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*Review*

# Planning Sustainable Energy Systems in the Southern African Development Community: A Review of Power Systems Planning Approaches

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**Abstract:** Southern Africa has a huge potential for renewable energy sources such as hydro, solar, wind, biomass, and geothermal. However, electricity access remains a key policy issue for most member states, with a global average access to electricity of only 54% in 2019. This low electrification rate is a strong motivation for member states to increase renewable energy use and improve access to electricity for all. The goal of this paper was to present a literature review of methodologies, energy plans, and government programs that have been implemented by the Southern African Development Community member states to address the region's low average electrification rate and greenhouse gas emission reduction targets. The study presents the most commonly used methodologies for the integration of renewable energies into electrical systems, considering the main grid and distributed generation systems. LCOE minimization methodologies and software options, such as GIS, HOMER, LEAP, and EnergyPLAN, are the most common among the identified studies. The traditional method of electrifying by expanding the grid has not contributed to the eradication of energy poverty in rural areas. Therefore, to improve electricity access in Southern Africa, it is essential to consider off-grid solutions based on renewable energy sources.

**Keywords:** renewable energy; electricity access; generation expansion planning; low electrification; sustainable energy



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## 1. Introduction

Humanity is currently facing several global challenges, and one of them, given its urgency, is the guarantee of future growth in the energy sector, to ensure electricity access in a secure, sustainable, sufficient, and affordable way for all [1]. In that regard, the United Nations (UN) has defined universal access to electricity as one of its Sustainable Development Goals (SDGs) to be reached by 2030 [2]. Being recognized as a key driver of human and economic development [3], SDG 7 calls for ensuring access to affordable, reliable, and sustainable energy for everyone [4]. Moreover, in developing countries, higher energy access is associated with higher literacy rates, improved health care, enhanced employment opportunities, and higher productivity, combating global poverty in general [3]. Nevertheless, according to the International Energy Agency (IEA) [5] at least 770 million people worldwide still live without access to electricity, mostly in Sub-Saharan Africa (SSA) and developing countries in Asia. In addition, due to the economic recession caused by the COVID-19 pandemic, many vulnerable people from these countries have lost the ability to pay for electricity, also leading to energy poverty problems [5]. Estimates point to more than 100 million people, mainly located in SSA and developing Asia, being in extreme poverty in 2020, with more than 200 million people falling into poverty [6]. Hence, it is important to highlight that, in addition to the low electrification rate in such countries, which hinders many households from connecting to the electrical grid, other households, despite being connected to the grid, are not able to meet the costs of electricity, and continue to use inefficient traditional fuels.

To increase the electricity access rate, developing countries in Asia, specifically India and the Southeast countries, point out projections of an electrification rate of nearly 100% by 2030. However, the same cannot be projected for the SSA countries, since only 60% of the population is expected to have electricity access by 2030 [5]. In 2019, 578 million people in SSA did not have access to electricity, equivalent to more than half of all unelectrified people globally, with the electrification rate remaining at 48% [2]. Additionally, due to the COVID-19 pandemic, the progress of new connections has decreased, resulting in an increased number of people without electricity access in SSA for the first time since 2013 [5], which could lead to around 530 million people without electricity access by 2030 [7]. From policy scenarios perspectives, many countries on the African continent are developing strategies that, if implemented on time, would allow providing electricity access to more than 20 million people each year until 2030 [8]. However, this rate of progress is only one-third of what would be needed to achieve universal access by 2030.

The Southern African Development Community (SADC) region includes all the countries located in the southernmost region of Africa, with the Democratic Republic of Congo on the northern boundary of the region. In 2017, more than 341 million people were living in SADC, representing around 33% of SSA's total population of 1.02 billion, and with an annual growth rate of 2% [9]. Yet, this population is expected to increase to over 500 million in the next 20 years. To meet all the demands resulting from the increase in population in the coming decades, a strong commitment to industrialization needs to happen, in order to guarantee the economic development of the region. Additionally, energy security is another issue that needs attention from SADC member states, and to achieve it two options have been used: (i) increase the generation capacity and (ii) increase the transmission capacity at the national level and interconnections.

SADC member states have been driving strategies and plans for the expansion of generation capacity, in order to increase the electrification rate at the national level, and also to increase the sustainability of power systems through the exploitation and integration of renewables into the energy mix. Furthermore, SADC has pointed to the interconnection between member states as a way of increasing the availability of electricity throughout the region, creating an energy market, as well as ensuring energy security. However, for most SADC Member States, electricity access remains a key policy problem, with the global average access to electricity being around 54% in 2019 [9].

Hydropower is currently the main renewable energy source in most member states, including Angola, the Democratic Republic of Congo, Lesotho, Malawi, Mozambique, Namibia, and Zambia. Therefore, to accelerate energy access for a higher share of the population, countries like South Africa, Botswana, and Zimbabwe are continuing to exploit mainly non-renewable energy sources, particularly coal. Additionally, SADC needs to face the reduction of GHG emissions to ensure sustainability, and to this end, every effort should be made to guarantee carbon neutrality and a zero-carbon economy. To meet this transition goal, the integration of RES into Generation Expansion Planning (GEP) is essential. SADC member states have assumed the goal of ensuring an increasing penetration of renewables into the national energy mix. The main objectives are to facilitate reduction in dependence on fossil fuels, and to ensure greater sustainability, as well as to explore different sources of electricity generation, mainly to supply rural areas, which are essentially characterized by low electricity consumption and are located far from the main urban centers.

This paper presents a literature review of methodologies, energy plans, and government programs that have been implemented by the SADC member states to address the region's low average electrification rate and its greenhouse gas emission reduction targets. The main objective is to present the most commonly used methodologies that take into consideration the integration of renewable energy sources into power systems both for the main grid and distributed generation systems for rural communities. The remainder of the paper is organized as follows. A description of the Southern African energy situation is presented in Section 2. The literature review of the integration of renewable energy in the generation expansion plan for the region is presented in Section 3. Section 4 presents the planning of power systems within the context of Sub-Saharan Africa. Section 5 presents the discussion, and the main conclusions are highlighted in Section 6.

## 2. Southern African Landscape

The SADC was established in 1992 as a regional economic community made up of sixteen (16) Member States, namely: Angola, Botswana, Comoros, the Democratic Republic of Congo (DRC), Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, and Zimbabwe. In terms of geographic extension, it covers an area of almost 10 million km$^2$ [10]. Figure 1 depicts the geographic distribution of SADC member states. SADC has been committed to regional integration and the eradication of poverty in Southern Africa through economic development, as well as ensuring peace and security [11]. Additionally, as the region industrializes on its way to better development, the energy demand is expected to increase dramatically. Therefore, the electricity sector in the region is a key component in driving regional integration and economic growth, with energy security being increasingly important for continued development across the region [12].

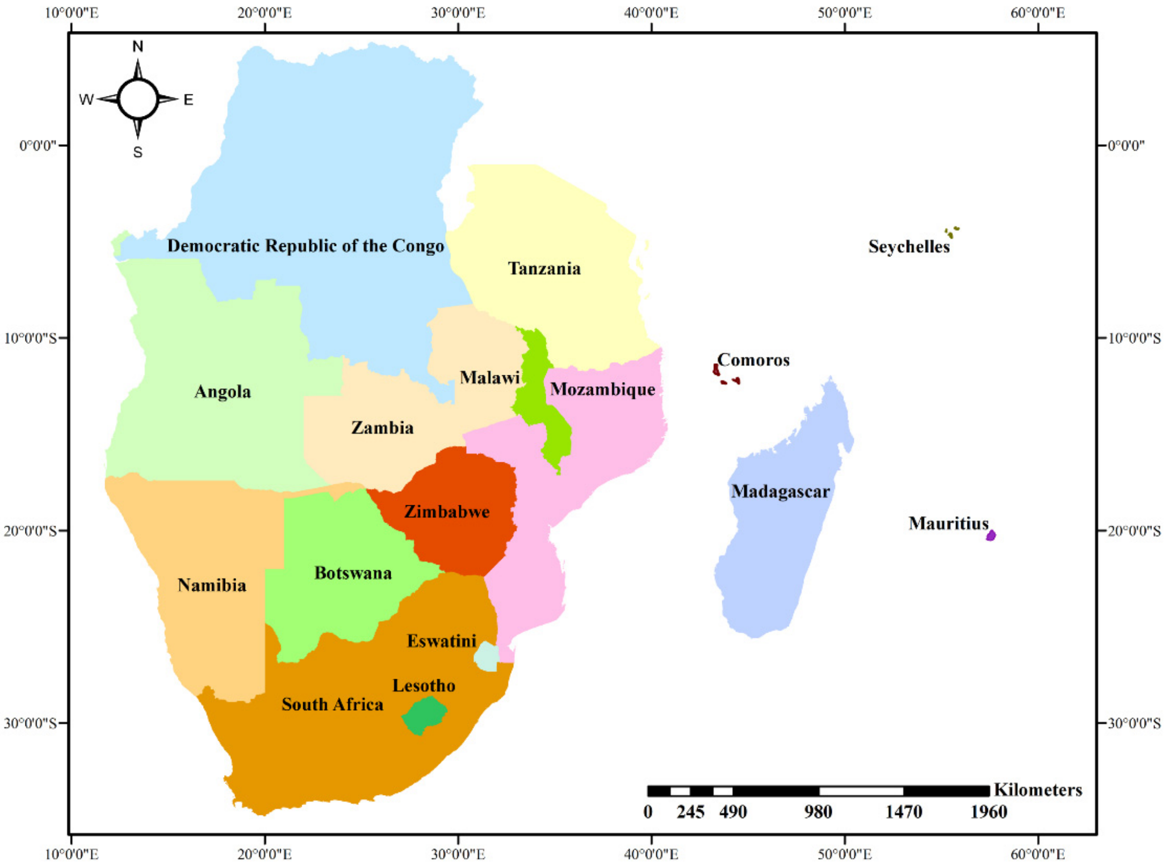


**Figure 1.** Geographic distribution of SADC member states.

However, for most SADC Member States, electricity access remains a key policy problem, with the global average access to electricity being around 54% in 2019, achieving only a slight increase compared to the average of 48% in 2015 [9]. SADC needs to face the low electrification in several member states, since electricity access rates are less than 15% in Malawi and DRC, although some member states, such as Mauritius, Seychelles, South Africa, and Eswatini have electrification rates above 90%, as presented in Figure 2.

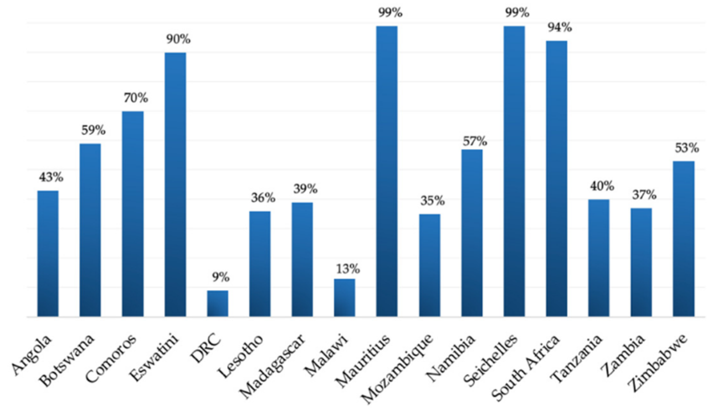


**Figure 2.** SADC electricity access in 2019. Data from [13].

In terms of electricity consumption per capita, the region has numerous inequalities, as Figure 3 presents. Seychelles and South Africa have an electricity consumption of more than 4 MWh/cap, while countries such as Comoros, Madagascar, DRC, Malawi, and Tanzania show very low values of electricity consumption per capita, ranging between 60 kWh/cap, and 150 kWh/cap.

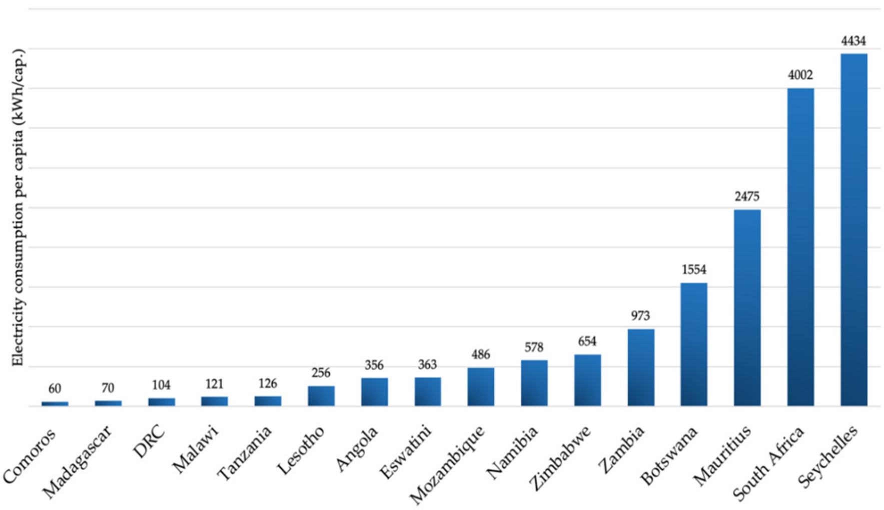


**Figure 3.** Yearly electricity consumption per capita for the SADC countries, 2018. Data from [14].

In 2017, the percentage of the population living in rural areas in SADC member states was 54%, of which only 32% had access to electricity [9]. The low electrification rate and low per capita consumption in many SADC countries, especially in rural areas, should be a strong motivation for member states to increase the adoption of distributed generation systems using mainly renewable energy technologies to improve access to electricity for rural populations and communities in low-income and peri-urban areas. It is important to note, that electricity supply for all, especially in developing countries such as those in SSA, is likely to be achieved through decentralized systems, led by solar photovoltaic (PV) in off-grid and mini-grid systems [15], although grid extension will play an important role, especially in urban and suburban areas.

Some member states, to accelerate energy access for a higher share of the population, are continuing to exploit mainly non-renewable energy sources, particularly coal. This is the case in South Africa, Botswana, and Zimbabwe, which presented a large share of coal in their national generation mix (i.e., 89%, 97%, and 48%, respectively, in 2017) [16]. In the same year, in the overall context of SADC, coal represented more than 62% of the installed capacity [17]. Many countries argue that to deal with heavy electricity consumption by the industrial sector and low electrification rate, renewable energy sources are not enough. As a consequence, several member state institutions continue to support and fund coal projects, leading to an industrialization policy mostly dependent on coal and hydro energy sources.

Renewable energy sources, such as hydro, solar, wind, biomass, ocean, and geothermal energy are abundant in SADC. The region presents a hydropower potential of 40,874 MW, and solar radiation of more than 2500 h per year, implying a generation capacity of 20,000 TWh/year [9]. Wind resources are mainly concentrated in coastal areas, with a potential of about 800 TWh/year. The large potential of biomass, based on agricultural waste, is estimated at 9400 MW and locations, such as the Rift Valley in Tanzania, Malawi, and Mozambique, have significant potential for geothermal energy that can be tapped and is estimated at 4 GW [9]. However, despite having a large domestic renewable energy potential, the share of non-hydro renewable energy sources in the generation mix is still very low in SADC.

Currently, hydropower is the main renewable energy source in most member states, including Angola (63%), the Democratic Republic of Congo (99%), Lesotho (100%), Malawi (90%), Mozambique (82%), Namibia (97%), and Zambia (85%) [18]. Nevertheless, most member states are leading the way in investing in large and small hydropower projects to harness the enormous potential of hydropower [15]. This is because hydropower has traditionally been the cheapest renewable energy source in the SADC region with a life cycle that is very long. However, the current dependence of the power sector of the above-mentioned countries on hydropower may jeopardize the reliability of the power system, especially during drought periods. Indeed, the main drawback is that rainfall patterns in the SADC region are becoming increasingly unpredictable, due to climate change [19].

For SADC member states, rural electrification corresponds to an important issue of the development programs in the region, and, therefore, the option of distributed generation and mini-grids and/or household solar systems and other mini- and micro-scale technologies are being considered as part of their rural electrification plans. This trend has been strongly pushed as national utilities face significant financial constraints that hinder their ability to meet government targets for energy access and grid expansion. SADC has, since 2015, experienced a remarkable maturing of the renewable energy market. This is the result of the vision of some member states to make renewable sources a normal part of generation capacity planning and to implement measures to integrate these technologies into their overall energy supply systems [9].

### 2.1. Regional Power System Integration

To enable economic growth and community development, SADC member states realized that regional integration, cooperation, and coordination, particularly for the power sector, would bring clear benefits [10]. Therefore, the regional electricity trade has become a top priority for the SADC [20]. The disparities in energy resources and consumption, and the low electrification rate among member states, strongly justify power sector integration and promotion of regional energy trade. Since each country exploits its own resources to generate electricity, some are not able to meet their own demand due to the high generation cost, while other nations became self-sufficient using non-sustainable energy resources, as is the case of South Africa. The interconnection of power grids and the exchange of energy contribute to minimizing the total operational costs of supplying the customer due to the optimization of energy resources available in different countries [21]. In addition, other benefits can be highlighted as power utilities support each other in emergencies, thus increasing the reliability of the power system.

In August 1995, at the SADC summit held in Kempton Park, South Africa, the Southern African Power Pool (SAPP) was created in order to promote the exploitation of energy resources, and consequent regional integration [22]. SAPP establishes the cooperation of the various national power utilities in SADC member states, creating an interconnected power transmission network [20], and developing a common electricity market within the region. The objective was to "provide a forum for the development of a world-class, robust, safe, efficient, reliable and stable interconnected electrical system in the Southern African region" [18] and the sharing of operating reserves [23]. Thus, SAPP ensures that there is a cooperation platform for power generation and supply solutions throughout the coordinated planning and operation of the regional power system, which consists of international generators and interconnectors [24].

Currently, only twelve (12) national power utilities are part of SAPP, namely RNT from Angola, BPC from Botswana, SNEL from DR of Congo, LEC from Lesotho, ESCOM from Malawi, EDM from Mozambique, NAMPOWER from Namibia, ESKOM from South Africa, TANESCO from Tanzania, ZESCO from Zambia, and ZESA from Zimbabwe. However, Angola, Tanzania, and Malawi are not yet interconnected to the SAPP grid. Figure 4 presents the SAPP interconnected power grid map, as well as ongoing projects, specifically the interconnection of Angola with Namibia and the DRC, and the interconnection of Tanzania and Zambia, as well as the interconnection of Malawi and Mozambique.

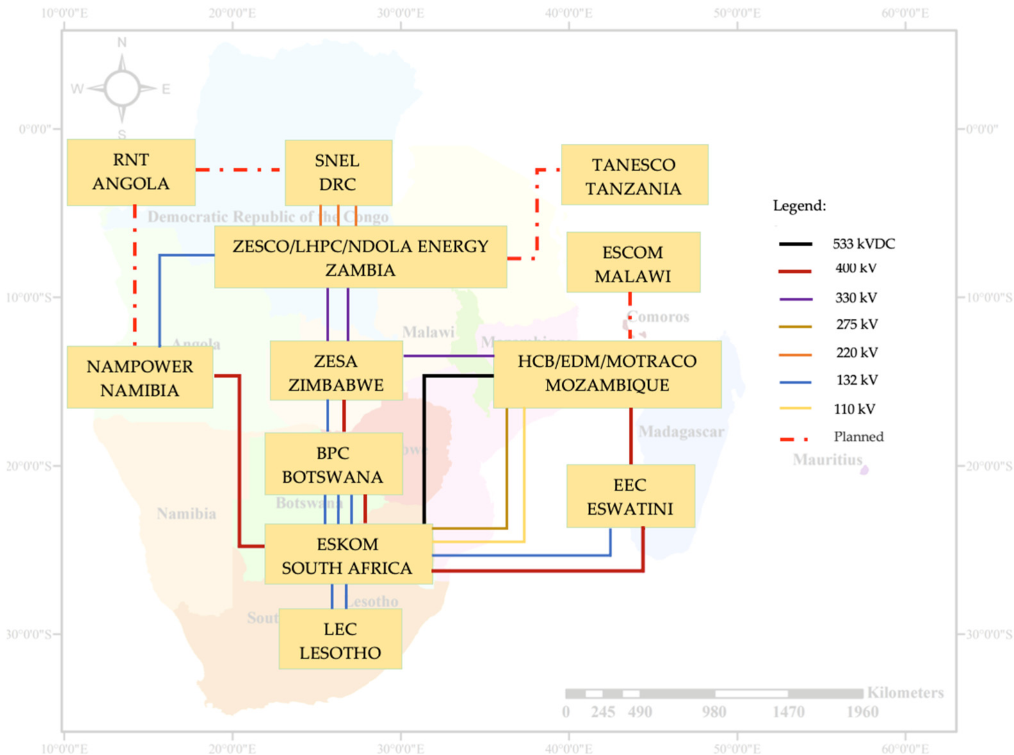


**Figure 4.** SAPP interconnected power grid map by countries in 2020/2021. Data from [18].

## 2.2. Southern African Power Pool Energy Overview

The total SAPP installed generation capacity in 2021 was 80923 MW [18], with an increase of 24923 MW in the last 10 years [25], which represented an annual increase of 4.4%. However, the SAPP is dominated by the state-owned utility of South Africa, Eskom, with 75% of all of SAPP's installed power capacity. South Africa is, by far, the greatest exporter of electricity of SAPP [25], with 4169 GWh (69.1%) of all net exports in the period 2020/2021, followed by Zambia with 1223 GWh (20.2%), Zimbabwe with 355 GWh (5.8%) and Mozambique with 280 GWh (4.6%), while Namibia imported 1756 GWh to meet the domestic demand [18].

Whereas most countries rely on hydro resources, thermal power, specifically coal, is ESKOM's main source of energy supply. Coal still represents the greatest part of the SAPP generation mix with 59%, followed by hydropower with 24%, crude oil derivatives (like diesel fuels and fuel oils), solar PV with 4%, and nuclear and wind power with 3%, while the share of biomass is practically insignificant. Figure 5 presents the share of the installed capacity mix by generation technology in all 12 SAPP member states.

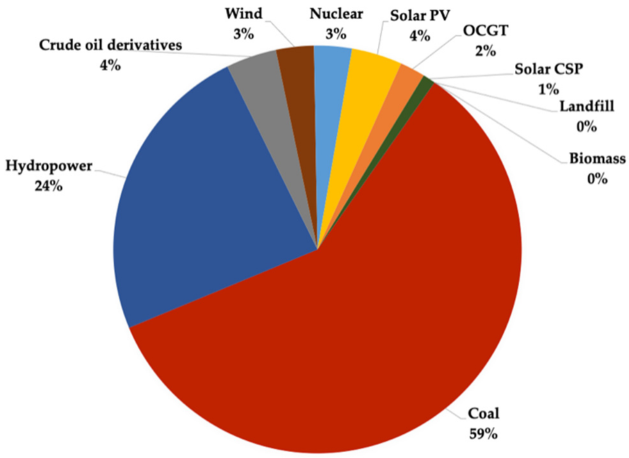


**Figure 5.** Share of SAPP installed generation mix (2021). Data from [18].

For the reference year, SAPP had an operating capacity of 65 GW against a peak demand of 55 GW and total energy consumption of 313 TWh [18]. Four (4) member states showed capacity surplus, namely Angola, DRC, Mozambique, and South Africa, representing respectively 21.9%, 10.6%, 4.03%, and 79.88% of the total capacity, while others, due to capacity shortfall, relied on imports to satisfy their growing demand [26]. Therefore, as Angola is not yet interconnected to the SAPP grid, this resulted in 2190 MW not being accessed by other members. Table 1 presents an overall energy statistic for 2021 to SAPP member states. It is important to note that, although the installed capacity of SAPP is 81 GW, only the operating capacity is considered.

**Table 1.** Southern African Power Pool energy statistics (2021). Data from [18].

| Country | Utility | Installed Capacity (MW) | Operating Capacity (MW) | Peak Demand (MW) | Generation(GWh) | Imports (GWh) | Exports (GWh) | Domestic Demand (GWh) |
|---|---|---|---|---|---|---|---|---|
| Angola | RNT | 5878 | 4877 | 2687 | 9507 | 0.00 | 0.00 | 9507 |
| Botswana | BPC | 892 | 322 | 675 | 4203 | 312 | 0.00 | 4515 |
| DRC | SNEL | 2880 | 2770 | 1705 | 8639 | 0.00 | 0.00 | 8639 |
| Eswatini | EEC | 71 | 65 | 259 | 197 | 841 | 0.00 | 1038 |
| Lesotho | LEC | 74 | 70 | 173 | 332 | 294 | 0.73 | 625.3 |
| Malawi | ESCOM | 506 | 330 | 380 | 2053 | 0.00 | 0.00 | 2053 |
| Mozambique | EDM | 2796 | 2642 | 2240 | 16,636 | 68.2 | 280 | 16,424 |
| Namibia | NamPower | 624 | 389.5 | 695 | 2672 | 1756 | 0.00 | 4428 |
| South Africa | ESKOM | 60,326 | 48,215 | 40,256 | 233,503 | 2.94 | 4169 | 229,337 |
| Tanzania | TANESCO | 1565 | 1382 | 1382 | 6934 | 0.00 | 0.00 | 6934 |
| Zambia | ZESCO | 2891 | 2736 | 2887 | 14,654 | 656.6 | 1223 | 14,087 |
| Zimbabwe | ZESA | 2412 | 1400 | 1896 | 8513 | 1178 | 355 | 9336 |
| SAPP | | 80,923 | 65,198 | 55,235 | 307,843 | 5109 | 6028 | 306,923 |
| Total Interconnected | | 72,966 | 58,609 | 50,786 | 289,349 | 5109 | 6028 | 288,429 |

In 2020, 2781 MW of new generation capacity was commissioned from projects by both national utilities and Independent Power Producers (IPPs). IPPs contributed 90 MW, equivalent to 3% of new generation capacity [18]. Table 2 presents the projects commissioned by type of generation source, with a predominance of coal, representing 56%, followed by gas projects in Angola, Botswana, and Tanzania, representing 22%.

**Table 2.** Generation projects commissioned in the region in 2020. Data from [18].

| Utility | Country | Name | Type | Capacity (MW) |
|---|---|---|---|---|
| RNT | Angola | Lauca | Hydro | 65 |
| RNT | Angola | Soyo | Gas | 375 |
| BPC | Botswana | Mini-grids | Solar PV | 10 |
| BPC | Botswana | Morupule A | Coal | 100 |
| SNEL | DRC | Busanga | Hydro | 240 |
| SNEL | DRC | Nzilo | Hydro | 120 |
| IPP | Malawi | IPP Gas | Gas | 60 |
| IPP | Mozambique | Metoro | Solar PV | 40 |
| NamPower | Namibia | Solar | Solar PV | 37 |
| ESKOM | South Africa | Kusile | Coal | 723 |
| ESKOM | South Africa | Medupi | Coal | 723 |
| TANESCO | Tanzania | Kinyerezi II | Gas | 185 |
| ZESCO | Zambia | Lusiwasi Upper | Hydro | 86 |
| ZESCO | Zambia | Chishimba | Hydro | 15 |
| LHPC | Zambia | LHPC | Hydro | 12 |
| SAPP | | | | 2781 |

SAPP is committed to the global objective of reducing its carbon footprint by investing more in renewable energy generation [18]. However, as presented in Figure 6, coal-fired power plants still ensure the majority of new generation capacity. This is mainly because South Africa continues to invest in coal-fired power plants, making this transition an increasing challenge, as it represents the country with the highest percentage of energy generation, consumption, and exports. On the other hand, the share of new non-hydro renewable energy is insignificant, with only 3% of Solar PV.

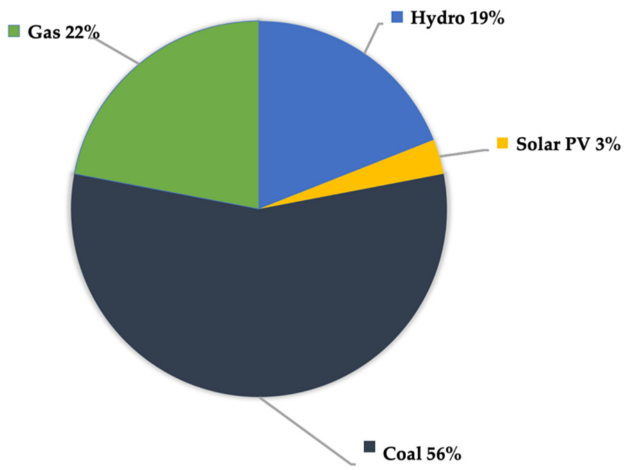


**Figure 6.** New generation capacity projects in 2020. Data from [18].

Continued use of, and dependency on, the use of fossil fuels will not address energy poverty in the SADC region [27]. On the contrary, it is expected to have an increasingly negative impact on human health, fauna, and flora, due to the increase in GHG emissions. In order to meet current and future energy demand, it is necessary to consider a more holistic approach, aiming at the strategic development of climate-resilient infrastructure, so that the potential of renewable energy is taken advantage of, promoting energy efficiency [18].

Although the region represents a small percentage of global GHG emissions, electricity generation by coal thermal power plants poses a high health risk and increases the emissions in the region [1]. Table 3 presents the overall $CO_2$ emission for SAPP member states, including all energy sectors, and it is possible to observe the impact of the emissions from South Africa, which is considered one of the largest GHG emitters, ranking 13th in the world in 2020 [28]. Angola represents the second most polluting country, although it has a generation mix composed of 63% hydropower.

**Table 3.** $CO_2$ emissions in the SAPP member states in 2020. Data from [28].

| Country | $CO_2$ Emissions (MT/Year) | $CO_2$ Emissions Per Capita (T/Year) |
|---|---|---|
| Angola | 22.51 | 0.69 |
| Botswana | 7.05 | 2.92 |
| DRC | 3.23 | 0.04 |
| Eswatini | 1.46 | 1.02 |
| Lesotho | 0.65 | 0.28 |
| Malawi | 1.38 | 0.07 |
| Mozambique | 9.94 | 0.31 |
| Namibia | 4.01 | 1.49 |
| South Africa | 435.13 | 7.41 |
| Tanzania | 1.46 | 0.18 |
| Zambia | 7.5 | 0.4 |
| Zimbabwe | 11.56 | 0.65 |
| SAPP | 476.32 | 15.46 |

The reduction of GHG emissions is fundamental to ensuring sustainability, and to this end, every effort should be made to guarantee carbon neutrality [29]. To meet the objective of the Paris Agreement of keeping global warming well below 2 °C, this needs to happen shortly after the mid-century [29] and many countries around the world have committed to reducing the amount of GHG emissions [30]. Since the carbon pathway of a country's power system has a strong impact on the country's ability to meet deep emission reduction targets [31], it is important to increase the amount of RES in the energy system and shift power generation to renewable technologies to directly avoid GHG emissions [29,30,32,33]. Moreover, this can contribute to the sustainable development of the economy, providing environmental, social, and economic benefits enabling considerable improvement of public health, and leading to a sustainable society [31,34].

SADC, to promote the development and integration of RES in the power systems of the member states, as well as to reduce the region's carbon footprint, defined the Renewable Energy and Energy Efficiency Strategy and Action Plan (REEESAP) for the horizon 2016–2030 [19]. This is, in practice, a long-term vision for the achievement of clean, sustainable, sufficient, reliable, modern and affordable energy by intensifying the exploitation of clean and sustainable energy sources and the application of energy efficiency in energy systems. REEESAP is a regional framework that aims to support member states in developing their national strategies for implementing renewable energies, energy efficiency, and action plans, in order to accelerate the energy transition in the region.

To meet the targets of REEESAP, SADC established, in 2015, the Center for Renewable Energy and Energy Efficiency (SACREEE) to work with member states and related institutions in the energy sector at the national level. This aims to contribute to increased access to modern energy services and improved energy security across the region by promoting energy markets with RES and energy efficiency technologies and services. Herewith, it is intended to guarantee that member states, during the planning process of new generation plants, take into consideration the integration of RES into their power systems.

## 3. Renewable Sources in Generation Expansion Planning

The transition to a low- or zero-carbon economy is strongly related to the integration of RES into GEP [29]. GEP is a process that aims to reach an optimal generation mix, by determining the time, location, size, and type of different candidate generating facilities/sources to meet the future load demand, guaranteeing that the power system stays reliable [35,36], within a security requirement over a planning horizon of typically 10–30 years [37]. This is one of the most discussed topics within academia and among decision-makers and plays a critical role in the power sector and sustainable energy development [31,35,38].

GEP initially tackled the needs of centralized power systems, with vertically integrated state-owned electric utilities having a monopoly in the generation, transmission, distribution, and retail sectors. Traditionally, it aimed at minimizing costs, whether of installation, operation, or maintenance, becoming a mono-objective problem. However, the liberalization of electricity markets, as well as technological developments, have led to a rapid transformation of power systems and electricity markets [38]. In addition, with the increase of climate change concerns, aiming to reduce GHG emissions from the power sector, the integration of RES into power systems has been considered, due not only to the growing environmental concerns, but also due to economic reasons, given the quick reduction of the levelized cost of energy (LCOE) of some renewable technologies, like wind and solar photovoltaic power [31,39,40]. This turns the GEP into a multi-objective problem with several aspects to be evaluated, for instance, economic, technical, and environmental issues.

The literature presents several models that have been used to determine the GEP. These are identified as Mixed-Integer Nonlinear Programming (MINLP) [37,41], Mixed Integer Linear Programming (MILP) [42–45], Multi-Objective Linear Programming (MO-LP) [46–48] and Multi-Objective Mixed Integer Linear Programming (MO-MILP) [34–37]. Studies by [47] and [48] present MO-LP, while [49] presents MO-MILP. Both formulations were used to assess renewable energy penetration into GEP. However, the integration of RES presents challenges to be overcome, since most of these sources rely on external weather conditions (hydropower, wind, and solar photovoltaics), being designated as Intermittency Renewable Energies Sources (IRES). Such intermittency represents the main limitation for integration into the electrical grid in many countries [40,50–53], since such generation fluctuates in time and space following its driving climate variables, mostly precipitation, wind speed, solar radiation, and temperature. Therefore, IRES does not offer the same services as conventional generators and, as a consequence, high IRES penetration levels in the energy sector, if not carefully anticipated, could hinder power system management, and strongly increase the power supply costs [32]. Additionally, there are concerns about the capacity of some grids to cope with IRES [33], and some utilities and grid operators often argue that today's power systems cannot accommodate significant variable wind and solar supplies [40], without affecting supply reliability and power quality [54].

In addition to its variability characteristics, it is also difficult to control, or easily adjust, the power generation output, mainly for wind and solar photovoltaics, making these highly non-dispatchable sources of energy and causing operational uncertainty, due to the mismatch between demand and generation [34,35,53,55]. As RES penetration has increased rapidly in recent years, power system flexibility, ramping capability, and sufficient reserves are urgently required to deal with the inherent intermittency and uncertainty of RES [29,35]. In a scenario where intermittent renewables are widely deployed, the power system must have adequate means to compensate for the effects of variability and unpredictability in the availability of wind and solar power [54]. This is necessary to plan for a long-term, sustainable, future power generation system, especially for developing countries, since access to electricity has not yet reached the entire population [56].

Some approaches, technologies, and strategies to compensate for the effects caused by the variability and unpredictability of IRES on a large scale can be found, namely in [57,58], such as the following: operating reserve, interconnection with other grids, complementarity between renewable sources, demand-side management (DSM), energy storage (i.e., batteries, hydrogen, flywheels, pumped hydro storage, electricity-to-thermal, power-to-gas and vehicle-to-grid), supply-side flexibility, and infrastructure (i.e., supergrids, smart grids, microgrids and smoothing effects of spatial power distribution).

### *3.1. Complementarity between Renewable Energy Sources*

Although the IRES technologies are already implemented in most power systems (with different levels of penetration), traditionally, the compensation of the effects caused by intermittency and uncertainty has been mainly ensured through hydropower reservoirs in countries with high potential for hydropower [59]. Over the decades, hydropower has been the major contributor to renewable energy and the cheapest option for renewable power generation [59,60], currently representing more than 50% of all renewable electricity worldwide [61]. However, most of the locations with the highest potential around the world are being explored [62], and the construction of large hydropower plants is a slow process with relevant environmental and social impacts. Therefore, due to the increase in environmental restrictions, there has been a reduction in the construction of hydropower projects [47].

Additionally, the use of hydropower is conditioned by the geographical topology, as well as by climatic factors, since the annual rainfall cycle forces the system to store water during the wet period to be used in the dry season, to guarantee stability in the generation of energy [59,62]. Extreme climatic events, due to climate change, such as droughts, are more likely to occur in the coming years and will be responsible for reducing the flow of rivers, compromising more than half of hydropower generation, and decreasing the reliability of the energy systems based on hydropower [47,57]. This loss of output, due to the drying climate, could shift generation to fossil fuels, making it more difficult for developing countries like southern African countries to meet their climate change mitigation commitments under the Paris Agreement to the United Nations Framework Convention on Climate Change (UNFCCC) [12].

The focus on wind and photovoltaic solar power has been followed by many countries, leading to recent RES additions [63]. However, the increasing participation of IRES requires greater flexibility in the power system, which will not be achieved with the use of hydropower only [57,64]. Therefore, it is essential to take advantage of the complementarity between different options of RES and the integration of dispatchable technologies, such as biomass and geothermal. Complementarity is defined as the ability of a spatial–temporal distributed mix of generation resources to enable better electricity supply conditions, reducing operational challenges and the need to add enabling technologies, due to improved matching of outputs to demand profiles [65]. This concept is also defined in [66] as the ability of two or more energy sources to work together, complementing generation, and improving energy performance.

Complementarity is one effective way to reduce the energy storage requirements in hydropower reservoirs [40], as well as to guarantee power-system flexibility [67], increasing the balance between energy generation and demand [40], and smoothing the effect of the variable renewable resource output [65,68,69]. By evaluating the complementarity between multiple RES and determining the best combination of RES, the impact of the variability from each RES can be mitigated [70]. Since different power supply technologies have different operational characteristics that could complement each other, the deployment of renewable technologies cannot be planned in isolation from the rest of the power system, but rather needs to be looked at from the perspective of their integration into the system [60]. By combining generation systems with minimum and maximum power at different periods, the variability of power generation is reduced [71]. There is potential for energy sources to complement each other on a temporal, spatial, or spatio–temporal scale, thereby ensuring supply reliability and minimizing fluctuations or shortages in power output. This improves the efficiency and reliability of the energy supply and reduces the need for energy storage [72].

Complementarity is commonly expressed in terms of a correlation coefficient [73], Pearson's correlation coefficient being the most widely used and accepted method to investigate and quantify the degree of correlation between pairs of RES variables [71–75]. The Person's correlation coefficient measures the association strength between two specific energy generation options, with values ranging from $-1$ to +1 [71,75,76]. A negative value implies anti-correlation between variables, meaning that when the value of one increases the other decreases, and vice-versa. This characteristic is the most important characteristic when it comes to complementarity. On the other hand, a positive value implies a correlation between variables and a zero value implies that no association exists between the two variables. The literature presents several studies where the complementarity between RES was applied. Many of these studies are related to assessing the complementarity between solar and wind energy [34,65–67,69], solar and run-of-the-river energy [40], hydropower and offshore wind power [59], solar, wind and tidal [77], and wind, solar and hydropower [69,70,73–75]. There are also assessments of complementarity between regions, for instance in Brazil [57], Colombia [74] and Latin America [75].

### *3.2. Feasibility of 100% Renewable Power Systems*

A methodology is presented in [59] to introduce the complementarity between RES into the GEP to ensure the demand in 2050 is met with 100% RES addressing the possibility of complementing the hydro system with offshore wind power in the Brazilian case. An objective function is proposed to optimize the solar, wind, biomass, and hydropower mix, without loss-of-load or curtailment of intermittent technology, and optimize the water flow of hydropower reservoirs, considering daily and yearly variations.

A multi-objective method for optimizing the renewable energy mix by maximizing the contribution of renewable energy to the peak load and minimizing the combined intermittence at the minimum cost is proposed in [54]. This model was applied in the Portuguese context to optimize the complementarity between renewable energy sources, instead of only using one renewable energy source. The greatest load-loss concern associated with the large-scale integration of wind, water, and solar energy (WWS), due to its variability and uncertainty, is addressed. A new grid integration model was used in [39] to find low-cost, no-load-loss, nonunique solutions to the problem of electrification of all energy sectors in the United States, considering also pumped hydropower, hydrogen, and demand response, and without considering fossil fuels. As a result, from 2050 to 2055, the social cost of a reliable 100% WWS system should be much lower than the cost associated with the use of fossil fuels.

The question of the complementarity between hydropower based on run-of-the-river generation of small rivers (with less than 1000 km$^2$) and solar energy for a scenario of 100% renewable energy supply was considered in a region of Northern Italy in [40]. The potential value of complementarities of wind–solar resources to California's power grid was assessed in [34]. The study was performed using one-year hourly demand data, together with the hourly-simulated output of various solar and wind technologies distributed throughout the state.

With support policy, Ukraine could reach a 100% renewable power system by 2050, according to [64], deploying solar, wind, water, biomass, and geothermal resources. A long-term planning model dedicated to the French power system was used by [32] to explore different levels of RES penetration, adding new technologies (ocean energy, energy storage, new interconnections, and demand-response). An hourly simulation of future electricity generation based on wind, solar and tidal data, to assess the feasibility of a 100% renewable energy system in Japan, was conducted in [30], to ensure that electricity demand in the year 2030 can be met.

The high-resolution energy system model REMix was applied in Brazil in [33] so as to analyze the least-cost composition and operation of a fully renewable power supply system. The results revealed that the expansion of wind and solar power was more cost-efficient than the construction of additional hydropower plants and indicated that a completely renewable power system in Brazil would not lead to a significant increase in costs, despite the additional transmission and generation capacity. For the same country, [47] presented a multi-objective model for GEP with a high share of RES, promoting the use of non-hydro RES. The results showed that, to meet the government's goals and the peak demand, solar power was the main non-hydro renewable source to ensure expansion, since its daily curve coincided with the peak load period. To ensure 100% RES scenarios in the Brazil context, a non-linear multi-objective problem for power generation expansion planning was proposed, that maximizes complementarity and minimizes total expansion costs, with battery storage integration, complementarity between sources and regions, DSM, hydropower storage requirements and spatial technology distribution with hourly resolution [78]. The methodology was able to guarantee that three consecutive years of extreme drought in 2050 could be encountered without the need for new large reservoirs.

A multi-objective framework for finding optimal storage and a renewable generation mix for the Chilean power system for the year 2050 was developed, considering three optimization criteria for a 100% renewable power supply, specifically: minimizing investment and operational costs of the power system, environmentally friendly operation of hydropower reservoirs, and minimizing additional transmission systems [29]. A feasible transition strategy is presented to achieve 100% renewable energy considering all German energy sectors in [79]. Such a study demonstrated that it is possible to transition the German energy system to a 100% renewable energy supply within sustainable domestic renewable resources, and simultaneously keep costs at an acceptable level, similar to the energy system costs of a 2050 reference system. Seven scenarios were modeled in [80] for a 100% renewable European power system in 2050 that could operate with the same level of system adequacy as the current power system, even when relying only on domestic European sources in the most challenging weather.

### *3.3. Power Management Strategies for Systems with Renewable Energy Sources Penetration*

The penetration of RES is an increasingly growing topic, but due to the intermittent behavior of the main renewable sources, namely hydro, solar, and wind power, whether off-grid or on-grid, power systems need to face especial requirements. Therefore, in cases of high penetration of these sources, management strategies must be adopted in order to deal with the deficits and surpluses of generated power. In the literature, some strategies have been pointed out to minimize the impacts of RES penetration into power systems.

For instance, an energy management strategy in a hybrid wind/solar/fuel cell plant is proposed, using a self-made simulation tool developed in MATLAB/Simulink, in [81]. The objective was to improve some very simplified models that are used by HOMER to avoid unfair results and erroneous conclusions. In other work, a two-stage energy management strategy was developed for networked microgrids under the presence of highly renewable resources [82]. The proposed method, according to the presented results, could identify optimal scaling results, reduce operational costs of risk aversion, and mitigate the impact of uncertainties. A day-ahead optimal energy management strategy for the economic operation of industrial microgrids with high-penetration renewables under both isolated and grid-connected operation modes was also proposed in [83]. Such an approach is based on a regrouping particle swarm optimization, formulated over a day-ahead scheduling horizon with one hour time steps, and considering forecasted renewable energy generations and electrical load demands.

The advantages and disadvantages of three main strategies were also assessed [84], which included storing the surplus generation by electrical storage, converting it to hydrogen, or injecting it into the main grid. A new Real-Time Hierarchical Congestion Management technique was also proposed that reschedules generators in two stages, based on the Available Congestion Clearing Time of the transmission lines in the presence of renewable energy sources [85]. Chaotic Darwinian Particle Swarm Optimization was also used for determining the optimal schedules of demand response loads and rescheduling conventional generators to mitigate congestion. The solar and wind energy sources were modeled using Rayleigh and Beta probability density functions.

A novel demand response integrated day-ahead energy management framework subjected to remote off-grid power systems is presented in [86]. The results demonstrated that for an isolated remote community in Northern Canada, for both summer and winter seasons, it was possible to achieve the intended objectives of day-ahead energy management. A different work, [87], proposed a management system for a future household equipped with controllable electric loads and an electric vehicle equipped with a PV–Wind–Battery hybrid renewable system connected to the national grid. The proposed management system was based on a linear programming model with non-linear constraints solved with MATLAB toolboxes. The simulation was based on a database of meteorological conditions resulting from TRNSYS and processed to achieve a frequency of one hour.

Uncertain behaviors are also considered in several studies. For instance, a novel reinforcement learning approach to the management of a microgrid incorporating the uncertain behavior of electric vehicles and renewable energy sources was developed in [88]. In order to predict the output power of the renewable energy sources of wind units and solar panels, the proposed approach used a Q-learning technique, which enhanced the prediction of conventional models, such as neural networks. A new management methodology to find the optimum operation of a grid-connected microgrid, which was modeled as an optimization approach and aimed to minimize total cost was presented in [89]. The uncertainties in renewable energy-based distributed generation units, including wind turbines and PV panels, were also considered in this study. The simulation results demonstrated that the proposed methodology could supply all required electricity and simultaneously optimize power transactions between the microgrid and the main grid.

## 4. Power Systems Planning in the Sub-Saharan Context

### *4.1. Generation Expansion Planning*

In the literature, several studies have already addressed the issue of GEP. Some have models to optimize energy generation, using energy storage, both through batteries and hydro reservoirs. Other studies consider a power system 100% based on RES, through resource optimization, and applying complementarity between the RES and regions. However, such models are focused on countries with a high electrification rate and are not suitable for most developing countries, where electrification rate remains very low and there is limited electrical infrastructure. For most developing countries, these models need to be adapted, as access to electricity is still a challenge, mainly in rural communities, being directly related to poverty levels. The adoption of long-term GEP in developing countries changes the problem in many fundamental ways compared to traditional formulations.

The following three crucial aspects that characterize the problems of long-term energy planning in developing countries have not been addressed in the actual GEP literature [7]: (1) the presence of substantial planned suppressed demand due to insufficient initial power infrastructure, as evidenced by electrification rates below 100%; (2) the challenge of dealing with highly unequal access to electricity on a sub-national level; (3) the importance of integrating on-grid and off-grid electrification options into an expansion planning optimization model. Off-grid solutions have been found to be cheap electrification alternatives in many developing countries and, thus, need to be part of an integrated planning approach [79].

Access to clean and reliable electricity services is a prerequisite for sustainable development and an important factor to promote, among other things, economic activities, poverty reduction, health, education, and gender equality [90,91]. Electricity plays an important role in modern society, and the lack of this resource has become a major barrier to the development of most SSA countries. In order to deal with the problem of the low electrification rate in SSA countries, [7] presents a long-term, spatially explicit MO-MILP energy planning model to expand the long-term GEP suitable for developing countries with limited initial electricity infrastructure. The model was applied to the case of the Ugandan national power system and the achieved results showed that, in contrast to the government's focus on grid extension, which would imply sub-national electrification inequality, widespread electrification equality could be cost-optimal if off-grid options were considered. Therefore, although the study considered the integration of decentralized solutions for rural electrification, the large-scale integration of renewable into power systems and strategies, such as complementarity between renewable energy sources, was not addressed.

The Open Source Spatial Electrification Tool (OnSSET) was applied to two ECOWAS countries, Burkina Faso, and Côte d'Ivoire [92], to determine the optimal combination of grid-connected and off-grid systems to serve rural and urban demand by 2030, using high-resolution data by geospatial information systems (GIS), highlighting the fundamental role of off-grid solar photovoltaics and wind technologies in bridging the electricity access gap, particularly in Burkina Faso. Least-cost electrification strategies were provided on a country-by-country basis for SSA using a GIS, i.e., datasets derived from satellite imagery and from a plethora of existing maps to fill data gaps coupled with OnSSET in [90]. In both studies, the electrification options included grid expansion, micro-grids, and stand-alone systems in rural, suburban, and urban contexts across the economy, becoming a powerful tool to design effective electrification strategies in developing countries. The results showed that, in the case of low electricity demand (rural areas), there is a strong penetration of stand-alone technologies, while in areas with higher demand the cheap electrification options shift from stand-alone systems to micro- and mini-grids, as well as to grid extensions.

Likewise, with the objective to find the least-cost electricity solutions for SSA, the area was subdivided into 16 sub-regions, hourly resolved, and based on 100% RES in [91]. A detailed least-cost optimization model was developed to estimate the additional cost of power generation and provide grid access for households that currently do not have electricity and to inform decision-makers and other stakeholders of the true costs of providing electricity in SSA in [3]. A geo-referenced LCOE model was used in [93] to reach 100% electricity access in Burkina Faso to provide power to more people quickly by mini-grids, instead of the national policy for electrification through grid extension and the government subsidizing fossil fuel electricity production.

The indicative power plant investment plan was assessed in [94] regarding forty-seven African countries, based on the power transaction potential. Using OSeMOSYS (a cost optimization tool for long-term energy planning) a cost-effective system configuration was developed. A comparison of the scenario before 2040 with the establishment of the TEMBA (Electrical Model Bank of Africa) business relationship shows that an improved grid could change the power generation mix in Africa and reduce the cost of power generation. The possibility of using hybrid systems was investigated in Nigeria [95], considering PV/Diesel with or without batteries. The results showed that the LCOE value for PV/Diesel was lower than for a diesel-only system. The same approach was applied in Burkina Faso, [96], to ensure electricity access to rural areas. Renewable off-grid systems, mainly using solar photovoltaic generation (solar systems for private households and small grids), could provide technically feasible and economical solutions to the energy problem, mainly when the cost of expanding the grid is not profitable [91].

In order to study the long-term planning of power generation capacity in developing countries, a new multi-period stochastic optimization model was proposed and used in Ghana [97]. The results showed that for most rural areas, single-grid and micro-grid are the cheapest options and could be used as a temporary solution until the extension of the power grid. A multi-step integer linear programming method was proposed for South-Eastern Nigeria in [98], to design a renewable energy network based on hybrid solar and wind power plants that would take advantage of energy resource availability and demographical conditions.

It can be concluded from the literature that, to improve electricity access over SSA, it is essential to consider off-grid solutions based on RES. The traditional method of electrifying SSA by expanding the grid has not contributed to the eradication of energy poverty in rural areas. To do so, the selection of technologies for rural electrification must consider socio-economic feasibility, geographical potential, and compatibility of renewable technology options. In addition, spatial analysis and feasibility studies help determine the most cost-effective electrification options for remote areas. Renewable energy, especially solar photovoltaic energy, can be used to improve services, due to its decentralization, playing an important role in promoting rural electrification [91].

### *4.2. Renewable Energies in SADC Power Systems*

Over SADC member states, studies have been conducted to enhance the exploitation of RES and their integration into the power system. Table 4 presents a compilation of some studies found in the literature, which consider the application of RES, either through grid integration or through off-grid systems. From the literature, several methodologies have been applied, such as minimization of LCOE, Weather Research and Forecasting model (WRF), Political, Economic, Social, Technological, Legal and Environmental criteria (PESTLE), as well as software like Hybrid Optimization Model for multiple energy resources (HOMER), Long-range Energy Alternative and Planning System (LEAP), EnergyPLAN, GIS, ArcGIS, etc. Yet, some studies conducted research based on government documents. SADC member states have an enormous potential for RES in its various sources and the results of the studies demonstrate that their proper exploitation could, in the long term, increase the electrification rates in rural areas, reduce $CO_2$ emissions and, consequently, reduce dependence on imports by some countries to meet growing demand.

**Table 4.** Renewables energies overview in SADC member states.

| Country | Reference | Method | Work Description and Main Findings |
|---|---|---|---|
| Angola | [99] | HOMER software | The authors evaluated the renewable solar and wind potential for power generation, proposing the implementation of an autonomous solar and wind system to electrify rural areas. The results revealed a reliable method for increasing access to electricity. |
| | [100] | LEAP software | Presented four scenarios to horizon 2020–2040 in order to guarantee energy mix diversification, and minimization of GHG and costs (considering electricity generation and carbon costs). The conclusions indicated a considerable reduction in generation by diesel in 2040. |
| Botswana | [101] | LEAP software | Five scenarios were designed to examine plausible pathways and to find the cost-optimal energy mix for the power sector in the horizon of 2015–2030. The results identified solar PV as the most viable option to replace a considerable share of coal in the future energy mix. |
| Comoros | [102] | HOMER software | Designed a hybrid system using diesel generators and PV systems to improve rural electrification. The results were satisfactory in terms of cost, reliability of the system and reduction of GHG emissions. |
| | [103] | HOMER software | A hybrid microgrid, using PV panels, a wind turbine, an electrolyzer, a fuel cell, and a storage tank for hydrogen, was presented. The results showed that the micro-grid PV-wind-H2 was an appropriate solution for autonomous applications. |
| Eswatini | [104] | Daily weather measurements | Conducted a study to investigate the potential of renewable energies, specifically solar PV, wind and hydro. The results showed that solar power could be utilized, in conjunction with hydropower, to mitigate the crisis of importing most of the power supply in the country of Eswatini. |
| Lesotho | [105] | PLEXOS software | Produced an integrated electricity expansion plan for Lesotho to determine the generation capacity mix on the horizon of 2015–2050 with a focus on the security of supply at the national level. As a result, large hydro and solar PV represented the least cost options to integrate the mix, while pumped hydro would be used to meet peak demand. |
| | [106] | WRF | Applied Weather Research and Forecasting (WRF) to provide an estimation of the photovoltaic and wind energy potential for Lesotho and assessed the complementarity of these resources. The results provided a picture of the potential of wind and PV electricity generation over Lesotho to 2015 as a reference year. |
| | [107] | WebGIS software | A hydrological map, a wind atlas and a solar radiation map were produced in this study in order to assist the Government in the planning and development of renewable energy exploitation. The results of the project confirmed the high potential of Lesotho in terms of RES. |

**Table 4.** *Cont.*

| Country | Reference | Method | Work Description and Main Findings |
|---|---|---|---|
| Madagascar | [108] | Energy sector review | Presented a detailed overview of the energy sector situation in the whole country, highlighting the high potential of RES on the territory. Hydropower, wind and solar energies appeared as the main RES that could strongly and widely ensure power generation in the country for the future. |
| | [109] | Energy sector review | A review of the biomass potential was presented to support energy demand in Madagascar to about 80% of the total energy supply. |
| Malawi | [110] | Literature review and Government reports | The study assessed the generation potential of small-scale hydropower systems for decentralized generation systems, which, if fully exploited, could contribute to the country's electricity and power supply, especially for rural electrification. |
| | [111] | PESTLE | Using the PESTLE framework, it presented an overview of the Malawi energy situation and the potential of renewable energy resources, including solar, wind, biomass, hydro and geothermal. The results showed that solar, biomass and hydropower were the most certain renewable energy resources that could contribute significantly to the energy supply of the country. |
| Mauritius | [112] | LCOE | Using the minimization of LCOE to prioritize the most cost-effective technologies, this study focused on obtaining Mauritius-specific costs and renewable resource data to accurately determine the local LCOE and assess the cost-competitiveness of renewable energy systems in Mauritius. The results demonstrated great potential in terms of renewable energy generation. |
| | [113] | OSeMOSYS software | Modeled a fully renewable electricity grid for Mauritius in the year 2040. The study found that optimal renewable portfolios combined all the available resources to different extents, including solar, wind, hydroelectricity, biomass, and electricity storage. The variable nature of solar and wind electricity was mitigated, partly by a diversity of sources, partly by coupling with dispatchable biomass and hydropower and further with electricity storage. |
| | [114] | Literature review and Government reports | The study aimed to critically analyze the present and the proposed energy resource mix in Mauritius in order to make recommendations for a 100% renewable energy system for the island by 2050. The results showed the technologies that had the potential to transform the island and achieve carbon neutrality by the year 2050, namely, hydrogen, electric vehicles, bagasse gasification, solar PV, CSP, wind, biofuels, smart grids, etc. |
| | [115] | GIS software | Analyzed the spatio–temporal variability of the solar photovoltaic potential of Mauritius. A Multiple Criteria Decision Making (MCDM) analysis, coupled with an Analytical Hierarchy Process (AHP), was performed in the GIS environment in order to map the solar photovoltaic potential of Mauritius from a list of social, technical, legal, environmental and climatological factors comprising of constraint, conditional and influential factors. The results showed that the northern region of the island was suitable for the placement of photovoltaic systems. |
| | [116] | EnergyPLAN software | This work presented the modeling of the Mauritian energy system in EnergyPLAN software to identify and gain insights into the major technical challenges involved to achieve that target. Based on the simulation of alternative scenarios, it was shown that if solar PV was to be the main source of renewable energy by 2025, operation of the conventional generation fleet at very low levels (20 or 30% of instantaneous demand) and high ramping requirements became indispensable to avoid significant curtailment and meet the net load. |

**Table 4.** *Cont.*

| Country | Reference | Method | Work Description and Main Findings |
| --- | --- | --- | --- |
| | [117] | GIS | This paper investigated the spatial suitability for installations of ground-mounted solar farms, based on legal, social, technical, economic, environmental and cultural perspectives, through the use of GIS analysis combined with MCDM. The results indicated that the most appropriate region for exploitation was found in the northern region of the island owing to the right microclimate regimes of these localities, the morphology of the land and nearness to high voltage lines and road systems. |
| Mozambique | [118] | LEAP software | Presented a comprehensive energy and emission scenario analysis for Mozambique until 2030. The results showed that sustainable energy policies on the supply side led to far higher cumulative emission reductions than demand-side policies. In addition, even in the long run, a complete ban on thermal electricity generation capacity in Mozambique would by no means lead to shortages in the domestic electricity market, but only slightly limit potential electricity export. |
| Namibia | [119] | MS Excel-VBA | The aim of this study was to develop and validate an optimization model, written in MS Excel-VBA, which calculated the optimal Solar Home Systems (SHS) component capacities guaranteeing the minimum costs and maximum system reliability. |
| South Africa | [120] | LCOE and AHP | Developed a framework of analyses using LCOE and Analytical Hierarchy Process (AHP), to assess renewable energy technologies in South Africa (solar PV, wind, CSP, hydro, biogas, and biomass). From the performed analysis, solar PV and wind were favored. due to technology maturity and financier perception, while CSP also scored highly, due to the potential to meet baseload energy requirements. |
| | [121] | Weibull probability distribution function | Explored an off-grid renewable energy system consisting of solar PV and wind turbine with a hydrogen storage scheme to meet the electrical energy demands of a health clinic. The results showed that the proposed renewable energy microgrid, with a hydrogen storage system, wasa viable option for the health clinic in a rural community. |
| Tanzania | [122] | GIS and MCDM | This study investigated the spatial suitability for large-scale solar power installations in Tanzania by using GIS analysis combined with MCDM. The study identified six exclusion criteria to mark unsuitable areas. Then the AHP method was used to determine the weights of seven identified ranking criteria. |
| Zambia | [123] | ArcGIS Software | Assessed the solar energy distribution and potential in Zambia. The results showed that the country had a high technical potential for solar energy for PV electricity generation and various applications. |
| | [124] | HOMER Software | Investigated a hybrid system using the available renewable resources (biomass, wind, and solar) in the Misisi rural area. The obtained results showed that Zambia had the required renewable energy to produce power that could be used to supplement conventional systems. |
| Zimbabwe | [125] | LCOE | Presented a technologic–economic comparison of standalone wind and solar PV in addition to hybrid PV/wind systems with the objective of maximizing the share of RES generation, and minimizing the LCOE. The results indicated that the PV/wind hybrid system had economic benefits and good performance. |

### *4.3. SADC Member States' Programs and Renewables Targets*

The Paris Agreement, introduced in 2015, at the United Nations Framework Convention on Climate Change (UNFCCC), aims to keep global warming below 2 °C, limiting it to 1.5 °C compared to pre-industrial levels. To be part of this international agreement, each country prepared a National Determined Contributions (NDC) document. In these documents, countries communicated the actions they would take to reduce GHG emissions.

Such national contributions naturally imply the reduction of electricity generation by fossil fuels, and the increase of generation through RES.

The SADC member states assumed and ratified this agreement, having in mind that programs with different horizons were elaborated, but whose transversal objective was the gradual increase of penetration of renewables into the national energy mix. The main aim is to reduce dependence on fossil fuels, and ensure greater sustainability, as well as explore different sources of electricity generation, mainly to supply rural areas, which are essentially characterized by low electricity consumption and are located far from the main urban centers. Thus, the proposal of the SADC member states involves the integration of renewables in the national energy mix and the implementation of off-grid systems powered by renewable sources, such as solar PV, wind, and mini-hydro.

Table 5 presents the programs and targets defined by some selected SADC member states to guarantee the sustainability of energy systems and the consequent reduction of GHG emissions. Some targets are very ambitious, given the country's energy context, such as South Africa, whose energy mix is mostly through coal, having defined in the Integrated Resource Plan for Electricity 2010–2030, a 65% reduction in the sector's dependence on coal. This measure would demand a great effort in terms of policies and incentives from the South African government. Both Botswana and Eswatini set 100% access to electricity by 2030. Currently, Angola has a 63% penetration of renewables in the energy mix, and this percentage is only due to the production of electricity through large hydroelectric plants. By 2025, this percentage should increase to 7.5%, which would come from other renewable sources, namely solar PV, wind, and mini-hydro, representing more than 70% of the energy mix. However, many of the targets presented are not meeting the partial deadlines, due to several factors, from lack of policies, incentives, financing, and technical, economic, and social barriers.

**Table 5.** Sustainable energy programs to selected SADC member states.

| Country | Reference | Program | Targets |
|---|---|---|---|
| Angola | [126] | Angola Energia 2025 | • 800 MW installation (7.5% of the national electricity mix) from new renewables (solar PV, wind, mini-hydro and biomass) by 2025.<br>• 50% of the population with access to electricity.<br>• More than 70% of the national electricity mix from renewables in 2025, including large hydro. |
| Botswana | [14,127] | National Energy Policy 2020–2040 | • 15% reduction of GHG emissions by 2030.<br>• 100% access to electricity by 2030.<br>• 15% of the power mix from renewables by 2030 and 50% by 2036.<br>• Increase installed generation capacity from about 732 MW to 1430 MW by 2040 from local resources (coal, solar and wind). |
| Eswatini | [128] | Energy Masterplan 2034 | • 180 GWh of energy savings per year by 2025.<br>• 100% access to electricity by 2030.<br>• 50% penetration of renewable electricity in the electricity mix by 2030. |
| Lesotho | [129,130] | Renewable Energy Policy 2015–2025 | • Additional renewable energy generation capacity of 200 MW by 2030.<br>• Achieve 75% household electrification by 2030, primarily through renewable energy. |

**Table 5.** *Cont.*

| Country | Reference | Program | Targets |
|---|---|---|---|
| Madagascar | [131] | New Energy Policy 2015–2030 | • 70% access to electricity by 2030<br>• 80% of the energy mix from renewables by 2030<br>• 60% of families, businesses and industries to adopt energy efficiency measures. |
| Mozambique | [132] | Nacional Electrification Strategy for All 2018–2030 | • 70% of electricity to households from the national power grid and 30% from off-grid systems by 2030<br>• 20% integration of renewable into the power grid by 2030. |
| Namibia | [133] | National Renewable Energy Policy 2030 | • 70% or more of the electricity generation from renewable by 2030.<br>• 89% GHG emissions reduction by 2030. |
| South Africa | [134,135] | Integrated Resource Plan for Electricity 2010–2030 | • 65% reduction in electricity generation from coal by 2030, i.e., decommissioning of 11.5 GW of coal power plants.<br>• 20% of the energy mix from nuclear by 2030.· 9% of the energy mix from renewables (CSP, wind and solar PV) by 2030.<br>• 5% of the energy mix from the importation of hydro. |
| Zimbabwe | [136] | National Renewable Energy Policy 2030 | • 1100 MW of renewable capacity by 2025 (16.5% of the total electricity demand).<br>• 2100 MW of renewable capacity by 2030 (26.5% of the total electricity demand). Mini hydro (150 MW), solar PV (1575 MW), wind (100 MW) and bagasse (275 MW). |

## 5. Discussion

Worldwide, several studies have already addressed the issue of GEP, using models to optimize energy generation, such as MINLP, MILP, MO-LP, due to growing concern about climate change, the need to integrate RES into energy planning to mitigate environmental impacts caused by power generation, the need to consider an electrical system 100% based on RES, through optimization of resources, and application of complementarity between the RES and regions. However, for most developing countries, with emphasis on SSA, these models need to be adapted, as access to electricity is still a challenge, mainly in rural communities, due to the impact of the poverty of these regions. GEP with the integration of off-grid options, instead of only relying on on-grid solutions, has been pointed out as a cheaper alternative with less implementation time in SSA. Therefore, even with the exploration of RES in SSA countries to increase electrification levels, mainly through off-grid solutions for rural areas, strategies, such as complementarity between renewable energy sources, as well as regions, have not been addressed.

SADC has a huge potential for RES, from virtually all types of sources, namely hydropower, solar PV, wind, biomass, and geothermal power. However, this potential has not been properly explored, with the region's energy mix comprising 59% from coal. This is because the SAPP is, by far, dominated by Eskom from South Africa, with 75% of all installed power capacity in the region having coal as its main source of energy supply. Currently, hydropower is the main renewable source in the region and represents 24% of the energy mix. Countries such as Angola, DRC, Lesotho, Malawi, Mozambique, Namibia, and Zambia, have an energy mix dependent on hydropower, and for this reason, they do not have a strong energy guarantee in periods of drought.

In 2019, the overall average access to electricity in SADC was only 54%, although some countries, such as Seychelles, South Africa, Mauritius, and Eswatini, had electrification rates above 90%. However, the increase in the electrification rate at the SADC level is not linear, since the region has numerous rural communities whose energy supply through the main grid is not cost-effective, due to the high required investment associated with large distances to be covered and low energy consumption of those communities. Thus, the implementation of distributed energy generation systems has bee pointed out in the literature as a faster and more effective way to electrify rural communities. Distributed generation systems were guaranteed, mainly from small and medium-sized diesel generators, to supply the population and small businesses in these regions. Therefore, the use of diesel generators presents, among many inconveniences, the cost of operation and maintenance (O&M), but also the increase in GHG emissions. For the reduction of GHG emissions, the literature identifies hybrid systems as a potential option to minimize the use of diesel generators. For the present paper, distributed generation was explored using only RES, namely solar PV, mini-hydro, and wind.

SADC is committed to the Paris Agreement, and for this reason, many member states have developed national programs, whose targets include the increasing penetration of renewable energies in the national energy mix. This paper compared the programs and targets presented by the different countries. Regarding the integration of RES in the national energy mix, Angola, Lesotho, Madagascar, and Namibia stand out, as their defined targets are more than 70% in 2025, 75% in 2030, 80% in 2030, and 70% in 2030, respectively. Ambitious electrification rate targets are defined by Botswana at 100% by 2030, Eswatini at 100% by 2034, Lesotho at 75% by 2030, Madagascar at 70% by 2030, and Mozambique at 70% by 2030. Of note is the 65% reduction in energy generation through coal, intended by South Africa by 2030.

SADC is a region, with enormous endogenous resources for electricity generation, and has great potential to ensure industrial and economic development and the well-being of its populations, from health to employment opportunities. The interconnection of member states to SAPP is important to allow these countries to take advantage of the natural resources distributed throughout the region, guaranteeing reliability to national power systems. Previous studies have demonstrated that the economic development of SADC is directly related to the application of policies with a focus on the exploitation of the region's numerous energy resources, favoring renewable energy sources that are present in great abundance. The synergy of member states, through the interconnection of electricity transport grids, provides reliability for national power systems, opening the way for industrial development, and increasing the human development index of the region.

## 6. Conclusions

Access to electricity is one of the main challenges faced in many SSA countries, largely impeding economic and industrial development, as well as affecting people's lifestyles, such as being linked to lack of education, health, and so many other factors. SADC member states are committed to increasing the levels of electrification of their populations. However, the traditional method of electrifying by expanding the grid has not contributed to the eradication of energy poverty in rural areas. Grid expansion implies high costs and implementation times, and, therefore, rural communities would have to wait decades to get access to electricity, which would continue to condition access to basic services, such as health, education, etc. In addition, no access to electricity limits the development of the agricultural sector, forcing the practice of subsistence agriculture for small farmers, and increasing costs for medium- and large-scale farmers who are forced to acquire their own generating sources, mostly diesel. SADC has a huge renewable energy potential and to improve electricity access over member states, in the short term, it is essential to consider off-grid solutions based on RES. Applied hybrid solutions, using more than one source of energy, for instance, diesel and solar PV, or wind and solar PV would improve the energy capacity of the communities. On the other hand, incentivizing the creation of energy communities could bring opportunities for communities to handle their own energy demands.

Member states have been increasing electricity generation with the cheapest options, such as hydro power, diesel generators, coal thermal power plants, or gas turbines, to increase the electrification rate, and reduce suppressed demand. However, with the increase in environmental concerns, there have been restrictions on the construction of new hydropower plants, as well as the gradual abandonment of power plants based on fossil fuels. Due to the environmental impacts caused by the exploitation of fossil fuels, mainly in electricity generation, and the concern about global warming, it is unavoidable to integrate RES into GEP. In the literature review, it was found that many studies present this integration just by applying the concept of more competitive cost, i.e., hydro, solar, and wind. Yet, these sources are seen as intermittent and, therefore, their large-scale integration into the power grid involves several challenges in terms of the stability and reliability of the system, as well as the security of the supply. This paper presented an overview of the main studies present in the SADC literature that include the integration of RES into national power systems with limited initial electricity infrastructure, namely with a low electrification access rate. The methodologies of minimization of LCOE and options of software, such as GIS, HOMER, LEAP and EnergyPLAN, were the most common themes among the analyzed studies. These methodologies and software allow the assessment of the integration of RES into the national power system of countries, such as Angola, Botswana, Mauritius, Tanzania, and Zimbabwe.

To ensure the desired integration of RES, SADC member states need to explore some strategies in order to deal with intermittent sources. The strategies found were energy storage (e.g., reservoirs, batteries, hydrogen, pumped hydro storage, etc.), DSM, interconnection with other grids, complementarity between renewable energy sources and distributed generation (off-grid solutions). Therefore, taking into consideration the context of SADC members, characterized by high suppressed demand, and low electrification rate, strategies such as interconnection with other grids, complementarity between RES, and distributed generation, are seen as more appropriate and with a short-term impact, allowing acceleration of the electrification of the region.

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## Abbreviations

| | |
|---|---|
| AHP | Analytical Hierarchy Process |
| BPC | Botswana Power Corporation |
| CSP | Concentrated Solar Power |
| DRC | Democratic Republic of Congo |
| DSM | Demand-side management |
| E2T | Electricity-to-Thermal |
| EDM | Eletricidade de Moçambique (Mozambique Electricity) |
| ESCOM | Electricity Supply Corporation of Malawi |
| ESKOM | Electricity Supply Commission |
| GEP | Generation expansion planning |
| GIS | Geospatial information systems |
| GHG | Greenhouse gas |
| GW | Giggawatts |
| GWh | Giggawatts hour |
| HVDC | High voltage direct current |

| | |
|---|---|
| IEA | International Energy Agency |
| INAMET | National Institute of Meteorology |
| INE | National Statistics Institute |
| IPP | Independent Power Producers |
| IRENA | International renewable energy agency |
| IRES | Intermittency Renewable Energies Sources |
| HOMER | Hybrid Optimization Model for Multiple Energy Resources |
| LEAP | Long-range Energy Alternative and Planning System |
| LEC | Lesotho Electricity Company |
| LCOE | Levelized cost of energy |
| MCDM | Multi-Criteria Decision-Making |
| MINEA | Minister of Energy and Water of Angola |
| MINLP | Mixed-Integer Nonlinear Programming |
| MILP | Mixed Integer Linear Programming |
| MO-LP | Multi-Objective Linear Programming |
| MS | Member states |
| MW | Megawatts |
| NAMPOWER | Namibia Power Corporation |
| NDC | National Determined Contributions |
| OnSSET | Open-Source Spatial Electrification Tool |
| OSeMOSYS | Open-Source Modelling System |
| PESTLE | Political, Economic, Social, Technological, Legal and Environmental criteria |
| PV | Photovoltaic |
| P2G | Power-to-gas |
| REMix | Renewable Energies Mix |
| REEESAP | Renewable Energy and Energy Efficiency Strategy and Action Plan |
| RES | Renewable Energy Sources |
| REN21 | Renewable Energy Policy Network for the 21st Century |
| RNT | Rede Nacional de Transportes (National Transport Network) |
| SACREEE | Southern African Center for Renewable Energy and Energy Efficiency |
| SADC | Southern African Development Community |
| SAPP | Southern Africa Power Pool |
| SDG | Sustainable Development Goals |
| SNEL | Societe Nationale d'Electricite (National Electricity Company) |
| SSA | Sub-Saharan Africa |
| TANESCO | Tanzania Electricity Supply Company |
| TEMBA | The Electricity Model Base for Africa |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UN | United Nations |
| V2G | Vehicle-to-grid |
| WRF | Weather Research and Forecasting |
| WWS | Wind, Water and Solar energy |
| ZESA | Zimbabwe Electricity Supply Authority |
| ZESCO | Zambia Electricity Supply Corporation |

## References

1. Bowa, K.C.; Mwanza, M.; Sumbwanyambe, M.; Ulgen, K.; Pretorius, J.H. Comparative Sustainability Assessment of Electricity Industries in Sadc Region: The Role of Renewable Energy in Regional and National Energy Diversification. In Proceedings of the 2019 IEEE 2nd International Conference on Renewable Energy and Power Engineering, REPE 2019, Toronto, ON, Canada, 2–4 November 2019; pp. 260–268. [CrossRef]
2. UN. The 17 Goals. Available online: https://sdgs.un.org/goals (accessed on 17 February 2022).
3. Valickova, P.; Elms, N. The costs of providing access to electricity in selected countries in Sub-Saharan Africa and policy implications. *Energy Policy* **2021**, *148*, 111935. [CrossRef]
4. Bissiri, M.; Moura, P.; Figueiredo, N.C.; Silva, P.P. Towards a renewables-based future for West African States: A review of power systems planning approaches. *Renew. Sustain. Energy Rev.* **2020**, *134*, 110019. [CrossRef]
5. IEA. World Energy Outlook 2021. 2021. Available online: www.iea.org/weo (accessed on 14 February 2022).

6. IEA; IRENA; UN; World Bank; WHO. Tracking SDG7: The Energy Progress Report. 2021. Available online: https://trackingsdg7.esmap.org/downloads (accessed on 15 February 2022).
7. Trotter, P.A.; Cooper, N.J.; Wilson, P.R. A multi-criteria, long-term energy planning optimisation model with integrated on-grid and off-grid electrification—The case of Uganda. *Appl. Energy* **2019**, *243*, 288–312. [CrossRef]
8. IEA. Africa Energy Outlook 2019 World Energy Outlook Special Report. 2019. Available online: www.iea.org/t&c/ (accessed on 15 February 2022).
9. SADC. *Renewable Energy and Energy Efficiency—Status Report*; SADC: Gaborone, Botswana, 2018. Available online: https://www.ren21.net/wp-content/uploads/2019/05/SADC_2018_EN_web.pdf (accessed on 26 June 2022).
10. Wright, J.G.; van Coller, J. System adequacy in the Southern African Power Pool: A case for capacity mechanisms. *J. Energy S. Afr.* **2018**, *29*, 37–50, 2018. [CrossRef]
11. SADC. Towards a Common Future. Available online: https://www.sadc.int/about-sadc/ (accessed on 7 March 2022).
12. Spalding-Fecher, R.; Joyce, B.; Winkler, H. Climate change and hydropower in the Southern African Power Pool and Zambezi River Basin: System-wide impacts and policy implications. *Energy Policy* **2017**, *103*, 84–97. [CrossRef]
13. IEA. *World Energy Outlook*; IEA: Paris, France, 2020.
14. IRENA. Renewables Readiness Assessment Botswana. 2021. Available online: www.irena.org/rra (accessed on 14 July 2022).
15. Tazvinga, H.; Dzobo, O.; Mapako, M. Towards sustainable energy system options for improving energy access in Southern Africa. *J. Energy S. Afr.* **2020**, *31*, 59–72. [CrossRef]
16. IRENA. Planning and Prospects for Renewable Power: Eastern and Southern Africa. 2021. Available online: www.irena.org (accessed on 21 February 2022).
17. SADC. *Enabling Industrialization and Regional Integration in SADC*; SADC: Gaborone, Botswana, 2018.
18. SAPP. *Annual Report: Energising the SADC Region for Economic Development*; SAPP: Harare, Zimbabwe, 2021.
19. SADC. *Renewable Energy and Energy Efficiency Strategy and Action Plan (REEESAP) 2016–2030*; SADC: Gaborone, Botswana, 2016.
20. Zobaa, A.F. Southern African Power Pools. In Proceedings of the 2005 IEEE Power Engineering Society General Meeting, San Francisco, CA, USA, 16 June 2005; Volume 2, pp. 1813–1818. [CrossRef]
21. Zimba, K.S.; Chudy, M.; Janícek, F. Imbalance Energy in Southern African Power Pool. In Proceedings of the IEEE PES-IAS PowerAfrica, Accra, Ghana, 27–30 June 2017; pp. 407–412.
22. SAPP. A Overview of the Southern African Power Pool. Available online: https://www.sapp.co.zw (accessed on 7 March 2022).
23. Zimba, K.S.; Nyamutswa, I.; Chikova, A. Islanding Power Systems to Minimize Impact of System Disturbances in Southern African Power Pool. In Proceedings of the 2017 IEEE AFRICON, Cape Town, South Africa, 18–20 September 2017.
24. Spalding-Fecher, R.; Senatla, M.; Yamba, F.; Lukwesa, B.; Himunzowa, G.; Heaps, C.; Chapman, A.; Mahumane, G.; Tembo, B.; Nyambe, I. Electricity supply and demand scenarios for the Southern African power pool. *Energy Policy* **2017**, *101*, 403–414. [CrossRef]
25. Real, F.J.R.; Tovar, B. Revisiting electric utilities' efficiency in the Southern African power pool, 1998–2009. *J. Energy S. Afr.* **2020**, *31*, 1–13. [CrossRef]
26. SADC. *Annual Report 2020–2021*; SADC: Gaborone, Botswana, 2021.
27. Ramagoma, J.; Adendorff, C. Managing a transition to green energy sources: The perspectives of energy practitioners in the Southern African Development Community region. *J. Energy S. Afr.* **2016**, *27*, 77–90. [CrossRef]
28. World Population Review. Carbon Footprint by Country 2022. Available online: https://worldpopulationreview.com/country-rankings/carbon-footprint-by-country (accessed on 21 February 2022).
29. Haas, J.; Nowak, W.; Palma-Behnke, R. Multi-objective planning of energy storage technologies for a fully renewable system: Implications for the main stakeholders in Chile. *Energy Policy* **2019**, *126*, 494–506. [CrossRef]
30. Esteban, M.; Portugal-Pereira, J.; Mclellan, B.C.; Bricker, J.; Farzaneh, H.; Djalilova, N.; Ishihara, K.N.; Takagi, H.; Roeber, V. 100% renewable energy system in Japan: Smoothening and ancillary services. *Appl. Energy* **2018**, *224*, 698–707. [CrossRef]
31. Dagoumas, A.S.; Koltsaklis, N.E. Review of models for integrating renewable energy in the generation expansion planning. *Appl. Energy* **2019**, *242*, 1573–1587. [CrossRef]
32. Krakowski, V.; Assoumou, E.; Mazauric, V.; Maïzi, N. Reprint of Feasible path toward 40–100% renewable energy shares for power supply in France by 2050: A prospective analysis. *Appl. Energy* **2016**, *184*, 1529–1550. [CrossRef]
33. Gils, H.C.; Simon, S.; Soria, R. 100% Renewable energy supply for Brazil-The role of sector coupling and regional development. *Energies* **2017**, *10*, 1859. [CrossRef]
34. Solomon, A.A.; Kammen, D.M.; Callaway, D. Investigating the impact of wind-solar complementarities on energy storage requirement and the corresponding supply reliability criteria. *Appl. Energy* **2016**, *168*, 130–145. [CrossRef]
35. Li, Q.; Wang, J.; Zhang, Y.; Fan, Y.; Bao, G.; Wang, X. Multi-Period Generation Expansion Planning for Sustainable Power Systems to Maximize the Utilization of Renewable Energy Sources. *Sustainability* **2020**, *12*, 1083. [CrossRef]
36. Pourmoosavi, M.A.; Amraee, T.; Firuzabad, M.F. Expansion planning of generation technologies in electric energy systems under water use constraints with renewable resources. *Sustain. Energy Technol. Assess.* **2020**, *43*, 100828. [CrossRef]
37. Hemmati, R.; Saboori, H.; Jirdehi, M.A. Multistage generation expansion planning incorporating large scale energy storage systems and environmental pollution. *Renew. Energy* **2016**, *97*, 636–645. [CrossRef]
38. Koltsaklis, N.E.; Dagoumas, A.S. State-of-the-art generation expansion planning: A review. *Appl. Energy* **2018**, *230*, 563–589. [CrossRef]

39. Jacobson, M.Z.; Delucchi, M.A.; Cameron, M.A.; Frew, B.A. Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 15060–15065. [CrossRef]
40. François, B.; Borga, M.; Creutin, J.D.; Hingray, B.; Raynaud, D.; Sauterleute, J.F. Complementarity between solar and hydro power: Sensitivity study to climate characteristics in Northern-Italy. *Renew. Energy* **2016**, *86*, 543–553. [CrossRef]
41. Zhang, N.; Hu, Z.; Shen, B.; He, G.; Zheng, Y. An integrated source-grid-load planning model at the macro level: Case study for China's power sector. *Energy* **2017**, *126*, 231–246. [CrossRef]
42. Pozo, D.; Sauma, E.E.; Contreras, J. A Three-Level Static MILP Model for Generation and Transmission Expansion Planning. *IEEE Trans. Power Syst.* **2013**, *28*, 202–210. [CrossRef]
43. Guerra, O.J.; Tejada, D.A.; Reklaitis, G.V. An optimization framework for the integrated planning of generation and transmission expansion in interconnected power systems. *Appl. Energy* **2016**, *170*, 1–21. [CrossRef]
44. Georgiou, P.N. A bottom-up optimization model for the long-term energy planning of the Greek power supply sector integrating mainland and insular electric systems. *Comput. Oper. Res.* **2016**, *66*, 292–312. [CrossRef]
45. Sharan, I.; Balasubramanian, R. Integrated generation and transmission expansion planning including power and fuel transportation constraints. *Energy Policy* **2012**, *43*, 275–284. [CrossRef]
46. Ren, H.; Zhou, W.; Nakagami, K.; Gao, W.; Wu, Q. Multi-objective optimization for the operation of distributed energy systems considering economic and environmental aspects. *Appl. Energy* **2010**, *87*, 3642–3651. [CrossRef]
47. Luz, T.; Moura, P.; de Almeida, A. Multi-objective power generation expansion planning with high penetration of renewables. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2637–2643. [CrossRef]
48. Zhang, Q.; Mclellan, B.C.; Tezuka, T.; Ishihara, K.N. An integrated model for long-term power generation planning toward future smart electricity systems. *Appl. Energy* **2013**, *112*, 1424–1437. [CrossRef]
49. Muis, Z.A.; Hashim, H.; Manan, Z.A.; Taha, F.M.; Douglas, P.L. Optimal planning of renewable energy-integrated electricity generation schemes with $CO_2$ reduction target. *Renew. Energy* **2010**, *35*, 2562–2570. [CrossRef]
50. Antunes, C.H.; Martins, A.G.; Brito, I.S. A multiple objective mixed integer linear programming model for power generation expansion planning. *Energy* **2004**, *29*, 613–627. [CrossRef]
51. Koltsaklis, N.E.; Dagoumas, A.S.; Kopanos, G.M.; Pistikopoulos, E.N.; Georgiadis, M.C. A spatial multi-period long-term energy planning model: A case study of the Greek power system. *Appl. Energy* **2014**, *115*, 456–482. [CrossRef]
52. Unsihuay-Vila, C.; Marangon-Lima, J.W.; de Souza, A.C.Z.; Perez-Arriaga, I.J. Multistage expansion planning of generation and interconnections with sustainable energy development criteria: A multiobjective model. *Int. J. Electr. Power Energy Syst.* **2011**, *33*, 258–270. [CrossRef]
53. Gebretsadik, Y.; Fant, C.; Strzepek, K.; Arndt, C. Optimized reservoir operation model of regional wind and hydro power integration case study: Zambezi basin and South Africa. *Appl. Energy* **2016**, *161*, 574–582. [CrossRef]
54. Moura, P.S.; de Almeida, A.T. Multi-objective optimization of a mixed renewable system with demand-side management. *Renew. Sustain. Energy Rev.* **2010**, *14*, 1461–1468. [CrossRef]
55. Caldera, U.; Breyer, C. Impact of Battery and Water Storage on the Transition to an Integrated 100% Renewable Energy Power System for Saudi Arabia. *Energy Procedia* **2017**, *135*, 126–142. [CrossRef]
56. Khan, I. Power generation expansion plan and sustainability in a developing country: A multi-criteria decision analysis. *J. Clean. Prod.* **2019**, *220*, 707–720. [CrossRef]
57. da Luz, T.; Moura, P. Power generation expansion planning with complementarity between renewable sources and regions for 100% renewable energy systems. *Int. Trans. Electr. Energy Syst.* **2019**, *29*, e2817. [CrossRef]
58. Lund, P.D.; Lindgren, J.; Mikkola, J.; Salpakari, J. Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renew. Sustain. Energy Rev.* **2015**, *45*, 785–807. [CrossRef]
59. Silva, A.R.; Pimenta, F.M.; Assireu, A.T.; Spyrides, M.H.C. Complementarity of Brazils hydro and offshore wind power. *Renew. Sustain. Energy Rev.* **2016**, *56*, 413–427. [CrossRef]
60. IRENA. *African Power Pool: Planning and Prospects Energy*; IRENA: Abu Dhabi, United Arab Emirates, 2013.
61. REN21. *Renewables 2020 Global Status Report*; REN21 Secretariat: Paris, France, 2020.
62. Johnson, B.; Denholm, P.; Kroposki, B.; Hodge, B. Achieving a 100% Renewable Grid: Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy. *IEEE Power Energy Mag.* **2017**, *15*, 61–73.
63. REN21. *Renewables 2022: Global Status Report*; REN21: Paris, France, 2022.
64. Child, M.; Breyer, C.; Bogdanov, D.; Fell, H.J. The role of storage technologies for the transition to a 100% renewable energy system in Ukraine. *Energy Procedia* **2017**, *135*, 410–423. [CrossRef]
65. Solomon, A.A.; Child, M.; Caldera, U.; Breyer, C. Exploiting wind-solar resource complementarity to reduce energy storage need. *AIMS Energy* **2020**, *8*, 749–770. [CrossRef]
66. Gallardo, R.P.; Ríos, A.M.; Ramírez, J.S. Analysis of the solar and wind energetic complementarity in Mexico. *J. Clean. Prod.* **2020**, *268*, 122323. [CrossRef]
67. Jurasz, J.; Mikulik, J.; Dąbek, P.B.; Guezgouz, M.; Kaźmierczak, B. Complementarity and 'Resource Droughts' of Solar and Wind Energy in Poland: An ERA5-Based Analysis. *Energies* **2021**, *14*, 1118. [CrossRef]
68. Weschenfelder, F.; Leite, G.D.N.P.; da Costa, A.C.A.; de Castro Vilela, O.; Ribeiro, C.M.; Ochoa, A.A.V.; Araujo, A.M. A review on the complementarity between grid-connected solar and wind power systems. *J. Clean. Prod.* **2020**, *257*, 120617. [CrossRef]

69. Sun, W.; Harrison, G.P. Wind-solar complementarity and effective use of distribution network capacity. *Appl. Energy* **2019**, *247*, 89–101. [CrossRef]
70. de Oliveira Costa Souza Rosa, C.; da Silva Christo, E.; Costa, K.A.; dos Santos, L. Assessing complementarity and optimising the combination of intermittent renewable energy sources using ground measurements. *J. Clean. Prod.* **2020**, *258*, 120946. [CrossRef]
71. Kougias, I.; Szabó, S.; Monforti-Ferrario, F.; Huld, T.; Bódis, K. A methodology for optimization of the complementarity between small-hydropower plants and solar PV systems. *Renew. Energy* **2016**, *87*, 1023–1030. [CrossRef]
72. Miglietta, M.M.; Huld, T.; Monforti-Ferrario, F. Local Complementarity of Wind and Solar Energy Resources over Europe: An Assessment Study from a Meteorological Perspective. *J. Appl. Meteorol. Climatol.* **2016**, *56*, 217–234. [CrossRef]
73. Canales, F.A.; Jurasz, J.; Beluco, A.; Kies, A. Assessing temporal complementarity between three variable energy sources through correlation and compromise programming. *Energy* **2020**, *192*, 116637. [CrossRef]
74. Henao, F.; Viteri, J.P.; Rodríguez, Y.; Gómez, J.; Dyner, I. Annual and interannual complementarities of renewable energy sources in Colombia. *Renew. Sustain. Energy Rev.* **2020**, *134*, 110318. [CrossRef]
75. Viviescas, C.; Lima, L.; Diuana, F.A.; Vasquez, E.; Ludovique, C.; Silva, G.N.; Huback, V.; Magalar, L.; Szklo, A.; Lucena, A.F.; et al. Contribution of Variable Renewable Energy to increase energy security in Latin America: Complementarity and climate change impacts on wind and solar resources. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109232. [CrossRef]
76. Jurasz, J.; Canales, F.A.; Kies, A.; Guezgouz, M.; Beluco, A. A review on the complementarity of renewable energy sources: Concept, metrics, application and future research directions. *Sol. Energy* **2020**, *195*, 703–724. [CrossRef]
77. Neto, P.B.L.; Saavedra, O.R.; Oliveira, D.Q. The effect of complementarity between solar, wind and tidal energy in isolated hybrid microgrids. *Renew. Energy* **2020**, *147*, 339–355. [CrossRef]
78. Luz, T.; Moura, P. 100% Renewable energy planning with complementarity and flexibility based on a multi-objective assessment. *Appl. Energy* **2019**, *255*, 113819. [CrossRef]
79. Mahapatra, S.; Dasappa, S. Rural electrification: Optimising the choice between decentralised renewable energy sources and grid extension. *Energy Sustain. Dev.* **2012**, *16*, 146–154. [CrossRef]
80. Zappa, W.; Junginger, M.; van den Broek, M. Is a 100% renewable European power system feasible by 2050? *Appl. Energy* **2019**, *233–234*, 1027–1050. [CrossRef]
81. Cozzolino, R.; Tribioli, L.; Bella, G. Power management of a hybrid renewable system for artificial islands: A case study. *Energy* **2016**, *106*, 774–789. [CrossRef]
82. Wang, D.; Qiu, J.; Reedman, L.; Meng, K.; Lai, L.L. Two-stage energy management for networked microgrids with high renewable penetration. *Appl. Energy* **2018**, *226*, 39–48. [CrossRef]
83. Li, H.; Eseye, A.T.; Zhang, J.; Zheng, D. Optimal energy management for industrial microgrids with high-penetration renewables. *Prot. Control Mod. Power Syst.* **2017**, *2*, 12. [CrossRef]
84. Tabar, V.S.; Abbasi, V. Energy management in microgrid with considering high penetration of renewable resources and surplus power generation problem. *Energy* **2019**, *189*, 116264. [CrossRef]
85. Namilakonda, S.; Guduri, Y. Chaotic darwinian particle swarm optimization for real-time hierarchical congestion management of power system integrated with renewable energy sources. *Int. J. Electr. Power Energy Syst.* **2021**, *128*, 106632. [CrossRef]
86. Kaluthanthrige, R.; Rajapakse, A.D. Demand response integrated day-ahead energy management strategy for remote off-grid hybrid renewable energy systems. *Int. J. Electr. Power Energy Syst.* **2021**, *129*, 106731. [CrossRef]
87. Chakir, A.; Abid, M.; Tabaa, M.; Hachimi, H. Demand-side management strategy in a smart home using electric vehicle and hybrid renewable energy system. *Energy Rep.* **2022**, *8*, 383–393. [CrossRef]
88. Wei, L.; Yi, C.; Yun, J. Energy drive and management of smart grids with high penetration of renewable sources of wind unit and solar panel. *Int. J. Electr. Power Energy Syst.* **2021**, *129*, 106846. [CrossRef]
89. Ali Dashtaki, A.; Mehdi Hakimi, S.; Hasankhani, A.; Derakhshani, G.; Abdi, B. Optimal management algorithm of microgrid connected to the distribution network considering renewable energy system uncertainties. *Int. J. Electr. Power Energy Syst.* **2023**, *145*, 108633. [CrossRef]
90. Mentis, D.; Howells, M.; Rogner, H.; Korkovelos, A.; Arderne, C.; Zepeda, E.; Siyal, S.; Taliotis, C.; Bazilian, M.; De Roo, A.; et al. Lighting the World: The first application of an open source, spatial electrification tool (OnSSET) on Sub-Saharan Africa. *Environ. Res. Lett.* **2017**, *12*, 085003. [CrossRef]
91. Barasa, M.; Bogdanov, D.; Oyewo, A.S.; Breyer, C. A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030. *Renew. Sustain. Energy Rev.* **2018**, *92*, 440–457. [CrossRef]
92. Bissiri, M.; Moura, P.; Figueiredo, N.C.; Pereira da Silva, P. A geospatial approach towards defining cost-optimal electrification pathways in West Africa. *Energy* **2020**, *200*, 117471. [CrossRef]
93. Moner-Girona, M.; Bódis, K.; Huld, T.; Kougias, I.; Szabó, S. Universal access to electricity in Burkina Faso: Scaling-up renewable energy technologies. *Environ. Res. Lett.* **2016**, *11*, 084010. [CrossRef]
94. Taliotis, C.; Shivakumar, A.; Ramos, E.; Howells, M.; Mentis, D.; Sridharan, V.; Broad, O.; Mofor, L. An indicative analysis of investment opportunities in the African electricity supply sector—Using TEMBA (The Electricity Model Base for Africa). *Energy Sustain. Dev.* **2016**, *31*, 50–66. [CrossRef]
95. Adaramola, M.S.; Paul, S.S.; Oyewola, O.M. Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria. *Energy Sustain. Dev.* **2014**, *19*, 72–82. [CrossRef]

96. Ouedraogo, B.I.; Kouame, S.; Azoumah, Y.; Yamegueu, D. Incentives for rural off grid electrification in Burkina Faso using LCOE. *Renew. Energy* **2015**, *78*, 573–582. [CrossRef]
97. Afful-Dadzie, A.; Afful-Dadzie, E.; Awudu, I.; Banuro, J.K. Power generation capacity planning under budget constraint in developing countries. *Appl. Energy* **2017**, *188*, 71–82. [CrossRef]
98. Ikejemba, E.C.X.; Schuur, P. Locating solar and wind parks in South-Eastern Nigeria for maximum population coverage: A multi-step approach. *Renew. Energy* **2016**, *89*, 449–462. [CrossRef]
99. Garcia, F.P.K.; Raji, A.K. Potential and Reliability Assessment of Renewable Power: The Case of Angola. In Proceedings of the IEEE PES/IAS PowerAfrica, Nairobi, Kenya, 23–27 August 2021; pp. 1–5. [CrossRef]
100. Lemba, I.; Ferreira Dias, M.; Robaina, M. Electric energy planning in Namibe, Angola: Inserting renewable energies in search of a sustainable energy mix. *J. Energy S. Afr.* **2021**, *32*, 69–83. [CrossRef]
101. Baek, Y.J.; Jung, T.Y.; Kang, S.J. Low carbon scenarios and policies for the power sector in Botswana. *Clim. Policy* **2019**, *19*, 219–230. [CrossRef]
102. Aboudou, K.M.; el Ganaoui, M. Design of a Hybrid System for Rural Area Electricity Supply in Comoros. *J. Power Energy Eng.* **2019**, *7*, 59–78. [CrossRef]
103. Mariama, S.M.; Scipioni, A.; Davat, B.; el Ganaoui, M. The idea of feeding a rural area in Comoros with a micro-grid system with renewable energy source with hydrogen storages. In Proceedings of the 2018 6th International Renewable and Sustainable Energy Conference (IRSEC), Rabat, Morocco, 5–8 December 2018; IEEE: Piscataway, NJ, USA, 2018.
104. Mashwama, N.; Shongwe, T. Proposing the best combination of Reneable Energy resources available to the country of Eswatini. In Proceedings of the 2020 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD), Durban, South Africa, 6–7 August 2020; IEEE: Piscataway, NJ, USA, 2020.
105. Senatla, M.; Nchake, M.; Taele, B.M.; Hapazari, I. Electricity capacity expansion plan for Lesotho–implications on energy policy. *Energy Policy* **2018**, *120*, 622–634. [CrossRef]
106. D'Isidoroa, M.; Brigantia, G.; Vitalia, L.; Righinia, G.; Adania, M.; Guarnieria, G.; Morettia, L.; Raliselob, M.; Mahahabisac, M.; Ciancarellaa, L.; et al. Estimation of solar and wind energy resources over Lesotho and their complementarity by means of WRF yearly simulation at high resolution. *Renew. Energy* **2020**, *158*, 114–129. [CrossRef]
107. Pasanisi, F.; Righini, G.; D'Isidoro, M.; Vitali, L.; Briganti, G.; Grauso, S.; Moretti, L.; Tebano, C.; Zanini, G.; Mahahabisa, M.; et al. A cooperation project in lesotho: Renewable energy potential maps embedded in a webgis tool. *Sustainability* **2021**, *13*, 10132. [CrossRef]
108. Praene, J.P.; Radanielina, M.H.; Rakotoson, V.R.; Andriamamonjy, A.L.; Sinama, F.; Morau, D.; Rakotondramiarana, H.T. Electricity generation from renewables in Madagascar: Opportunities and projections. *Renew. Sustain. Energy Rev.* **2017**, *76*, 1066–1079. [CrossRef]
109. Qin, L.; Wang, M.; Zhu, J.; Wei, Y.; Zhou, X.; He, Z. Towards Circular Economy through Waste to Biomass Energy in Madagascar. *Complexity* **2021**, *2021*, 5822568. [CrossRef]
110. Kaunda, C.S. Energy situation, potential and application status of small-scale hydropower systems in Malawi. *Renew. Sustain. Energy Rev.* **2013**, *26*, 1–19. [CrossRef]
111. Zalengera, C.; Blanchard, R.E.; Eames, P.C.; Juma, A.M.; Chitawo, M.L.; Gondwe, K.T. Overview of the Malawi energy situation and A PESTLE analysis for sustainable development of renewable energy. *Renew. Sustain. Energy Rev.* **2014**, *38*, 335–347. [CrossRef]
112. Shea, R.P.; Ramgolam, Y.K. Applied levelized cost of electricity for energy technologies in a small island developing state: A case study in Mauritius. *Renew. Energy* **2019**, *132*, 1415–1424. [CrossRef]
113. Timmons, D.; Dhunny, A.Z.; Elahee, K.; Havumaki, B.; Howells, M.; Khoodaruth, A.; Lema-Driscoll, A.K.; Lollchund, M.R.; Ramgolam, Y.K.; Rughooputh, S.D.D.V.; et al. Cost minimization for fully renewable electricity systems: A Mauritius case study. *Energy Policy* **2019**, *133*, 110895. [CrossRef]
114. Khoodaruth, A.; Oree, V.; Elahee, M.K.; Clark, W.W. Exploring options for a 100% renewable energy system in Mauritius by 2050. *Util. Policy* **2017**, *44*, 38–49. [CrossRef]
115. Doorga, J.R.S.; Rughooputh, S.D.D.V.; Boojhawon, R. High resolution spatio-temporal modelling of solar photovoltaic potential for tropical islands: Case of Mauritius. *Energy* **2019**, *169*, 972–987. [CrossRef]
116. Edoo, M.N.; Ah King, R.T.F. New insights into the technical challenges of the Mauritius long term energy strategy. *Energy* **2020**, *195*, 116975. [CrossRef]
117. Doorga, J.R.S.; Rughooputh, S.D.D.V.; Boojhawon, R. Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: A case study in Mauritius. *Renew. Energy* **2019**, *133*, 1201–1219. [CrossRef]
118. Mahumane, G.; Mulder, P. Introducing MOZLEAP: An integrated long-run scenario model of the emerging energy sector of Mozambique. *Energy Econ.* **2016**, *59*, 275–289. [CrossRef]
119. Campana, P.E.; Holmberg, A.; Pettersson, O.; Klintenberg, P.; Hangula, A.; Araoz, F.B.; Zhang, Y.; Stridh, B.; Yan, J. An open-source optimization tool for solar home systems: A case study in Namibia. *Energy Convers. Manag.* **2016**, *130*, 106–118. [CrossRef]
120. Naicker, P.; Thopil, G.A. A framework for sustainable utility scale renewable energy selection in South Africa. *J. Clean. Prod.* **2019**, *224*, 637–650. [CrossRef]
121. Ayodele, T.R.; Mosetlhe, T.C.; Yusuff, A.A.; Ogunjuyigbe, A.S.O. Off-grid hybrid renewable energy system with hydrogen storage for South African rural community health clinic. *Int. J. Hydrogen Energy* **2021**, *46*, 19871–19885. [CrossRef]

122. Aly, A.; Jensen, S.S.; Pedersen, A.B. Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS multicriteria decision making analysis. *Renew. Energy* **2017**, *113*, 159–175. [CrossRef]
123. Mwanza, M.; Chachak, J.; Çetin, N.S.; Ülgen, K. Assessment of solar energy source distribution and potential in Zambia. *Period. Eng. Nat. Sci.* **2017**, *5*, 103–116. [CrossRef]
124. Malange, R.; Ayeleso, A.; Raji, A. Hybrid Renewable Energy System potentials in rural areas: A case of Zambia. In *AIUE Proceedings of the 2nd Energy and Human Habitat Conference 2021*; Elsevier: Amsterdam, The Netherlands, 2021.
125. Al-Ghussain, L.; Samu, R.; Taylan, O.; Fahrioglu, M. Techno-economic comparative analysis of renewable energy systems: Case study in Zimbabwe. *Inventions* **2020**, *5*, 27. [CrossRef]
126. MINEA. Angola Energia 2025. 2016. Available online: https://angolaenergia2025.gestoenergy.com/sites/default/files/editor/livro_angola_energia_2025_baixa.pdf (accessed on 24 March 2022).
127. MMGE. National Energy Policy Government of the Republic of Botswana. 2021. Available online: https://www.bera.co.bw/downloads/National%20Energy%20Policy%20Final%20April%202021.pdf (accessed on 10 July 2022).
128. MNRE. Kingdom of Eswatini Energy Masterplan 2034. 2014. Available online: https://www.esera.org.sz/legislation/docs/1550235366.pdf (accessed on 28 July 2022).
129. Lesotho. Renewable Energy Policy. 2013. Available online: https://nul-erc.s3.amazonaws.com/public/documents/reports/lesotho-renewable-energy-policy-draft-1532182953.pdf (accessed on 28 July 2022).
130. Lesotho. Energy Policy 2015–2025. 2013. Available online: https://nul-erc.s3.amazonaws.com/public/documents/reports/lesotho-energy-policy-2015-2025-1532182755.pdf (accessed on 28 July 2022).
131. MEEH. Investment Plan for Renewable Energy in Madagascar. 2015. Available online: https://www.cif.org/sites/cif_enc/files/srepinvestment_plan_for_madagascar_final.pdf (accessed on 28 July 2022).
132. EDM. Programa Nacional de Energia para Todos. 2018. Available online: https://portal.edm.co.mz/en/document/reports/brochuraa4-de-novas-energias-leiloes-de-energia-renovaveis (accessed on 28 July 2022).
133. Ministry of Mines and Energy. National Renewable Energy Policy of Namibia. 2017. Available online: https://mme.gov.na/files/publications/03f_National%20Renewable%20Energy%20Policy%20-%20July%202017.pdf (accessed on 28 July 2022).
134. Department of Energy. Integrated Resource Plan for Electricity 2010–2030. 2011. Available online: http://www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (accessed on 31 July 2022).
135. Yelland, C. South Africa's Energy Policies Are Changes Finally Coming? 2020. Available online: https://www.ifri.org/sites/default/files/atoms/files/yelland_south_africa_energy_policies_2020.pdf (accessed on 31 July 2022).
136. Ministry of Energy and Power Development. National Renewable Energy Policy. 2019. Available online: https://www.zera.co.zw/National_Renewable_Energy_Policy_Final.pdf (accessed on 31 July 2022).