastructures, and the implementation of regional integrated energy systems at different levels [13,18,19]. These systems have become the latest economical and efficient technique for the integration, coordination, and utilization of various energy resources and subsystems within a region (towns, cities, provinces, or inter-province) to satisfy the rising demand, enhance energy utilization efficiency, minimize carbon emission and energy cost and ensure energy supply reliability [20]. It enables multi-energy complementarity by taking full advantage of both traditional and renewable energy resources through coordinated scheduling, innovative coupling, conversion and storage technologies, and operation management to serve multiple loads (electricity, heat, cold, and gas) [21,22].

The potential benefit of regional integrated energy systems is vast. They might strengthen energy security by lowering reliance on foreign fuels and diversifying energy sources. Moreover, regional integration can foster economic development by attracting investment, creating jobs, and stimulating cross-border trade. It also offers opportunities for renewable energy development, as countries can leverage their unique resources and share the benefits of clean energy across borders. This is evident in a developing country like China, which is actively using this model to develop its energy sector by carrying out a large volume of RIES-related research, formulating supporting policies, and integrating subsystems based on their energy features and needs [23,24]. In an extensive review by authors [25], among the top 8 countries carrying out research in integrated energy systems, China tops the chart with over 827 research/projects. USA, Canada, India, Iran, England, Italy, Japan, and South Korea follow the pattern. Most of this research as summarized in Table 1, primarily aims at optimal scheduling and operation of integrated systems with a focus on multi-energy network modeling and energy hubs [26–33], optimal dispatching [34–36], energy storage [28,37,38], demand response [28,39,40], application of intelligent systems assessment model [41], review studies [25,42–45], among others. Moreover, the capabilities of integrated energy system for advanced energy management including real-time monitoring, grid stability and as flexibility mechanisms in demand-supply balance dynamics and energy market operations have been demonstrated in [46–53]. Similarly, with the increased utilization of renewable energy resources, researchers are recently beginning to explore the potentials and challenges associated with multi-energy complementary hydro, wind and solar energy [54]. However, comparing the volume of research and development between the developed and developing regions, the study [55] shows a geographical gap, particularly in SSA regions, as most of the pieces of literature are from developed countries' perspectives. It is crucial to note that different regions have different energy mixes and specific energy features, environmental factors, demand, and policies.

Besides, unlike the abovementioned regions, the existing literature on regional integration in SSA as highlighted in Table 2 focuses on integration across borders to increase energy access and promote energy trading [13,56–58]. Hence, the solutions put forward support policies and structures that can foster regional energy transmission and market between the different countries in SSA. For instance, while we agree with the debate by the authors in [59], emphasizing that national energy access is a prerequisite to regional integration and that the replication of a template from Europe may not be a feasible solution for SSA due to its peculiar challenges. After examining the regional geopolitics conducted by many parties and national interests' influence on regional collaboration, the authors concluded that standardization of electricity access benchmarks and technology transfer should be encouraged instead of advocating for more integrated electrical networks. However, regional integration should not be looked into only from the perspective of electricity transmission and trading on a cross-regional level; its application and impact within the communities, towns, cities and inter-cities in SSA should also be studied and promoted.

Going forward, we conclude that in literature, the concept of RIES for modern energy development has not yet gained the needed attention in SSA. Therefore, the questions are:

1. What are the barriers to regional integrated energy systems research and development in SSA countries?
2. Are there adequate supporting policies to drive RIES projects in SSA countries?
3. What lessons can be learned from other parts of the world to boost energy access in SSA?

This study contributes by addressing these key questions in the following ways:

- It provides a thorough overview of SSA's energy sector, focusing on the region's four power pools. It examines RIES status, challenges, and barriers in selected countries (Cameroon, Kenya, South Africa,

Table 1
Overview of articles on RIES and focus area.

Number	Focus	Refs.
1	Multi-energy network modeling and energy hubs	[26–33]
2	Optimal dispatching	[34–36]
3	Energy storage	[28,37,38]
4	Demand response	[28,39,40]
5	Energy management and market	[46–53]
6	Review	[25,42–45],
7	Application of intelligent systems, assessment model	[41]

Table 2
Summary of literatures aimed at sustainable development in SSA.

Year	Title	Focus	Refs.
2012	Energy access scenarios to 2030 for the power sector in sub-Saharan Africa	Economic scenario for universal access	[56]
2013	Sustainable energy planning: Leapfrogging the energy poverty gap in Africa	Rural electrification options in SSA	[60]
2015	Future energy system challenges for Africa: Insights from Integrated Assessment Models	Africa's long-term energy system developments within the context of global climate policy	[61]
2017	The role of decentralized systems in providing universal electricity access in Sub-Saharan Africa – A model-based approach	Model systems and technologies to increase access	[62]
2017	Electricity planning and implementation in sub-Saharan Africa: A systematic review	Electricity Planning research	[63]
2018	Rural electrification in sub-Saharan Africa with innovative energy policy and new financing models	Policy and economic models to increase energy access	[64]
2020	Integrated energy systems' modeling studies for sub-Saharan Africa: A scoping review	Energy planning using an integrated energy systems model	[55]
2022	Regional cooperation for mitigating energy poverty in Sub-Saharan Africa: A context-based approach through the tripartite lenses of access, sufficiency, and mobility	Electricity trading and regional cooperation to standardize energy access benchmarks	[13]
2024	This paper	Regional Integrated Energy System	

Nigeria), shedding light on opportunities and obstacles for integrated energy systems implementation in the region.

- Drawing comparisons between developed and developing countries, the study presents case studies from the United Kingdom and China to serve as benchmarks for successful RIES implementation strategies. Insights into effective policies, coupling methods, and deployment strategies are extracted, aiming to provide adaptable best practices for the SSA context.
- Building upon our findings, we conclude by offering recommendations for various stakeholders, including researchers, government agencies, and relevant bodies, on ways to promote and deploy RIES technologies in SSA. By providing actionable recommendations, the study seeks to contribute to efforts aimed at bridging the energy gap in SSA and fostering sustainable energy development.

The methodological approach used in this study is shown in Fig. 2. The remaining part of this study is arranged into five sections. Section 2 briefly summarizes the status of energy sectors in SSA using the four power pools mentioned in this section. Section 3 presents an overview of existing integrated systems in four countries from each power pool, respectively, alongside barriers to RIES implementation and potential benefits that can be derived from its full adoption. In Section 4, RIES enabling policies and solutions that have contributed to energy growth in the United Kingdom and China are presented. Interpretation and implementation pathways from the case studies are discussed in Section 5. In conclusion, from the implication of our findings, recommendations for policymakers and energy stakeholders for the promotion and application of RIES at lower levels within countries in SSA are outlined in Section 6.

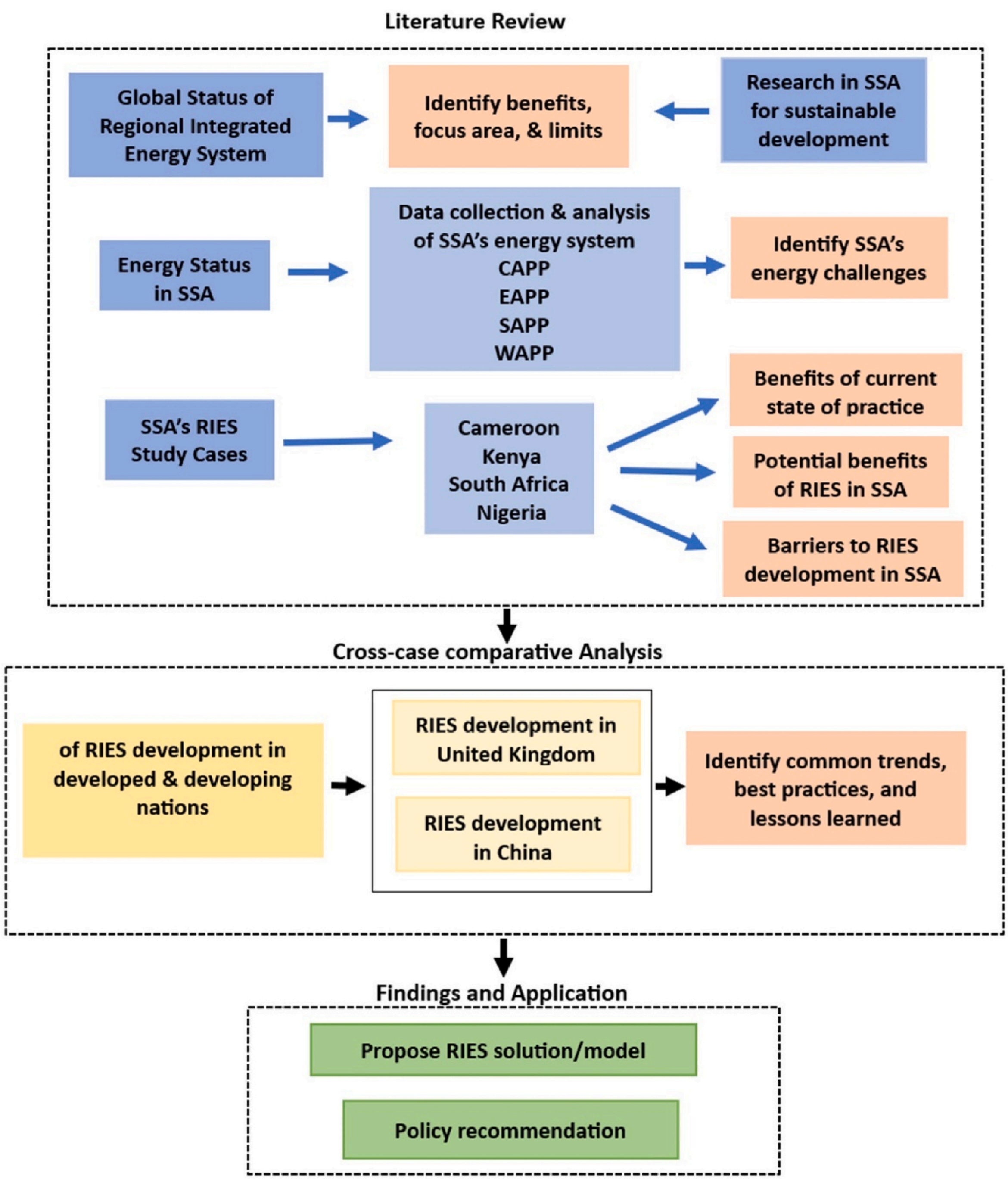

Fig. 2. Methodological approach.

2. Status of energy sectors in sub-saharan Africa

2.1. Central Africa Power Pool

This pool with ten member countries was created in 2003 to promote regional energy trading under the Economic Community of Central African States (ECCAS) energy policy for socio-economic development. Currently, the population of CAPP is over 190 million, with an installed generation capacity of about 7,500 MW and an electricity access rate of about 26% [65]. The main energy source, capacity, and access rate of each member country is shown in Fig. 3. The region depends on hydro energy resources with an estimated capacity of over 650 TWh, and most of the remaining capacity is from thermal plants. Characterized by the low access rate in most member countries, Gabon has the highest electricity access rate, while Chad, whose main energy source is gas, has the lowest access rate. On the other hand, Angola has an access rate of 46.9% and the highest energy generation capacity in the region. Due to the region's failure to adequately satisfy its energy demand, which is caused by weak incentives to encourage private investors, lack of power infrastructures, power losses, and lack of grid interconnection for regional energy trading. This pool is the least advanced among the four power pools.

2.2. East Africa Power Pool

The Inter-Governmental Declaration of Agreement created the Eastern African Power Pool in 2005, which comprises eleven member countries. With over 520 million people, a total installed capacity of over 64 GW, and an approximate energy consumption of 491 TWh in 2020, the pool is characterized by a low electricity access rate in about 70% of the member countries. It has the vision to manage the region's interconnection of the power system and energy trading for optimized energy usage, reduced power supply cost, and social, economic, and environmental benefits [66].

The energy profiles of its member countries are highlighted in Fig. 4. Hydropower is the region's primary energy source, followed by geothermal and then fossil fuel (oil and gas). Egypt has the highest energy generation capacity and access rate in the pool, and while Burundi has the lowest energy generation capacity, South Sudan has the lowest energy access rate topping the 2020 list of the least-electrified countries. Though the region has many energy resources (both renewable and non-renewable) and robust economic growth, challenges such as lack of infrastructure, insufficient generation capacity, political instability, weak capital, and boundaries regulations result in setbacks and instability. With SAPP lying in the south of the region and the Middle East to the north, cross-border transmission, power interconnection, and trading are serving as a means to increase the energy access rate for the population in the region. Albeit this, a harmonized regulatory and operational framework, an increase in generation capacity, investment in technical infrastructure, and financial support have been identified as ways to its development [67].

2.3. South Africa power pool

As the first African regional power pool created in 1995 to boost energy growth through set objectives, this regional integration consists of about 317 million people. The focus of SAPP is an expansion of its capacity to ensure reliable and affordable energy supply to consumers, enable energy trading among members in the region, and guarantee comprehensive economic, environmental, and social practices for sustainable energy development [66,68].

The pool leads in terms of technology among others, having achieved an installed power capacity of over 71 GW, energy consumption of about 353 TWh/year, and an electricity access rate of 47% has made it the most technologically advanced. Though the region's major sources of energy are coal and hydropower, alternative options including solar and wind energy, generations are also being explored for economic and environmental benefits [59]. Angola and Tanzania are blessed with natural gas, and South Africa with highest wind potential and biomass in Mozambique, Swaziland, Zambia, and Tanzania, respectively. All the countries in the pool have substantial potential for solar energy. Most member countries are inactive participants in the pool due to low energy generation capacity and demand. The energy generation source, generation capacity, and access rate of each member country in the pool are highlighted in Fig. 5. Also, South Africa is home to approximately 51% of installed generation capacity within the region. This factor has made

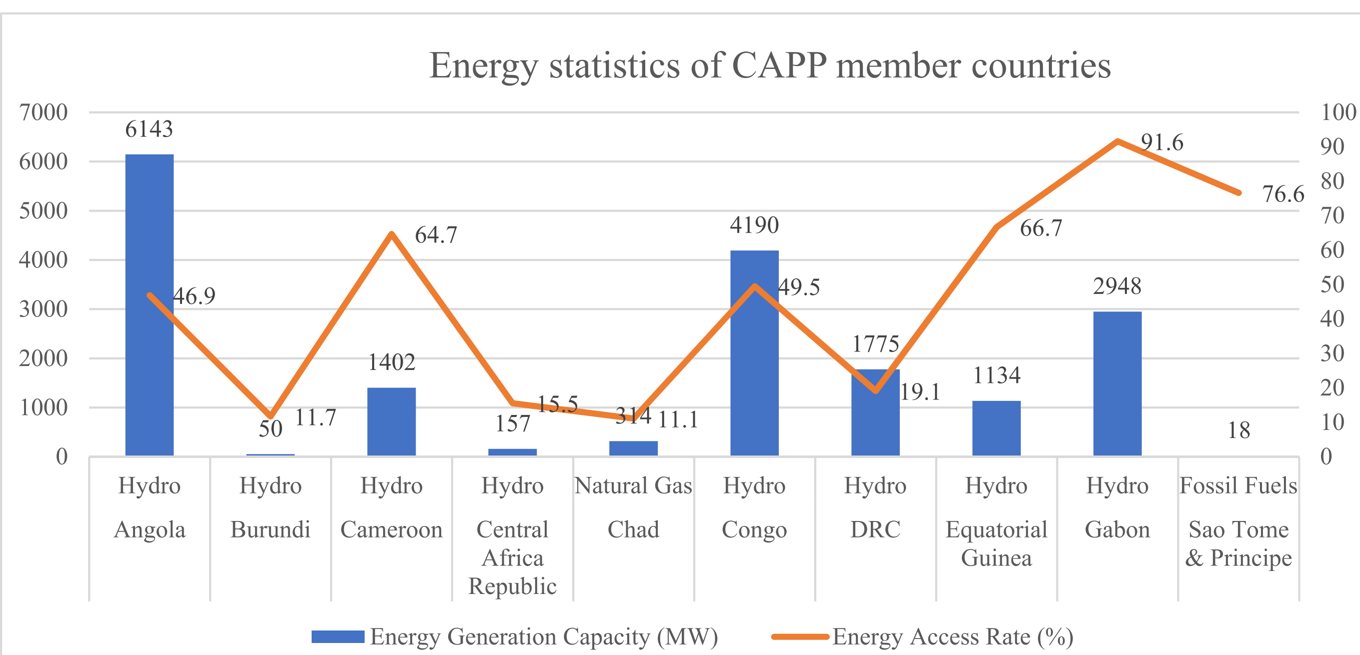

Fig. 3. Energy Statistics of CAPP (Access to electricity (% of the population) - Sub-Saharan Africa | Data (worldbank.org)) (Power Africa | US Agency for International Development (usaid.gov)).

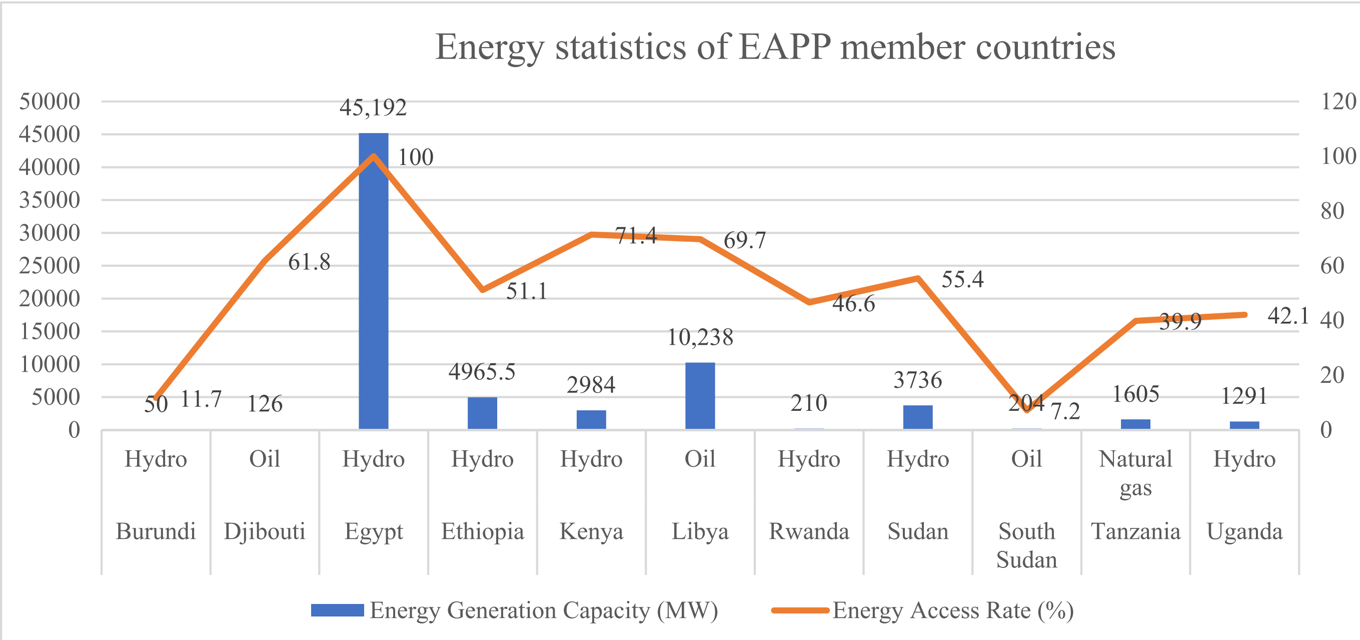

Fig. 4. Energy statistics of EAPP member countries (Access to electricity (% of the population) - Sub-Saharan Africa | Data (worldbank.org) (Power Africa | US Agency for International Development (usaid.gov).

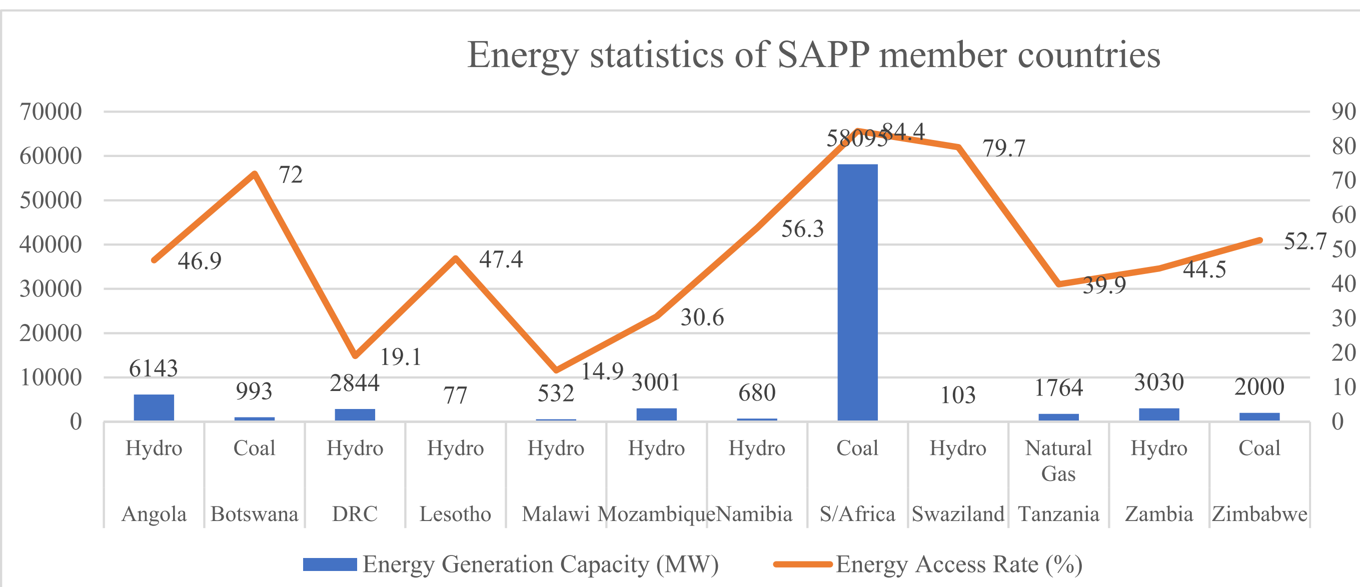

Fig. 5. Energy Statistics of SAPP member countries (Access to electricity (% of the population) - Sub-Saharan Africa | Data (worldbank.org) (Power Africa | US Agency for International Development (usaid.gov).

South Africa a dominant player in the electricity trade within the pool, while most of the other members rely on energy imports.

2.4. West Africa Power Pool

With a population of over 400 million, this pool was established in 1999 by the Economic Community of West Africa States, spread across fifteen members. With a vision of ensuring a reliable and secure power supply through the integration of the numerous national power networks to form a single energy market, the pool has a total installed capacity of about 23 GW (23 GW), energy consumption of about 58 TWh/yr and electricity access rate of 47% [59]. Nigeria, the most populous with a wealth of resources, has a generation capacity of 16,384 MW and an energy access rate of 55.5% and is a major financial contributor to the pool.

Fig. 6 shows the countries in the pool alongside their installed capacity and electricity access rate. The major generation source in the pool is natural gas, followed by one-fifth from hydropower, and oil makes up the rest. Nigeria and Ghana are the major contributors of natural gas, which generates electricity through gas flaring in thermal power plants. This natural gas is transported to other nations, such as Benin, Niger, and Togo, through the West African Gas Pipeline [69]. However, eight countries in the pool still have low electricity access rates and depend on energy imports from other regions and diesel

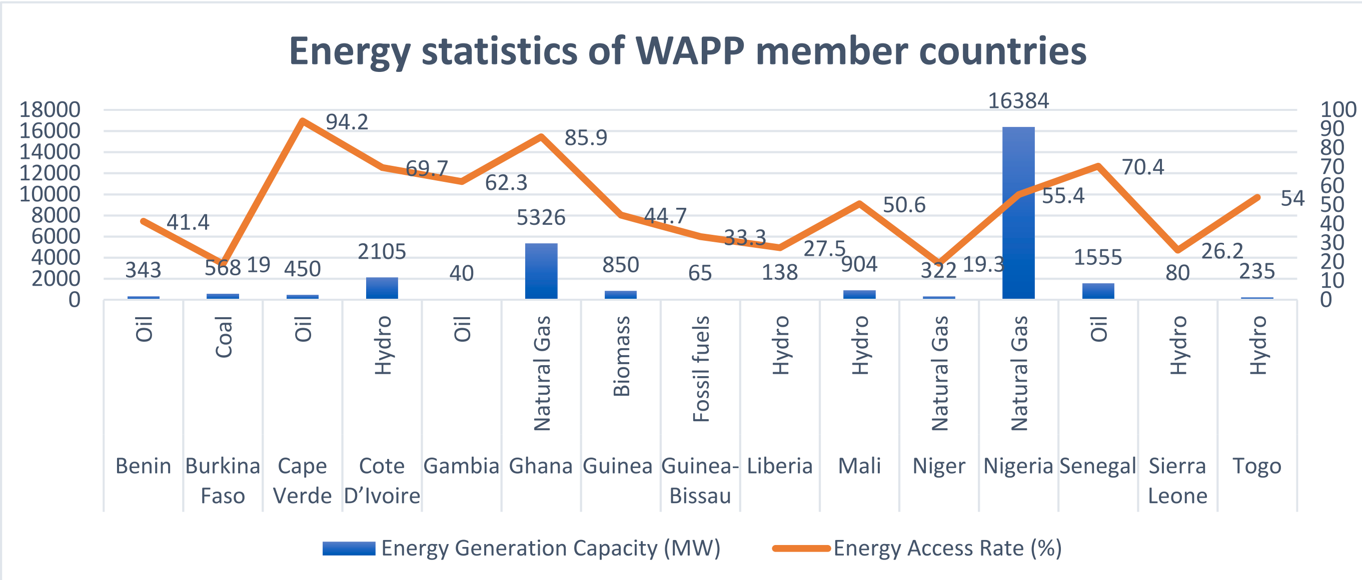

Fig. 6. Energy Statistics of WAPP Member Countries (Access to electricity (% of the population) - Sub-Saharan Africa | Data (worldbank.org) (Power Africa | US Agency for International Development (usaid.gov).

generators. This is due to the growing demand, which results in frequent load shedding and non-optimal solutions [66]. To meet this deficiency and consider technical and financial constraints, each country in the pool is diversifying its generation capacity by incorporating renewables like solar and wind into the existing power networks with a maximum capacity set by the region at 10% of peak demand [70]. The regional renewable resources in this pool cuts across hydro, solar, and wind energy. Nigeria and Niger have the highest opportunity for solar energy generation, while there is a large potential in all countries except Liberia and Mali. For wind resources, Niger and Senegal take the lead with high quality, while there are middle-quality wind resources in Gambia, Nigeria, and Burkina Faso. Most countries in the pool have hugely untapped hydro capacity. Despite these potentials, the contribution of renewables, excluding hydro, is still negligible for centralized and decentralized generation.

2.5. Sub-Saharan Africa's energy issues

Access to reliable, cheap, and sustainable energy is crucial for powering economic development, improving livelihoods, and enhancing overall well-being. However, Africa struggles with many energy-related issues, such as poor infrastructure, non-availability of contemporary energy utilities, overly depending on fossil fuels, energy poverty, and environmental degradation. Energy poverty has been a predominant issue in SSA, particularly for many decades now, as most of the countries region have about 20% electricity access rate and are without modern energy facilities. With a rapidly growing population, expanding economies, and increasing urbanization, the demand for energy in this region has surged, presenting complex and multifaceted energy challenges [71]. These challenges have far-reaching implications for Africa's socio-economic progress and its ability to achieve sustainable development goals. According to [72], over 1.3 billion individuals continue to live in areas without decent energy, with nearly 61% of this population from Sub-Saharan Africa. As a result, countries like Nigeria and many other African countries rely on other means of energy such as firewood, coal, petrol/diesel-powered generator etc, as discussed in [73]. Using these fuel sources poses challenges, such as diminishing oil reserves, greenhouse gas emissions, environmental degradation, and health implications.

Other challenges associated with grids preventing energy accessibility include inefficiency, outdated infrastructures, underfinancing, lack of regular maintenance, low generating power, etc. Many energy sectors are not financially unsustainable due to low revenue caused by poor billing systems, consumers' inability to pay for energy consumed, inadequate tariffs to fully cater to operating costs, energy investment depreciation, and ineffective management structure [74]. Moreso [5,75], highlighted the issues with utilizing the grid for energy access. This includes installing and supplying electricity to last miles invoking expensive costs and loss in transmission and distribution lines, logistics, especially with inadequate road-access channels, and not forgetting the unreliable/unstable electricity supply. Also, inadequate regulatory policies and political instability are issues that hinder investment in the energy sector, new technologies, and energy market growth. To alleviate the effects of energy challenges in the region, high investment in modern energy services, clean energy integration, productive use of energy, and efficiency are essential. The region can capitalize on its abundant natural resources to grow its energy sector efficiently while meeting its carbon target.

3. Regional integrated energy systems in sub-saharan Africa

3.1. SSA RIES study cases

With an emphasis on energy as the driver for economic development, some countries in SSA are making a conscious effort to incorporate renewable resources, energy-efficient technologies and formulate new energy policies and strategies that support the transformation of its energy sector with respect to resources diversification and utilization, modern energy infrastructures, licenses, and market structure. Though the concept of RIES is not yet widespread and widely employed compared to developed nations like the United States, and United Kingdom, and some developing regions with 100% energy access rate like China, there are a lot of existing and ongoing projects that capture some of the features of the integrated energy system. Distributed generations, hybrid renewable energy systems, and rural electrification are becoming popular solutions to the energy challenges in the region.

3.1.1. Cameroon

Cameroon has the highest population density in CAPP, with over 25 million people, a total energy generation capacity of 1402 MW, and an energy access rate of about 64%. The country has abundant natural assets including oil, gas, and renewables for consumption and energy trading [65]. Despite the rich energy resources, especially hydro and solar energy, the country continues to experience energy insecurity as demand exceeds supply [76,77]. This is due to the growing population, climate change, lack of funding and investors, and political instability. Although the government is taking steps to end energy poverty in the country by adding alternative resources into its energy mix, working to install new power infrastructures, creating sustainable laws, and engaging public and private organizations in the energy sector. As such, they have been employed for off-grid electrification in Cameroon [78]. In that regard [79], presented an evaluation of Building Integrated Photovoltaic (BIPV) systems in Cameroon's tropical area. An analysis was conducted for an apartment with BIPV installed as a rooftop in order to fulfill the standard daily energy requirement of 3 kW. This analysis demonstrated that such a system could reduce yearly energy utilization from 79.58 kW h/m^2 to 13.64 kW h/m^2 as well as reducing building materials and labor costs. To explore various power generation pathways [80], carried out a policy assessment of the electricity system in Cameroon using a back-casting methodology in order to determine the length of time in which it is possible to be heavily reliant on renewable energy sources to meet energy demands.

3.1.2. Kenya

After Nigeria and South Africa, Kenya, with a population of over 56 million, is the third-largest economy in SSA and the first and most progressive in East Africa. The country has a generating capacity of over 2.9 GW, with hydro and geothermal as the major sources. Other sources of power generation for the country include biomass and waste for biogas and wind energy [81]. The review by [82], the energy mix shows that Kenya has great potential in wind energy. Despite having great renewable energy generation potential, satisfying the increasing energy demand was a challenge for many years due to technical constraints, low access in rural communities, increasing demand, lack of funds for increased generation, and environmental factors [83,84]. The country usually imports fossil fuels from neighboring countries such as Sudan to satisfy demand. However, there has been an improvement in its energy access as one of the highest rates in EAPP through the creation of agencies and policies such as the Kenyan Electricity Generation Company, Kenya Electricity Transmission Company, Kenya Power and Lighting Company, Rural Electrification Authority and other licensed energy producers which are regulated and tasked with the mandate of creating national energy policies and grid network that ensures availability of inexpensive, constant, and sustainable energy. Some of these policies that led to increasing rural electrification include private ownership without interference from political stakeholders, waiver of tariffs, and VAT, among others. Hence, the focus on continuous promotion and increased utilization of several available renewable energy resources in the country has made Kenya a leader in the off-grid solar market [81,84,85]. However, most off-grid mini-grid systems are diesel-based and continue negatively impacting the environment. A study by [86] proposed a model to increase energy access through decentralized rural electrification considering the coupling of traditional diesel generation set, solar, wind, and hydro energy. Another notable project is Kenya's Lake Turkana Wind Power development, Africa's largest wind farm, aimed at providing 310 MW of reliable, clean, low-cost energy to the national grid [87].

3.1.3. South Africa

A typical example is South Africa, which is situated in the south region of SSA with a population of over 57.78 million people and a total energy generation capacity of 58 GW has electricity access of over 80% [88,89]. The nation is blessed with about fifty percent of the total energy capacity of the SSA grid, whose energy source is coal, making it the largest emitter of greenhouse gas in Africa [90,91]. It is also blessed with abundance of solar energy while its wind energy resource is only available in some of its coastal areas [92].

It is certain that the country can meet its energy need via coal but in recent years, the country has made a significant shift towards the Paris Agreement on climate change by creating new energy policies and investing in renewable energy systems [93]. These policies are formulated by the government through the country's state-owned power grid, Eskom but the renewable energy projects have been carried out mainly by the private sector, with a long-term energy plan to provide reliable and efficient energy service at competitive rates, and minimize carbon emissions by 42% by 2025 [94–96]. The policies include the National Development Plan (NDP), Renewable Energy Independent Power Provider Procurement Program (REIPPPP), Integrated Energy Plan (IEP), and Integrated Resource Plan (IRP) and the projects are either grid-connected or off-grid distributed generation with the integration of available renewable energy resources. The availability of wind, solar, and hydropower in different parts of the country has increased rural electrification, small and medium-scale distributed generation systems close to consumption centers, and integration of distributed generations to the grid. With coal as the base load, wind power and solar energy have been incorporated into the energy mix of the country. The coupling of these energy sources has reduced carbon emissions, increased energy efficiency, and met the energy needs of local communities, however, integration has been in a limited capacity due to the sparsely distributed renewable energy resources and insufficient research and studies to model and ensure system stability that may occur with the integration of a large network of integrated systems such as RIES [96]. Moreso, challenges like dependence on coal, aging infrastructures, and policy barriers such as monopolized electrical utility, increase tariffs, bureaucracy, high startup cost of investment in renewable energy generation, and load shedding create huge limitations to RIES development in the country [97,98].

However [99], conducted research on the reliability assessment of wind resource using optimum reservoir target power operations that utilizes integrated wind and hydropower system for maximum energy generation and storage. As a result, a 45% rise in the level of wind penetration in South Africa's power system was confirmed as well as a reduction in coal power usage. Also [100], examine South Africa's Integrated Energy Plan framework as well as the Integrated Resource Plan. These policies support a comprehensive strategy that involves the integration of renewable energy sources into the grid to ensure reliable and maximum energy demand, supply, efficiency, etc. and NPV rate are used as indicators for economic benefit assessment remains the same.

3.1.4. Nigeria

Another look at RIES in SSA considering Nigeria, one of the 15 countries in WAPP is the most populous nation in Africa and often referred to as the giant of Africa due to its status as the largest economy in Africa. It has about 240 million citizens and is greatly blessed with an abundance of both non-renewable and renewable energy resources including oil, gas, hydro, solar, and wind energy. Its primary energy sources are gas and hydropower which make up about 75 and 25 percent of its energy mix respectively [101]. Despite its energy potential, the country is faced with unreliable and lack of electricity to a larger part of the population as it is only able to dispatch about one-third of its capacity due to transmission and operational limits. A huge number of the population without access to electricity live in rural areas while the urban region experiences erratic and unstable power supply. A few of its population have resulted in the use of generating sets, solar systems for households and small commercial businesses [102]. Many others have resulted in relocating to urban areas where the electricity is still erratic [103]. The energy crisis is linked to ineffective energy resource utilization, lack of adequate planning and investment, inadequate infrastructures, dependence on the aged thermal plants and large hydropower stations, and lack of technical expertise in new technologies and innovation such as RIES [104,105]. The country has developed numerous policies such as the National Energy Policy (NEP), National

Renewable Energy and Energy Efficiency Policy (NREEEP), Sustainable Energy for All (SE4All) Action Agenda, National Renewable Energy Action Plan (NREAP), and the Nigeria Energy Transition Plan (ETP) among others to diversify its energy resources and solve its energy challenges, advance the energy sector and meet its global energy goals [106]. Despite the robust ambitious energy policies, no form of distributed generation integration to the national grid has been implemented [107]. However, distributed energy systems consisting of stand-alone or hybrid renewables especially solar energy for households and small commercial businesses and mini grids combining one or more technologies of diesel generator set, small hydro power, solar and wind power for rural electrification and local energy community projects have become popular for meeting energy needs [108]. [109] for instance, carried out a study to examine the feasibility and economic viability of solar PV-grid-tied energy systems for electricity generation in a selected part of Nigeria using HOMER energy optimization software. Also [110], researched the possibility and criteria for hybridizing the various renewable energy sources such as solar, wind, and biomass in Nigeria and evaluated the sustainability of integrating these sources.

3.1.5. Benefits of the current state-of-practice

Generally, the use of distributed generation system technologies in SSA combines renewables and energy storage devices as mini-grids for rural electrification, and as stand-alone and backup power supplies for residential, small, and commercial. The common technologies employed include combine solar-wind mini-grids, small hydropower, solar-diesel generator, wind-diesel generator, and solar home systems [92]. Though this has increased energy access in certain countries like South Africa, Ghana, and Namibia inherently improving the standard of living and productivity, especially in unserved or underserved communities. In addition, the decline in utilizing fossil fuel generating sets and increasing usage of environmentally friendly resources in the distribution networks have reduced the volume of greenhouse gases released, hence minimizing health and environmental hazards.

However, its impact is negligible as the populace is without electricity due to the increasing electricity demand caused by rising population, unequal progress across countries, usage of fossil fuels indefinitely to meet demand, and inadequate infrastructures [13]. To achieve universal energy access by 2025, Africa needs to double its grid generation capacity which means connecting over 200 million households to the existing ones.

3.2. What more can RIES offer? Potential benefits of RIES in sub-Saharan Africa

RIES can positively change the energy situation in SSA by addressing challenges, including underutilization of energy resources, inefficiency, fuel and operating cost, and environmental concerns. In line with the World Bank statistics, global investment in energy in SSA is barely 5% which is majorly in oil production. With the clean energy transition agenda and economic crisis caused by COVID, there is a decline in energy investment. For instance, the government of China recently announced a reduction of debt financing of fossil coal-based projects abroad [16,74]. Also, it was reported in [111] that an estimate of about US$55 billion is annually to accomplish universal accessibility in Africa by 2030. Therefore, SSA must use innovative technologies/solutions like RIES to maximize energy resources and cut costs, losses, and environmental pollution in towns, cities, provinces, states, and countries. The efficient utilization of resources through proper planning, coordination, scheduling, and operation can increase energy efficiency, expand the thermal energy services potential, and significantly reduce the financial constraints associated with transforming the energy sector.

Though Africa accounts for the lowest emissions per capita and less than 4% contribution to global emissions, it is more affected by the impact of global warming brought on by greenhouse gas emissions outside the region. With continuous use of fossil energy resources, meeting the set carbon targets might become an impossible feat. South Africa, for instance, is still heavily dependent on coal and has the highest share of coal in its energy mix globally despite its high energy access rate and grid-connected and off-grid renewable energy projects. Low-carbon energy resources are being developed with more vigor; majority of the region's significant renewable energy projects are financed through the private sector using Public Private Partnership (PPP) investment model [74]. With the urgency to transition from fossil fuels and promote a low-carbon economy, applying RIES within countries can speed up decarbonization and ensure these targets are met in SSA by integrating the resources in a region economically and efficiently.

Moreso, taking the case of network losses in SSA, which is high compared to developed regions like the United Kingdom [112], optimal integration of the available energy resources within a region can significantly reduce power system losses, overloading on feeders, peak power constraint and enhance power quality, voltage profile, and flexibility. Consequently, there will be an improvement in power system stability and reliability.

3.3. Barriers to RIES development/implementation in SSA

The challenges of RIES development in SSA are the same as those associated with the ongoing energy poverty in the region resulting in low energy access. These challenges are categorized below.

3.3.1. Socio-economic challenges

Among the issues the SSA energy sector is dealing with is the high proportion of poverty. Lack of and insufficient investment in this sector by relevant stakeholders hinders research and development of modern energy infrastructures such as RIES. Additionally, about 40% of the population lives in abject poverty with high disparity in income [113]. A large portion of the populace, especially in remote areas with electricity, are unable and unwilling to pay for the electricity used. This low uptake results in supply and demand constraints, as affordability is a major criterion for energy access and utilization [71].

3.3.2. Technical challenges

Dilapidated energy infrastructures and poor maintenance culture have led to frequent power outages and unreliable supply in the region. In addition to this is the lack of modern energy structures and technology and its inability to leverage technology for energy generation, integration of renewables, demand forecast, and energy models [24, 114]. Most of the nations in SSA lack strong energy institutions and plan that would stimulate supply and increase demand consumption. The concept of research and development for regional development is lagging in SSA; hence there are fewer or no energy models or tools designed for the specific needs of most of the countries.

3.3.3. Political and policy challenges

In the past, government electricity agencies have overseen power assets and growths throughout Sub-Saharan Africa. While few countries have been able to diversify the energy sector through privatization, government bureaucracy has led to dependence on old power infrastructures, technologies, market structures, poor business models, and unsuitable energy policies [115]. Some of these policy challenges include the high cost of procurement for ancillary services, restricted access to regional grid development, difficulties in obtaining licenses, and lack of incentives and tax exemption [116]. This discourages interested stakeholders and investors in the energy sector and hampers development.

4. Possible solutions

4.1. A case study of energy growth (RIES) in the United Kingdom

The UK economy has established world-leading targets for realizing energy transition and low-carbon emission solutions. One such solution is the regionally integrated energy systems, which serve a critical part in the UK's energy shift to sustainable and clean economy by integrating multiple energy sources and optimising utilization at the regional level. The implementation of integrated energy systems has contributed to a 25% reduction in carbon emissions and a 15% increase in energy efficiency over the past decade [117,118]. Like China, the UK adopts RIES-based District Heating and Cooling (DHC) systems by utilizing waste heat from industrial processes, power generation, and local energy sources to provide heating and cooling services to communities and buildings [119]. gave an instance where the University of Warwick installed an integrated energy system consisting of electricity, district heating, and district cooling networks interconnected through gas-fired CHP units, gas-fired heat-only boilers, electric chillers, and heat-driven absorption chillers. This integrated energy system increases energy efficiency and is optimized by utilizing a multi-energy or polygenerating supply network to supply different energy forms across various paths, such as electricity, cooling, and heat. From a consumer standpoint, smart devices such as smart meters, monitoring systems, and integrated energy resources such as power generators, electric vehicles, and batteries accelerate the smart transition of energy systems. Essentially, it helps to measure energy generated or consumed in real-time, adjust demand and supply, define electricity costs for a period, etc.

In addition [120], used renewable energy to link the power network with different energy sources like hydrogen. This increases generation and adoption of renewables and allows the generation, storage, and reconversion of hydrogen. This model can be improved to increase energy access and provide clean fuel for transportation in SSA. The UK created policies that support the deployment and installation of the RIES system. For instance, the Smart Systems and Flexibility Plan passed in 2017 outlines policies that support adopting smart technologies, demand response, and energy storage, creating an enabling environment for RIES and flexible energy systems. Adopting such a policy in SSA will help facilitate an enabling environment for developing, deploying, and utilizing innovative RIES solutions across Africa. In addition to supporting an energy transition plan, it creates a favorable business environment for energy companies to deploy REIS-based solutions and foster the utilization of renewable energy. Moreso, the Energy White Paper passed in 2020 [121] also outlines strategies and policies by the UK government in transitioning to a low-carbon energy system, including measures to support RIES implementation and accelerate renewable energy deployment. Strategies and policies of the Energy White Paper, related to creating a more sustainable future for humanity and protecting the fuel, will work well to facilitate green industries, transportation, energy systems, and green jobs if adopted in SSA. Another potentially viable policy that could be incorporated into SSA is the Carbon Pricing policy. The UK operates a carbon pricing mechanism called Carbon Reduction Commitment (CRC) Energy Efficiency Scheme. It consists of a carbon tax and a cap-and-trade system [122,123]. The CRC scheme applies to large energy-consuming organizations and incentivizes them to reduce carbon emissions through financial mechanisms. This strategy is replicable in SSA, and large energy-consuming organizations like Dangote would be regulated by introducing mechanisms like carbon credits or carbon offset, which encourage companies to go green and install integrated energy systems.

4.2. A case study of energy growth (RIES) in China

In recent years, China, the world's largest emerging economy and highest energy consumer due to its high population, has greatly transformed its energy sector through several energy development strategies, technologies, and policies toward sustainable economic development. Before this transformation, coal was the major energy resource which made up roughly 75% of its installed energy capacity, thereby being among largest emitters of carbon emission [124]. This causes a great barrier to poverty alleviation, especially in remote and rural regions characterized by poor energy supply and pollution. Focused on achieving energy security and net-zero carbon targets, the government created policies at national, sub-national, sectoral, and provincial levels that are targeted at the significance and need to optimize the China's energy resources through the establishment of modern energy services and green innovative technologies like RIES [125,126]. These policies are aimed at efficient energy utilization, diversification, minimizing coal import, and the creation of a strategic reserve system, which encourages collaborations between different provinces and regions and international cooperation, promotes interprovincial electricity exchanges and cross-regional energy trading, streamlines administrative procedures, and incentivize investment in RIES. Some of these policies are highlighted in Table 3 including the year it was created, amended, policy name and the target. China has been actively integrating and strategically deploying renewable energy generation in clusters in resource-rich provinces, owning 32% of global renewable energy market, alongside an installed capacity of about 1.26 TW in the first quarter of 2023 [14]. The integration of renewable energy sources into regional energy systems has led to a 30% increase in renewable energy capacity and a 20% decrease in coal consumption since 2010 [127].

As the highest producer of solar, wind, and hydropower, the integration is facilitated through smart grid technologies, optimized energy management, and coordinated dispatch strategies which enable the establishment of RIES. By fusing local realities with important areas notably Guangdong-Hong Kong-Macao Greater Bay Area, Yangtze River Delta, Yangtze River Economic Belt, and Yellow River Basin, energy reform and sustainable economic growth low-carbon development and energy transformation have been encouraged.

For instance, to increase electricity consumption and improve the poor energy efficiency and inadequate facilities in rural China [140], examined the features of creating an Integrated Energy System for Rural Electrification in China (IESREIC). The system involves the use of solar water heaters as well as ground source heat pumps, liquefied petroleum gas,

And biomass digesters for rural users [141]. also developed a brand-new bi-level robust game that offers the best RIES scheduling for large-scale renewable energy. The RIES structure and operation discussed in this study were a bus-structured model deployed, which

Table 3
Policies in China that promotes RIES.

Year Created/ Amended	Policy/Strategy	Goal
1997, 2007, 2016, 2018	Energy Conservation Law	To enhance energy efficiency [128,129]
2012	Energy White Paper	Enhance energy efficiency by facilitating the clean use of low-carbon fossil energy and increasing the percentage of non-fossil energy [128,130]
2005,2009	Renewable Energy Law (REL)	Encourage the development and exploitation of renewable energy sources [131–133]
2014	Energy Development Strategic Action Plan	Substitute coal with clean energy [134,135]
1996,2009,2018	Electric Power Law	Promote the electric power industry, protect investors' and consumers' legal rights, and regulate generation, distribution & consumption [136]
2017	Energy Supply & Consumption Revolution Strategy	Maximum primary energy consumption at 6000 Mtce, increases the share of non-fossil [137]
2014	100 Energy Efficiency Standards Promotion Project	Set the amount of carbon to be emitted per year in all power plants [138]
2010, 2012, 2017	Low Carbon Pilot Cities & Provinces	Set carbon peak goals at 84 cities/ provinces [139]

enables the integration of several sources of power including those that produce heat, store energy, and convert cold into heat and vice versa. The introduction of the CCHP (Combined Cooling, Heat, and Power (Trigeneration)) unit provides all types of demands, combined with large-scale renewable energy and electric energy. All these lead to enhanced grid stability, increased renewable energy penetration, and localized energy production, all of which help promote distributed generation, allowing communities and regions to produce and consume their renewable energy and fostering energy self-sufficiency.

5. Discussion

Given SSA's energy inaccessibility problem and abundant renewable energy sources, China's approach to building Local Energy Communities (LEC), such as adopting the IESREIC technique to facilitate energy access and efficiency, has great potential in SSA. This can help promote access to dependable and effective energy, especially in rural places without grid access. It also creates opportunities for multi-energy trading among consumers and prosumers. China's industrial sector consumes a large amount of the country's energy resources, including hydro, solar, and thermal energy. RIES aids the integration of advanced energy management systems, real-time monitoring, and optimization techniques to improve industrial energy efficiency. This enables the integration of waste heat recovery and cogeneration systems, which enhances the overall efficiency of industrial operations.

Additionally, it facilitates synergy among industries as the system allows for industrial symbiosis, where waste energy from one industry becomes a valuable resource for another, fostering resource circularity and minimizing environmental impact. Using a similar approach, countries in SSA can increase energy access and efficiency and minimize carbon emissions by coupling their resources within a region. From the power pools, it is evident that three of the four power pools have an abundance of hydro energy resources, with 7 out of 10 countries hydro dependency in CAPP, 6 out of 11 in EAPP, 9 out of 12 in SAPP and 5 out of 14 in WAPP as shown in Fig. 7. This underscores the potential for coupling hydro, solar, and thermal energy resources within RIES to address energy gaps as illustrated in Fig. 8, a RIES sample model deployed for rural electrification in China. Moreover, the increasing popularity of self-consumption of renewables, particularly solar and wind energy, in SSA for household electrification necessitates technologies to ensure curtailment, maximize efficiency, and reduce associated costs.

However, the growth in UK and China has been made possible through adequate research, supporting policies, and enabling infrastructures. Based on the 2021 Renewable energy report 2018, China led in yearly expenditure on renewable energy and fuels with the highest production capacity in hydropower, concentrated solar thermal energy, solar PV, wind, and solar water heating capacity [142]. The energy growth in the stated case studies is driven by policies that govern several energy reforms, including integrating renewables into the grid, energy usage in buildings, heating and cooling sector. The role of government policies for technological innovation to drive economic development cannot be over-emphasized [143].

6. Conclusion and policy implication of our findings

6.1. Conclusion

This study examined the status and policy frameworks of each SAPP, WAPP, EAPP, and CAPP power pool, including some Sub-Saharan African countries, to find fewer to no regional integrated energy systems (RIES) deployed to these regions. In addition, assessing the use of RIES in developed and developing countries like UK and China as case studies has revealed the transformative potential of RIES to address the energy challenges of the SSA region. In the United Kingdom, the implementation of integrated energy systems has contributed to a 25% reduction in carbon emissions and a 15% increase in energy efficiency over the past decade. Similarly, in China, the integration of renewable energy sources into regional energy systems has led to a 30% increase in renewable energy capacity and a 20% decrease in coal consumption since 2010. China owns 32% of global renewable energy market, alongside an installed capacity of about 1.26 TW in the first quarter of 2023.

By leveraging renewable energy resources, enhancing energy access, and promoting sustainable practices, RIES can drive economic development, social progress, and environmental sustainability in Sub-Saharan Africa. Using a similar approach, countries in SSA can increase energy access and efficiency and minimize carbon emissions by coupling their resources within a region. Our observations from the power pools indicate that three out of the four pools possess significant hydro energy resources. Specifically, within the CAPP region, 7 out of 10 countries heavily rely on hydro energy, while in EAPP, 6 out of 11 countries exhibit a similar dependency. Moreover, within SAPP, 9 out of 12 countries and within WAPP, 5 out of 14 countries rely significantly on hydro energy. These nations have the opportunity to leverage a combination of hydro, solar, wind, and thermal energy resources within their Regional Integrated Energy Systems (RIES) to address their energy deficits.

However, concerted efforts are needed to overcome existing barriers and unlock the full potential of RIES in Sub-Saharan Africa, and this requires a multifaceted approach, combining tailored policies and

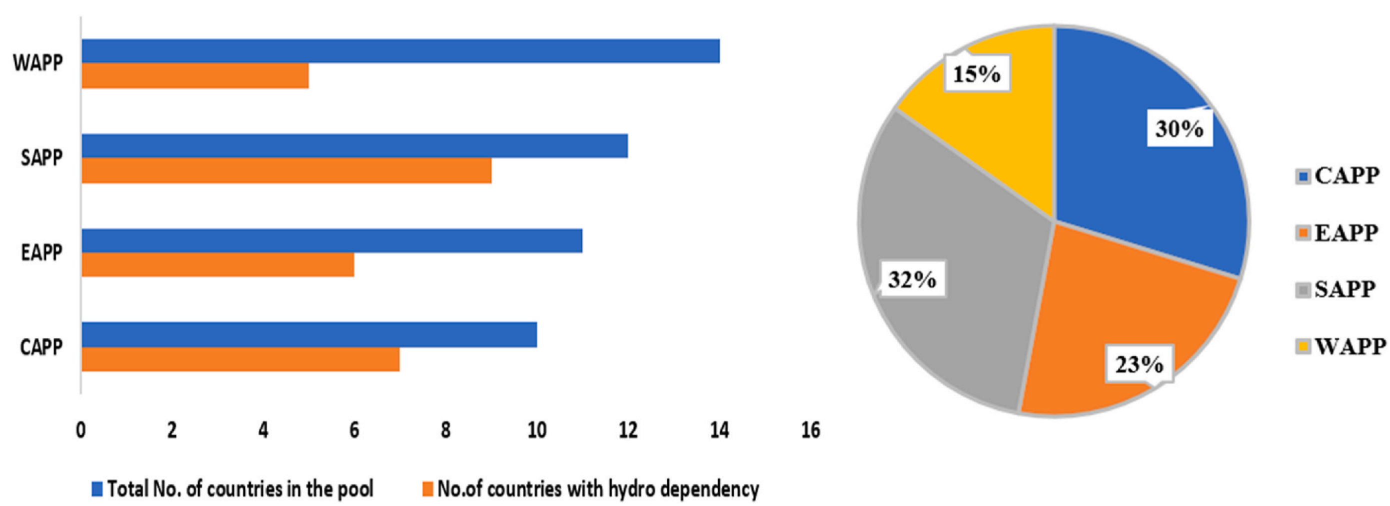

Fig. 7. Distribution of member countries with hydropower as main energy source.

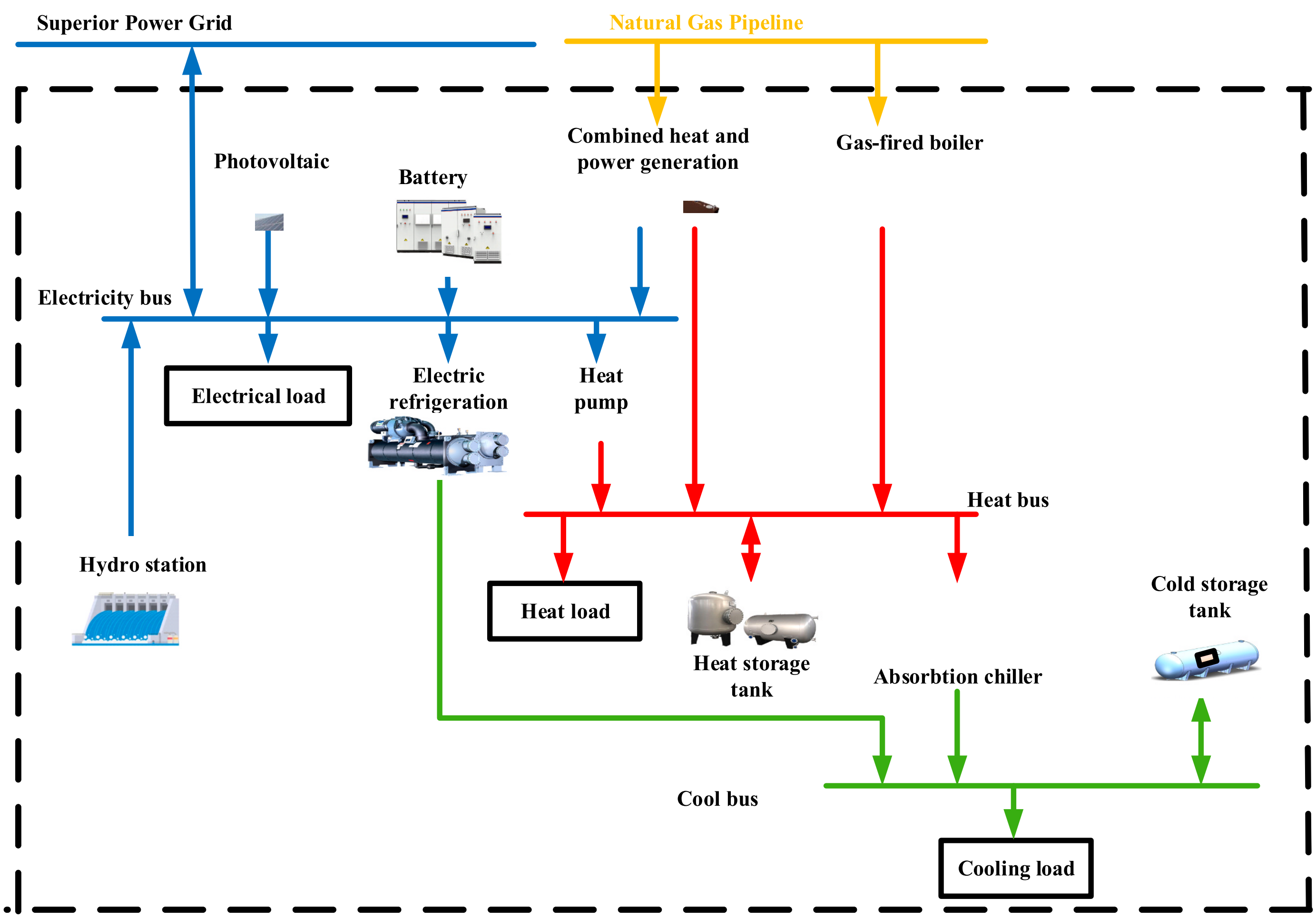

Fig. 8. Proposed RIES model that was deployed in China for rural electrification.

sustainable technological solutions. The stakeholders must collaborate to adopt a holistic approach that accelerates the deployment of regional integrated energy systems. This includes promoting knowledge sharing and capacity building, facilitating technology transfer, and establishing supportive regulatory frameworks and governance structures that strengthen regional institutions and promote public-private partnerships. International partnerships, innovative financing mechanisms, and private sector engagement can play crucial roles in scaling up regional integrated energy systems.

While this research provides valuable insights into the status and potential of RIES in SSA, challenges related to data availability and case study selection poses limitations. Insufficient access to comprehensive and current data on energy infrastructure, policies, and practices in Sub-Saharan Africa (SSA) may hinder the depth and accuracy of the analysis. This could lead to potential gaps in understanding the state of regional integrated energy systems (RIES) in the region. Furthermore, the selection of representative countries for case studies from each power pool may not fully encompass the diverse energy challenges and contexts across SSA. This could overlook countries or regions with unique characteristics or significant energy developments, potentially limiting the applicability of findings. Hence, these limitations need to be addressed in future works. In addition, future research may focus on a variety of areas, including:

- Incorporating new technology: Exploring the integration of emerging technologies, such as energy storage, smart grids, and blockchain, within RIES frameworks can enhance system reliability, flexibility, and efficiency. Future research should assess the technical feasibility, economic viability, and potential benefits of integrating these technologies into RIES projects in Sub-Saharan Africa.
- Techno-economic analysis: Conducting in-depth techno-economic analyses of specific RIES projects in Sub-Saharan Africa can provide a more accurate assessment of their financial viability, cost-effectiveness, and return on investment. This analysis should consider factors such as project development costs, operation and maintenance expenses, revenue streams, and the overall economic impact of RIES deployment.
- Policy evaluation: Evaluating the effectiveness and impact of existing policies related to RIES in Sub-Saharan African countries can shed light on their strengths, weaknesses, and areas for improvement. Comparative studies across countries can identify best practices, policy gaps, and opportunities for policy harmonization to create a conducive environment for RIES deployment.

By addressing these research gaps, understanding RIES in Sub-Saharan Africa can be further advanced, enabling policymakers, researchers, and stakeholders to make informed decisions, develop robust strategies, and foster sustainable energy development in the region. Subsequent works will showcase the possibility of a regionally integrated energy system in a SSA country by proposing a model for the region.

6.2. *Policy implications*

Key actions must be taken to unlock the full potential of regional integrated energy systems. Several implications drawn from the regionally integrated energy system developed at different levels of case studies are as follows:

- It is not enough to be aware of the potential of energy resources in a region; a detailed assessment of these resources and their spatial distribution should be conducted to identify suitable sites and create realistic scenarios for deploying RIES within a country. This can only be feasible if the government and regulating bodies create policies that enable and support energy generation,
distribution, and trading within towns, communities, provinces, and inter-provinces, not just at the national level. Consequently, the benefits of clean energy can be shared across borders.
- Policies and strategies specific to the development of RIES are helpful. Though a number of policies promote growth of renewable energy resources for the energy transition in SSA, it is pertinent to create policies specifically targeted at integrating energy resources, energy efficiency, demand response, and heating and cooling energy utilization, among others.
- Policies and regulatory frameworks should not be a one-off exercise; there should be continuous provision and amendment of a supportive policy framework, including long-term power purchase agreements, transparent regulatory processes, streamlining licensing procedures, and establishing tariff structures that incentivize investments in RIES to attract private investment in like projects. This would help accommodate new innovative technologies.
- RIES deployment should consider the adaptability and scalability of technologies to suit the unique needs of sub-Saharan African countries. Emphasizing modular and flexible solutions allows for easier implementation, especially in rural and remote areas, not focusing only on cross borders between pools. Countries like Nigeria with hydropower should consider integrating RIES into their energy infrastructure, ensuring reliable electricity supply and enabling energy storage. The Kainji Dam in Niger state Nigeria, integrated with solar farms and coupled with pumped-storage hydropower projects, demonstrates the potential for RIES deployment, allowing for renewable energy integration and grid stabilization.
- Incorporating research tailored toward specific energy needs within a region can help build capacities and develop energy models and solutions that address local, national, and regional challenges. The government and relevant stakeholders should invest and create opportunities that spur research in RIES and SSA would help to close the existing geographical gap in this area and, more importantly, the resources and needs of different regions differ. For instance, a successful model in China might not capture the need of a country in SSA due to variations in resource type, climate conditions, and load type.
- Establishing platforms for knowledge sharing, such as regional networks and partnerships, allows sub-Saharan African countries to learn from each other's solutions and experiences and from countries like the UK and China in deploying RIES. This enhances collaboration and enables the transfer of successful strategies.

CRediT authorship contribution statement

Abimbola S. Ajagun: Investigation, Methodology, Formal analysis, Writing – original draft. **Wanning Mao:** Investigation, Formal analysis, Writing – review & editing. **Xiaorong Sun:** Conceptualization, Supervision, Project administration, Writing – review & editing. **Jinpeng Guo:** Supervision, Project administration, Writing – review & editing. **Bamidele Adebisi:** Supervision, Writing – review & editing. **Abiodun Musa Aibinu:** Supervision, 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

The authors do not have permission to share data.

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