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Sustainability of power generation for developing economies: A systematic review of power sources mix

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ABSTRACT

With affordable and clean energy being one of the Sustainable Development Goals (SDG7), most developing economies are still caught up with the dilemma of inadequate power supply and heavy dependence on fossil fuel. This social menace is premised on rapid population growth, industrialization, modernization, etc. Even though these sources of power appear to be far-fetched from being sufficient, they are noted for creating a significant level of environmental pollution, global warming, and health-related risks. The Conference of Parties 26 (COP26) assembly held in Glasgow, United Kingdom, stressed the need to bring down the rising annual global temperatures to 1.5°, with developing economies having a significant role in achieving this target. This article has presented a review with insight into certain power generation metrics within the context of (SDG7). This span across the investigation of different energy modelling tools, their depth of effectiveness, the general pros and cons of energy policies premised on these tools, and progress made so far towards the development of an affordable and clean power sources mix in developing economies. A deduction was reached that there is an immense potential for power generation from affordable and clean energy sources as this bridges the enormous gap between power demand and supply as well as mitigates greenhouse gases (GHGs) effects.

1. Introduction

Power is generated by utilizing primary energy sources such as natural gas, biomass, coal, uranium, sunshine, wind, tidal, etc. In 2013, power constituted 18% of global energy demand, making it crucial to nations' social well-being and economic competitiveness [1]. Recent population boom, industrialization, modernization, and most recently, the arrival of the fourth industrial revolution have made power generation an issue of increasing global concern with a much more devastating effect on developing and underdeveloped economies [2]. Considering electricity's versatility across all endeavors of human activity, including households, agriculture, industry, transportation, and the service sector, the need to objectively analyze various power generation mix to determine their sustainability has become crucial. To name a few, the depletion of fossil fuel supplies, energy stability, global warming, and the damaging environmental effects of continuous utilization of specific power generation systems brings about a discussion premised on multi-objective optimization. This domain of the problem, which is strongly linked to electricity supply mix, equilibrium, and optimization, is worth investigating for the sustainability of the power sector in developing economies [3]. Coal and fossil fuel are still heavily utilized in generating electricity in developing economies and this trend will continue until 2035 because of their vast reserve, despite having a huge disregard for environmental, health, and safety implications [4,5]. The negative impact of fossil fuel on the environment, health, and energy security is significant. As a result, Presidents from various countries convened for the 26th UN Climate Change Conference also referred to as COP26, in Glasgow the United Kingdom to address these global challenges. The COP26 conference, Glasgow (2021) committed all nations that rely on carbon-related power generation sources to a sustainable facing out deal with all the necessary support in place. These countries span across the developed nations (where carbon-centered power sources are utilized for heavy industrial and agricultural operations) to the developing and underdeveloped economies where (carbon sources are utilized primarily for power generation) [6].

Assessing the Ubuntu, Retrievability Reconstructability, Reusability,

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Repeatability, Interoperability and Auditability (U4RIA) criteria against the power sources mix of developing countries considered in this study, touched on Ubuntu which is pinned to accessibility of power by everyone in a given community through effective energy mix policy leading to availability and sustainability. Retrievability on the other hand was addressed through simplicity to locate and retrieve information from a single comprehensive source for green energy policy formation; Reusability was addressed herein through handiness and convenience of information availability without any form of restrictions; Repeatability goes with the possibility of replicating the energy mix policies in more communities and nations that are in need of such and Reconstructability focused on the flexibility and robustness of the green energy policy. This creates room for possible modification and improvement in line with the changing times. Furthermore, Interoperability (i.e., high model output compatibility) and auditability (i.e., Peer evaluation of the modeling is made possible by the transparency resulting from the aforementioned). Without a shared database, it is more challenging to create a communication platform and cooperation amongst institutions. Scientific evidence supporting the round table recommended power source mix may improve the efficiency and sustainability of demand-driven aid provided by development partners to nations involved in strategic energy.

However, on the part of the developed economies, the conveyed need is to make the nationwide energy strategy ecosystem more self-sustaining and efficient. It is envisaged that this would become more significant as the drive for decarbonization, green energy and mixed energy sources from renewables become fully embedded as energy policies for the projected future. Furthermore, websites, links, conferences, journals, videos, webinars and audio information sources have been collated and preserved for easy retrievability. Reusability herein was addressed under two auspices namely: reusability of resource materials and reusability linked to the documentation process for future energy policies in developing underdeveloped economies. Reusability of the resource materials was facilitated by the attained retrievability whereas reusability of the research work to guide the formulation of sustainability of the green energy policy across developing economies was achieved through clarity of the documentation process. Repeatability herein was facilitated through the adaptable or adoptable nature of the multi-objective optimization energy mix model proposed at the tail-end of this review paper and fully developed and validated in an accompany energy mix optimization paper which technically is an extension and a continuum of this review paper. The adaptable nature of the proposed model entrenches the repeatability component of U4RIA. The term reconstructability was achieved in this research through the principle of systematic traceability for a possible enhancement. This was imbibed in the proposed multi-objective energy mix model. The model can be enhanced in all its sections via extension or reduction to meet a specific need. Interoperability was achieved through systems thinking. Diverse factors interlinked towards energy mix for sustainable power generation were identified from a holistic perspective and built into an integrated model that satisfies interoperability of multiple and diverse level of factors for effective energy policy. Auditability in this research is linked to every aspect of the research from conception to completion. The power generation planning, design, development, deployment, operations and discarding will be monitored by the community that formed part of the entire modeling process from scratch. As the world is transitioning to a sustainable power supply mix, accountability and potentially improved public acceptance (reasons behind U4RIA) as highlighted in this review are of great benefit if targets set at COP26 are to be achieved.

Researchers have conducted studies to forecast the demand and supply of electricity due to the significant increase in demand. The increased interest in power demand and supply forecasts is primarily due to the growing population and the incorporation of new and advanced technology. A few of these technologies revolve around the ever-increasing use of rechargeable and renewable domestic and industrial devices, the growing need for distributed electricity, growing numbers of electric vehicles, and smart metering systems. A reliable and workable optimum electricity supply mix can evolve with a sound knowledge of today's electricity demand drivers.

Electricity planning is at the forefront of most research work conducted around the world with 1250 publications in 2019 but studies carried out in relation to the development of clean and affordable power sources mix are less than 300. This highlights the significance of achieving an equilibrium between electricity demand and supply for nations to meet their electricity supply obligations and mitigate GHG emissions. The significant determinants for a more robust power generation system vary across different societies, from underdeveloped to developed economies. Developing economies have a 3% electricity demand growth rate fueled by income levels, industrial output, and service rendering [7]. On the other hand, developed economies have a modest electricity demand growth rate of 0.7%, which is driven by digitalization and electrification with a gradual migration towards a carbon-free electricity supply mix mostly made up of renewable energy sources [8]. Again, the electricity supply forecast is essential to policymakers, investors, and researchers because it can facilitate the matching of growing electricity demand with the available supply.

Studies that have systematically reviewed the literature on power generation mix in developing countries in line with the SDG7 (affordable and clean energy) are hard to come by or unavailable in the existing literature. This paper examined the pros and cons of various power supply mix for developing economies in a way to attain a reasonable assessment of how to overcome the complex problem of insufficient power supply while reducing GHG emissions. This was done by exploring and summarizing power supply mix that are in line with SDG 7 in developing economies and the various energy modelling tools used for power supply mix. Thus, this review will contribute to the realistic representation and the accurate planning of an affordable and clean mixed sources of power generation. Natural gas, coal, biomass, uranium, wind, solar, tidal, form other energy sources for electricity generation. After being harnessed, most of these primary renewable energy sources are frequently converted into heat energy (steam), which is then used to power a turbine connected to an electric generator to produce power. When it comes to wind, wind's kinetic energy is used to rotate the turbine, whereas hydro uses the kinetic energy of water. Solar photovoltaics convert sunlight into electricity using a solar photovoltaic collector. Table 1 compares the power generation mix of Brazil, Argentina, Chile, Mexico, Nigeria, South Africa, Ghana, China, Egypt, Ethiopia, Cameroon, Malaysia, Pakistan, India, Kenya, Turkey, Thailand, and Iran for 2020. The developing countries chosen for this review were based upon the availability of literature information on power generation mix that are in line with the Sustainable Development Goal (SDG) 7 premised on the utilization of different energy modelling tools.

2. Renewable energy potential in developing economies

This section examined the enormous potential of Renewable Energy Systems (RES) such as solar, wind, hydro, distributed renewable energy systems, and bioenergy as well as evaluating them against the U4RIA criteria.

2.1. Solar energy

The energy generated by nuclear fusion within the sun is referred to as solar energy. The latitude and climate of a certain location on earth, has an impact on how much energy is received from the sun [27].

Nigeria receives 1.804×10^{15} kWh of incident solar energy yearly with 6.5 h of sunlight per day based on a surface area of 924,103 km^2 and an average of 5.535 $kWh/m^2/day$ [28]. This study utilized the U4RIA criteria of retrievability in which data is easily accessible coupled with auditability due to the peer review process undergone for

Table 1
Power generation mix, 2020 [9–26].

Country	Solar (MW)	Hydro (MW)	Biomass (MW)	Nuclear (MW)	Wind (MW)	Thermal (MW)	Geothermal (MW)
Brazil	3262	102,206	–	1970	16,813	43,952	–
Argentina	2501	10,812	–	1755	402	24,549	–
Chile	5194	7280	438	–	3720	12,773	39
Mexico	5795	12,612	408	1608	6977	55,776	951
Nigeria	7	2062	–	–	10	11,972	–
South Africa	2323	3485	–	1920	2323	48,380	–
Ghana	23	1580	–	–	–	2796	–
China	253,430	370,160	23,610	49,890	281,530	1,130,870	–
Egypt	190	2832	–	–	967	51,424	–
Ethiopia	–	3743	–	–	337	126	–
Cameroon	–	787	–	–	–	614	–
Malaysia	132	4359	–	–	–	28,301	–
Pakistan	1304	9688	373	2608	559	23,102	–
Kenya	51	826	28	–	331	749	828
India	36,911	50,440	10,146	6780	38,434	230,811	–
Turkey	8776	31,531	408	2041	11,123	46,430	1735
Thailand	2023	3079	3348	–	244	40,961	–
Iran	450	15,976	234	1000	300	48,800	–

transparency. According to Ghana's energy commission, there is a significant solar energy potential throughout the whole nation. With annual sunshine durations ranging from 1800 to 3000 h per year and daily solar irradiation levels between 4 and 6 kWh/m^2, there is a significant grid connection potential [29,30]. The review data was collated through an in depth interaction with both literature sources and a few energy experts with a focus on power supply mix for sustainability of the earth through (SDG) 7 (Ubuntu). The data and information presented was largely organised for ease of accessibility depicting (Retrievability and Auditability). Due to its tropical position, Malaysia has the highest chances of utilizing solar energy, according to Abd. Aziz et al. [31]. With an average daily solar irradiation of 4500 kWh/m^2/day and 12 h of sunlight, Malaysia likewise has a naturally tropical climate. Ubuntu criteria for U4RIA was addressed through the core focus of the review exercise that is, (SDG) 7 covering affordable and clean energy. Furthermore, the study underwent a thorough peer review process which showcased (Auditability). Turkey, which has a typical Mediterranean climate and is located between 36° and 42° N latitudes, has a considerable solar-energy potential as stated by Kaygusuz and Sar [32]. The yearly radiation exposure is 2610 h with an average solar radiation intensity of 3.6 kW h/m^2/day. The number of solar radiation occurrences on a horizontal surface and the duration of the day are counted by a number of recording stations in Turkey. Results for India showed that the yearly exposure to solar radiation was between 1200 and 2300 kWh/m^2, with an incidence of 4–8 kWh/m^2 in a day. There are 250–300 sunny days and 2300–3200 h of sunshine per year. On 3000 km^2 of land, or 0.1% of India's total land area, the country's power needs may be met. This study incorporated the input and voice of various energy stakeholders (Ubuntu), it is also easily accessible (Retrievability) and underwent a rigorous peer review (Auditability) [33–35]. Bob et al. [36] investigated the potential of solar energy in Ethiopia, where irradiation levels ranged from 1858 Wh/m^2/month (in December) to 15,348 Wh/m^2/month (in April) and from 207,232 Wh/m^2/month (in February) to 255,147 Wh/m^2/month (in April) (in May). According to the Laurea University of Applied Sciences [37], the average sun irradiation in Cameroon is 5.8 kWh/m^2/day. The U4RIA criteria of retrievability in which data is easily accessible and auditability due to the peer review process undergone for transparency were all considered in this study. As a developing nation, Mexico can generate vast amounts of power from solar energy. 70% of the nation receives more than 4.5 kWh/m^2/day of insolation. Using photovoltaics that is 15% efficient, 0.01% of Mexico could generate all of the country's power. The U4RIA criteria of retrievability and auditability were considered in this study due to data availability and transparency [38]. Thailand has a lot of solar potential, especially in the southern and northern parts of the province of Udon Thani's northeastern region and certain locations in the center. Around 14.3% of the country gets between 19 and 20 MJ/m^2/day of daily sun exposure, while the other half gets between 18 and 19 MJ/m^2/day. Thailand trails the United States in solar potential but surpasses Japan. This study is easily accessible (Retrievability) and transparent (Auditability) [39].

Photovoltaic (PV) technology can be complemented with the concept of Concentrated Solar Power (CSP). High temperature heat is delivered to a typical power cycle using concentrating collectors. In order to produce electricity in accordance with the demand profile, efficient and affordable thermal energy storing technologies may be added to the CSP system. Additionally, CSP systems can minimize the requirement for "shadow plant capacity," which is necessary to ensure the ability to generate power during periods of low sunlight or wind, as well as offer grid services and, if wanted, black start capabilities. In order to avoid a significant segmentation of costly electric storage technologies in the national grid system, it encourages the infiltration of a higher percentage of sporadic renewable sources, such as wind or solar power. It was not until 2007 that CSP technology began to be widely used commercially, mostly in Spain and the US. Nearly 6 GW of capacity is now in use, and 1.5 GW more are being built globally. Recently, markets have begun to develop, particularly in North Africa and the Middle East, but also in India, China and South Africa [40].

2.2. Hydropower

Hydropower potential exists in almost all developing and underdeveloped countries. This section examines the hydropower potential of a few emerging countries, focusing on Nigeria, South Africa, Kenya, Argentina, Ethiopia, Turkey, Cameroon, and Mexico.

Nigeria has a large number of rivers, waterfalls, and dams, making hydropower the country's main source of electricity production. The total hydroelectric capacity of Nigeria is thought to be around 14,750 MW. Only 1930 MW has been used up to this point. This study integrated the input of various energy stakeholders (Ubuntu), it is also easily accessible (Retrievability) in addition to the rigorous peer review process (Auditability) [41]. Despite being currently underutilized, Cameroon's entire hydro potential is now estimated to be 23 GW, with a production capacity of 103 TWh per year. This study utilized the U4RIA criteria of retrievability in which data is easily accessible including auditability following to the peer review process undergone for transparency [42]. Turkey's gross annual hydro potential, which makes up more than 1% of the total worldwide, is 433,000 GWh. This information is readily available and easily accessible (Retrievability) [43]. The National Commission for the Efficient Use of Energy (CONAE) has branded over 100 excellent locations, despite the fact that Mexico's true capability to generate renewable energy has not yet been determined. For instance, Veracruz and Puebla states are anticipated to produce 3570 GWh annually, which is equal to a mean installed capacity of 400 MW. The related data is easily accessible (Retrievability) and transparent (Auditability) [44]. In comparison to other countries, South Africa has a low average annual rainfall of 500 mm. This, the seasonal flow of the nation's rivers, and extreme droughts or floods all have an impact on how much hydropower can be generated. The eastern escarpment, which has between 6000 and 8000 feasible sites, is where most of the country's hydroelectric potential is concentrated. 8360 MW of hydropower are available in South Africa. Ubuntu, Retrievability and, Auditability are the U4RIA criteria considered in this country [45]. With a theoretically feasible capacity of 130,000 GWh, only around 23% of Argentina's theoretical total hydropower potential (354,000 GWh, 40, 400MW) has been utilized. About 9,780MW of the total generating capacity is now deployed (41% of the total capacity). The data was collated through the involvement of energy experts both locally and internationally (Ubuntu), the data is easily accessed and critically reviewed (Retrievability and Auditability) [46]. Ethiopia has a huge hydropower potential with an about 45,000 MW capacity [47]. Retrievability and Auditability are imbibed in this study [48]. About 6000 MW of electricity are anticipated to be produced by Kenya's hydropower potential, which includes small-scale hydro facilities with a total capacity of more than 3000 MW. This study is easily accessible (Retrievability) and transparent (Auditability) [49].

Many African nations rely largely on hydropower, but during the past few decades, the frequency of droughts has had a significant impact on hydropower output. Installing floating photovoltaics (FPV) in existing hydropower reservoirs will assist offset hydropower output during dry spells, minimize evaporation losses, and sustainably meet the present and future energy demands of the rapidly expanding African population. The installed power capacity of current hydropower facilities may be doubled, and energy output can increase by 58%, producing an additional 46.04 TWh annually, as achieved, with less than 1% complete coverage. In this instance, the water savings might amount to 743 million m^3/year, resulting in an increase of 170.64 GWh in the annual hydroelectricity output. The data was compiled with the help of energy specialists from both domestic and foreign sources (Ubuntu), and it is simple to access and evaluate (Retrievability and Auditability) [50].

2.3. Bioenergy

Photosynthesis produces biomass, which is a kind of indirect solar energy. The most common biomass energy source is fuelwood. This section will assess the potential of bioenergy in underdeveloped and developing countries, focusing on Nigeria, Mexico, Turkey, South Africa, Egypt, Cameroon, and Ghana.

Nigeria's biomass resources are believed to be 8102 MJ, according to Garba and Bashir [51]. In autonomous businesses, plant biomass may be used as a fuel source. Anaerobic bacteria might also mature it, producing highly flexible biogas at a low cost. Mexico has a potential for bioenergy that ranges from 2635 to 3771 PJ annually. This study involved the input of various energy stakeholders (Ubuntu), it is also easily accessible (Retrievability) and underwent rigorous peer review (Auditability) [52]. Turkey's yearly biomass potential is 32 million tons of oil equivalent (Mtoe). Turkey has a 32 million tons of oil equivalent annual biomass potential (Mtoe). There is a total of 16.92 million tons of oil equivalent in recoverable bioenergy (Mtoe). Ubuntu, Retrievability, and Auditability are the U4RIA criteria considered in this study [53]. In South Africa, contemporary and household trash may generate around 11.000 GWh of electricity each year. This study utilized the U4RIA criteria of retrievability in which data is easily accessible and auditability due to the peer review process undergone for transparency [54]. Khalil [55] focused on how Egypt produces over 60 million tons of oil-equivalent (Mtoe) annually, mostly from urban garbage, fuel crops, and agricultural products including sugar cane, rice, maize, and wheat, which can be utilized to generate electricity. The primary sources of Cameroon's biomass potential are agriculture and forestry. Sixty-six locations added 2.7 million m^3 of transformation capacity in 2006. The data was collated through the involvement of energy experts both locally and internationally (Ubuntu), the data is easily accessed and critically reviewed (Retrievability and Auditability) [56]. The accumulation of wood will rise to more than 2.5 million tons by 2020 and to about 3 million tons by 2025 as a result of Ghana's expanding horticulture industry. Alone, the waste from ranches, forestry operations, and sawmills could generate 95 MW of power, enough to handle 600 GWh annually. Ubuntu criteria of U4RIA was considered in the gathering of data and the study underwent peer review showcasing auditability [57].

2.4. Wind energy

The wind is natural when the earth's surface warms up unevenly. The wind's kinetic energy provides lift, which causes the blade of a turbine to spin. Blades coupled to a driving shaft rotate the electric generator, generating power. Wind power output has expanded significantly over the last 30 years, and governments are giving incentives to encourage the use of wind for power generation. This section will look at the wind potential of developing and underdeveloped nations focusing on Nigeria, Mexico, South Africa, Kenya, Ethiopia, Turkey, India, and Argentina.

Similar to South Africa, wind speeds in Nigeria range from 4.0 to 5.12 m/s in the extreme northern region and 1.4–3.0 m/s in the southern part of the country. In most coastal locations, wind speed ranges between 4.0 and 5.0 m/s, although they may exceed 8.0 m/s in hilly places. Ubuntu criteria of U4RIA was considered in the gathering of data and the study underwent peer review showcasing auditability [58–61]. Mexico has a 71,000 MW [62] wind energy potential, however only 1.7% of that capacity is now being used. This study is easily accessible (Retrievability) and transparent (Auditability). There are 500 to 2000 MW of wind energy in Malaysia. The data was collated through the involvement of energy experts both locally and internationally (Ubuntu), the data is easily accessed and critically reviewed (Retrievability and Auditability) [63]. Around Lake Turkana and the Ngong Hills, Kenya offers wind resource potential that might be used to produce power. In the northwest of Kenya, the average wind speed is around 9 m/s at 50 m, but it is about 5–7 m/s at 50 m closer to the shore. This study utilized the U4RIA criteria of retrievability in which data is easily accessible and auditability due to the peer review process undergone for transparency [64]. Ethiopia's overall wind energy potential is more than 10,000 MW, claim Gaddadal and Kodicherla [65]. The U4RIA criteria of retrievability in which data is easily accessible and auditable due to the peer review process undergone for transparency, were all considered in this study. The coast of South Africa has strong wind potential overall, with typical wind speeds of 4–5 m/s at 10 m altitude and 8 m/s in certain hilly areas. This study is easily accessible (Retrievability) and transparent (Auditability) [66]. According to estimates, South Africa has a wind potential of 500 to 56,000 MW. Ubuntu, Retrievability and, Auditability are the U4RIA criteria considered in this country [67]. Turkey has an estimated 48,000 MW of wind energy capacity. However, there are only 7012.75 MW of installed electricity capacity in the entire nation. This study utilized the U4RIA criteria of retrievability in which data is easily accessible and auditability due to the peer review process undergone for transparency [68]. The Centre for Wind Energy Technology (C-WET) first pegged India's entire wind power capacity at about 45 GW; however, it recently increased that figure to 48.5 GW. This number is now considered to be the official estimate by the administration. Ubuntu, Retrievability and, Auditability are the U4RIA criteria considered in this study [69]. Furthermore, despite Argentina having a 2.5 TW projected offshore wind potential, no offshore wind turbines have yet been built. This study is easily accessible (Retrievability) and transparent (Auditability) [70].

2.5. Geothermal energy

The Greek words “geo” (for earth) and “thermos” combine to get the word “geothermal” (heat). Geothermal energy is produced by the radioactive disintegration of minerals in the Earth’s core, which results in the generation of radiant heat (alpha, beta, and gamma). This section examines the geothermal potential of several underdeveloped and developing countries, focusing on Mexico, Turkey, Ethiopia, Kenya, Cameroon, Argentina, and China.

According to recent estimations, Mexico’s geothermal power potential ranges from 2310 MW to 5250 MW [71]. Turkey has significant geothermal potential, contributing to one-eighth of the global total. Turkey has a total geothermal potential of 38,000 MW (MW) (electric and thermal) [72]. Ethiopia is one of Africa’s geothermal energy potential nations, with 5000 MW (MW) [73]. By 2018, Kenya has 653 MW of installed geothermal capacity, and further projects are being planned to enhance its proportion of the power generating mix [74]. The potential for geothermal energy in Cameroon has yet to be fulfilled. There are hot water locations. However, there have been no feasibility studies. To assess their genuine potential, tests have been carried out. They claim that the report on Cameroon is inaccurate [75]. According to Laura et al. [76], Argentina’s geothermal potential is 490–2010 MW. However, this resource is now only used for direct purposes such as balneology (52.7%), household usage (24.6%), home heating (4.6%), greenhouses (4.5%), aquaculture (1.5%), industrial applications (6.7%), and snowmelt (5.4%). The analysis by Hui et al. [77] revealed that China has considerable geothermal resources, making up around 8% of the world’s geothermal energy reserves [78].

2.5. Distributed renewable energy systems

The use of distributed energy resource (DER) projects is expanding in the industrialized nations, particularly in Europe. This has made it possible to reduce CO_2 emissions, utilize fewer primary energy sources (PES), and employ more renewable technologies [79]. However, low levels of economic growth and poor human development indices (HDI) are attributes associated with under developed and developing nations. Low income, unstable economy and poor governance, historical barriers to technology transfer, high costs of technical innovation, and a lack of effective environmental and technological policies are the causes of these issues [80]. Nevertheless, recent decades of industrial development and educational advancements have sparked changes in several economic sectors, including the adoption of new laws and policies governing the energy markets [81]. The adoption of technology that might lessen environmental effects and promote social and economic growth in local communities has been encouraged by these changes [82]. As a result, the application of mathematical modeling tools has been provided, taking into consideration the unique characteristics of developing nations, for detecting trends, impediments, problems, possibilities, and benefits in the startup of distributed energy resources [83]. The greatest obstacle to expanding the contribution of renewable resources to energy generation in developing nations is the economic situation [84]. Therefore, employing more efficient technology is a means of encouraging the implementation of distributed energy systems as opposed to centralized ones. Based on unique criteria and the relative low reliance and operability with regard to the technologies that use fossil fuels and biofuels, there is a significant preference for renewable sources employed as the core of energy systems, especially in off-grid setups. Renewable energy use has grown in developing nations; for example, India has seen a 20% evolvement in power generation emanating from green sources. Brazil has created major economic mechanisms to enhance the utilization of renewable, green energy sources within the energy sector’s technological transformation [85]. However, the reliance on environmental factors forces the employment of conventional technologies as a fallback and the incorporation of new technologies as storage units. As a result, capital costs rise and lead to a dependency on subsidies and outside strategies. Around 15% of the world’s population lacks access to energy facilities, the World Bank reports. This group is primarily found in rural, low-income areas of emerging nations [86]. Therefore, it is crucial to take into account a variety of technical options when defining the design and configuration of the system rather than focusing on a single energy source and taking the availability of nearby energy resources into account. In this view, hybrid systems are viable substitutes for enhancing the systems’ economic performance and quality of energy, notwithstanding the complexity involved in modeling and operating the units. Determining taxes and rates, however, is a significant issue. Despite the potential dual involvement of consumers and producers in the creation of Distributed Generation (DG) projects, the primary actors in the deployment of DG systems at this time are external carriers, the government, and private companies. Therefore, a pressing problem for developing technologies is the establishment of appropriate tariff and pricing regulations for local manufacturing taking into account the needs of the end user [87]. The economic benefit for the end users must also be taken into account as a specific concern in this examination. Due to the establishment of a micro-grid and the existence of several linked players, this problem becomes more difficult.

3. Power supply mix for developing economies

Even among industry experts and veterans, the terms “renewable power supply” and “sustainable power supply” are frequently interchanged. Many sustainable energy sources are also renewable, so there is some overlap between the two. These two terms, however, are not synonymous.

Renewable energy sources replenish themselves at a pace that enables us to meet our power needs. The sustainable power supply is from sources that can meet our current power needs without putting future generations at risk [88].

Energy efficiency (EE) is frequently promoted as a way to conserve both money and energy. By shifting the emphasis from saving to purchasing more goods and services, emerging nations will be able to expand more quickly while simultaneously fostering a more sustainable future for everybody. To support this development, developing nations are attempting to obtain more energy. The developing world’s predicted increase in energy consumption spans South Africa, Indonesia, India, and South America. Between 2015 and 2030, it is anticipated that the overall energy consumption of emerging nations would increase by around 30%, nearly double that of industrialized nations. Developing nations’ reliance on rising energy consumption to fuel economic growth (as opposed to mature economies, where energy demand has often already peaked) is somewhat a reflection of their stage of development. The argument that developing nations have more urgent objectives, such as the eradication of poverty, access to essential services, economic development, severe inequality, and public safety, is sometimes used to explain why these nations lack ambition in the area of energy efficiency [89].

The International Energy Agency (IEA) analysis [90] predicted that electricity demand would increase faster in the long run than any other energy source. Electricity is expected to supersede oil products as the principal ultimate energy carrier in the IEA’s main scenario. Electricity has many advantages, including being generated exclusively by sustainable sources and emitting no carbon at the point of use. It is the most adaptable, effective, and controllable source of energy. This makes it likely that the transition to a clean energy economy would need a renewable power system with a diverse range of renewable energy sources. At the same time, the growing need to increase power accessibility, combat climate change, and the local environment and health consequences of power generation emissions necessitate changing an energy system’s environmental footprint. These ongoing worries have encouraged several policymakers and academics to develop tsustainable power source mix for developing nations. This study summarized the pros and cons of each power source mix and compared them with the U4RIA criteria as shown in Table 2. The countries shown in Table 2 were selected based on the rigorous evaluation of available literature on power generation mix that are in line with Sustainable Development Goal (SDG) 7, (affordable and clean energy) spanning from 2014 to 2021.

4. Power generation models

Developing and analyzing computer models of power systems is known as power generation modelling. In these models, scenario analysis is widely applied. The system under consideration's viability, greenhouse gas emissions, total cost of ownership, resource use, and energy efficiency might all be outputs. There are many different strategies applied, from generally economic to broadly engineering [132]. Power generation models are instruments for analyzing energy policy and making medium- and long-term plans, according to the literature. They aid in establishing how energy technologies' technical and economic components interact and how choosing a particular technology affects energy security, accessibility, cost, and the environment.

The significance of power modeling has grown along with the urgency of addressing climate change. The largest contributor to global greenhouse gas emissions is the energy supply sector [133]. The IPCC asserts that combating climate change would need a thorough overhaul of the energy system, including the substitution of unrestricted (non-CCS) fossil fuel production methods with low-GHG substitutes [134]. In models, mathematical optimization is widely employed to handle redundant system requirements. Operations research is the foundation for several of the methodologies. While nonlinear programming is sometimes used, linear programming is the most common (including mixed-integer programming). The strategies used by solvers might be conventional or genetic. Recursive-dynamic models have the potential to solve each time interval in turn while evolving over time. Additionally, hourly transient responses are necessary for models to fully reflect the real-time dynamics of renewable energy and energy demand management as their significance increases especially during periods of global uncertainties.

In order to create pathways for the energy transition, particularly their ambitious decarbonization, policymakers and academics may simulate and assess energy systems using a variety of computer tools that cover a wide geographic range from towns to countries. Given that these models typically differ greatly from one another, these decision-makers and academics must select the most suitable power system modeling tool depending on the goal and particular objectives of their investigation [135]. Table 3 summarizes modelling tools, such as TIMES, EnergyPLAN, NECAL2050, LEAP, SWITCH, GAMS, Network Planner, ARDL, PLEXOS, GAMS, and MATLAB & MOSE were used for countries covered by this review. We produced the modelling tools in Table 3 from the studies that were reviewed on power generation mix that employed the models in Table 2.

The significance of power system modelling for energy planning cannot be overstated. This has prompted policymakers and academics to use various energy modelling tools to determine the best power generation mix for Nigeria, South Africa, Ghana, Kenya, Ethiopia, Egypt, China, and India. As a result, Table 4 provides an overview of modelling tools used by some underdeveloped and developing countries, including the application, the model used, study description, strengths and weaknesses of the models, and relevant references of each publication. The frequency of use of models in Fig. 1 is the number of studies from the total number of studies reviewed that employed each model. At 28% of policymakers and researchers adopting it, the LEAP model is the most used, followed by TIMES, GAMS, and SWITCH with 11% each. PLEXOS follows them, Network Planner, ARDL at 6%, MATLAB & MOSE, Network Planner, Portfolio approach, NECAL2050, and EnergyPLAN at 5%.

5. Comparison of power modelling tools used in developing countries

This section compares power modelling tools used in underdeveloped and developing countries summarized in Table 4. The power models reviewed in this study are either scenario analysis-based or optimization models. These models have been utilized to improve power access by looking to renewable energy and mitigating GHG emissions to achieve a sustainable power supply mix. A sustainable power supply mix among underdeveloped and developing economies will strengthen their economies, create jobs, improve the decaying infrastructure, security, etc. Such an electricity supply mix will address the significant issue of power accessibility, environmental and health risks, and global warming, which affects the entire world. The magnitude of the problem of global warming prompted nations to come together, as they have done in the past, to produce significant outcomes that will significantly reduce rising temperatures to 1.5°. The 26th UN Climate Change Conference (COP26) at Glasgow has several nations in attendance. The conference is keenly focused on addressing the issue of global warming, which is responsible for difficult situations of heavy rains leading to floods, excessive heat, and drought. The conference's primary goal is to convince governments to agree to keep global warming below 2%. The developed economies have pledged over 100 billion dollars annually to support developing countries in preserving their forest habitats and enhancing renewable energy investments. Furthermore, various developing countries have made pledges toward zero emissions. For instance, Nigeria, a powerhouse in fossil fuel exploration, has set a decarbonization target for 2060. Others include India with a target of 2070, Saudi Arabia with 2060, Israel 2050, Denmark 2050, etc. Several other nations, including South Africa, South Korea, Russia, China, Canada, the USA, etc., have also committed themselves via pledges towards achieving zero carbon-based energy system emissions. Therefore, it is fascinating to look at these countries' modelling tools to plan their electricity supply from literature. Comparing and contrasting each other in terms of application, strengths, and weaknesses.

These power planning models have been utilized for energy system analysis and analyzing CHP production for the Nigerian power system in the case of EnergyPLAN. The ECN's NECAL2050 was used in energy modelling, GHG emissions, and land use. Policymakers and researchers used LEAP for GHG emissions, energy planning, and cost analysis for Kenya, Nigeria, China, and Ghana. The TIMES energy model has been used for energy planning studies in Nigeria and Egypt. GAMS, SWITCH, ARDL, Network Planner, MATLAB & MOSEK, and PLEXOS were adopted for cost planning, energy planning, economic scenario analysis, emissions assessment, and energy optimization in other developing and underdeveloped nations, including India, China, Ethiopia, South Africa, and Egypt. This clearly shows the diversity in which these models have been utilized.

These power models have benefits and drawbacks, but none can be classified as the greatest or worst. Every approach has strengths and weaknesses based on its use in all planning implications and goals. Compared to other models, the NECAL2050 being a country-specific model using Nigeria's data and economic and technical alternatives makes projections much more accurate and closer to reality. The TIMES energy model has an advantage over models because of its simultaneous operation and investment optimization and explicit portrayal of the power system. Another model, LEAP is simple for energy planning, comes with a TED database, and is very adaptable to available data. These advantages have made LEAP the preferred modelling tool for developing and underdeveloped nations, mainly because of its low data requirements, adaptability, and ease of usage. LEAP is adaptable to a wide variety of users, from top global experts who want to devise policies and explain their advantages to decision-makers for trainers who wish to build capacity among new analysts who are taking on the challenge of comprehending the complexities of energy systems. NECAL2050 lists GHG emission sources as fuel combustion, industrial

Table 2
Overview of studies on sustainable power supply mix.

Country	Objective of study	Significant findings of the study	Pros	Cons	U4RIA criteria employed	Ref.
Brazil	To assess the environmental impact of hydropower generation in Brazil	The most significant contributor to air emissions from power generation is carbon dioxide.	1. Lower pollution levels, as measured by carbon footprints 2. Cleaner and healthier environment	Aside from hydro and bioenergy, other renewable energy sources appear to be non-existent due to a lack of funding.	• Retrievability • Reusability • Reconstructability • Auditability	[91]
	Five scenarios for the Brazilian power industry until 2050 were developed and evaluated.	Scenarios with a more significant proportion of fossil fuels are the least desired, whereas wind and biomass-based scenarios are the ideal alternatives through 2050.	1. Positive impact on the environment. 2. Job creation	Policy constraint.	• Retrievability • Reconstructability • Auditability	[92]
	The study examined emissions in the Brazilian power production industry.	According to the Brazilian power generation estimates, CO2eq and NOx emissions per MWh is on the increase.	1. Negative environmental impact. 2. The electricity mix is affordable in terms of emissions.	1. Large hydropower plants are not considered sustainable. 2. Electricity supply is dependent on rainfall. 3. LLack of energy efficiency and conservation guidelines.	• Ubuntu • Retrievability • Reusability • Auditability	[93]
Argentina	To investigate the complementary functioning of a hydro station and wind farm.	The Hydro Power Plant (HPP) may be coupled with the new Wind Farm (WF) to reduce future active power leakage.	1. Energy security. 2. Reduction in carbon emissions.	Financially challenging	• Ubuntu • Retrievability • Reusability • Auditability	[94]
	Energy conversion towards cleaner and explicit systems was investigated, and energy data for hydrogen storage of changeable renewable energy.	Fossil fuels should be phased out in favor of a system that can store vast amounts of power and fuels.	Hydrogen for sea transportation can be feasible	1. Transition to renewables is slow.	• Ubuntu • Retrievability • Reusability • Auditability	[95]
Chile	Employment of bioenergy for electricity generation was studied.	Biomass and biogas are typically employed for small capacity power generation, with biofuel used for transportation.	1. Saves the environment. 2. Employment opportunities.	1. Unavailability of skilled workforce.	• Retrievability • Reusability • Auditability	[96]
	A complete assessment of Chile's electrical generation's environmental sustainability across its entire life cycle.	For six effects, it was 13%, 98% better than solar PV, and for four categories, it was 17%, 66% better than wind.	1. Hydropower provides a cleaner and healthier environment, followed by wind and biogas.	1. To reduce human toxicity, global warming, and ecotoxicities, fossil fuels must be phased out of the current power supply mix.	• Ubuntu • Retrievability • Reusability • Interoperability • Auditability	[97]
	The environmental influence of electricity generated from solar energy was investigated.	PV systems will still contribute their quota to environmental degradation up until 2050, according to the findings.	1. Environment friendly.	1. Until 2050, solar panels will have a substantial environmental impact.	• Reusability • Reconstructability • Auditability	[98]
Mexico	The research investigated the present state of electricity generation in Mexico, with the social and environmental issues.	Renewable energy has great potential for power generation, but a lot still needs to be done by the government to ensure its integration target of 35% by 2025.	1. Renewable energy systems (RES) have the potential to address. Environmental and social issues. 2. Job creation.	1. There is a cultural impact in places where RES are deployed. 2. Because most technology is imported, there is a lack of long-term development.	• Retrievability • Reusability • Auditability	[99]
	This study generates and evaluates scenarios for achieving 75% integration of renewables to have a 100% renewable power system.	To transition to a 100% renewable power supply system by 2050, electricity demand must be drastically reduced.	1. The full potential of green energy can be attained. Hence, the harmful effects of fossil fuel will be eliminated.	–	• Retrievability • Reusability • Reconstructability • Interoperability • Auditability	[100]
	A sustainability impact assessment for electricity generation for solar thermal technology using the "Framework for Integrated Sustainability Evaluation" was performed.	The findings highlight that solar thermal electricity plants (STE) plants will stimulate the economy and decarbonize the electricity supply mix, which will lead to a massive reduction of fossil fuels' effect on the environment.	1. The power supply mix will help to boost the economy and create jobs.	1. Social effects.	• Retrievability • Reusability • Reconstructability • Auditability	[101]
Nigeria	Review of developments in the utilization of concentrated solar power (CSP) and other solar energy technologies.	The parabolic CSP is the cheapest with minor water usage. Still, it requires an adequate feasible application when minors to price per unit of energy and water utilization capacity.	1. Less land requirement. 2. Technical maturity.	1. High capital cost. 2. Water consumption is high.	• Retrievability • Reusability • Auditability	[102]
	A thorough examination of Nigeria's readiness to clean	In Nigeria, decentralized energy systems have been found to have significant	1. Environmentally friendly, efficient, cost-effective, secure, and dependable.	1. The scale of decentralized electricity projects is minimal.	• Ubuntu • Retrievability • Reusability	[103]

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Table 2 (*continued*)

Country	Objective of study	Significant findings of the study	Pros	Cons	U4RIA criteria employed	Ref.
	and modern energy was conducted.	advantages over traditional power generation. This holds in various areas, such as the environment, economics, efficiency, security, and dependability.		2. Only decentralized energy systems that involve users in planning, development, building, operation, and maintenance are long-term viable. 3. The federal government cannot provide the necessary funding.	• Reconstructability • Auditability	
	The paper looks at how a sustainable power supply system will evolve until 2050.	The findings show that integrating renewables with various energy storage technologies will be a competitive alternative.	1. In the medium term, incorporating RE into the existing power supply mix is the most cost-effective solution. 2. Local and international investors will find it quite appealing.	1. It is necessary to have a policy that is both steady and supportive.	• Ubuntu • Retrievability • Reusability • Auditability	[104]
South Africa	The study evaluated different renewable energy technologies (RETs).	According to the findings, solar PV and wind were preferred over CSP.	RE sources further enhance South Africa's social and environmental benefits.	1. Inadequate knowledge and maintenance abilities 2. Site suitability.	• Ubuntu • Retrievability • Reusability • Reconstructability • Auditability	[105]
	This study proposes an IEEM for South Africa that combines demand-side and supply-side management (DSM).	The study improves traditional grid expansion planning by providing practical policy advice on using IEEM to reduce related network losses, increase local energy resource use, and reduce construction and plant running costs.	Beyond normal demand growth development and generation capacity estimation, conventional generation expansion planning (GEP) is advanced.	1. Including industrial and commercial users in the analysis of flexible industrial loads (HVAC), revenue generation, and energy cost reduction is critical. 2. The significance of social institutional processes in promoting wise and equitable power growth has not been taken into account.	• Retrievability • Reusability • Auditability	[106]
Ghana	The report examines Ghana's Renewable Energy Act's regulatory structure, funding incentives, and other elements.	The performance of Ghana's renewable energy strategy on-grid-linked power has been determined to be inadequate compared to its aim.	1. Will address environmental and social issues.	1. Slow in addressing the rising power demand. 2. Rules are partially implemented. 3. Network grid is poor. 4. Financing is difficult to obtain. 5. Disparities in renewable energy policies.	• Ubuntu • Retrievability • Reusability • Reconstructability • Auditability	[107]
	This paper examines the Renewable Energy Act and the regulatory structure.	The policy's performance on grid-connected electricity was judged to be below target.	1. RE to be exploited to meet the growing electricity demand. 2. Great for GHG reduction and ensuring sustainable development.	1. Non-implementation of policies.	• Ubuntu • Retrievability • Reusability • Reconstructability • Auditability	[108]
	Building Ghana's power system model using OSeMOSYS and OnSSET, we termed it "business as usual" (BAU).	BAU might be a realistic alternative for lowering fossil fuel usage and CO_2 emissions, but it comes with the risk of an unstable electricity supply.	Good for the environment.	–	• Retrievability • Reusability • Auditability	[109]
Egypt	This study evaluates Egypt's energy policy and identifies the potential to fulfill rising electricity demand.	A balance of renewable and conventional energy sources is essential, the model's quantitative results suggest.	1. Improves energy security. 2. Reduction in emissions. 3. Reduction in reliance on fossil fuels.	1. Cost constraint.	• Ubuntu • Reusability • Reconstructability • Auditability	[110]
	To shed light on utilizing Egypt's enormous agricultural residual resources optimally and identifying enablers for promoting long-term biomass energy generation.	Gasification for ammonia and diesel fuel production is the preferred energy generation pathway for the implementation horizons. Even though no targets for biomass energy have been specified in Egypt's RE generation targets for 2022, a target proportion of 3% should be set for biomass energy.	1. Reduces carbon dioxide emissions. 2. It is possible to create fertilizer and diesel fuel.	1. No policy 2. Unavailability of incentives	• Retrievability • Reusability • Auditability	[111]
	To predict the evolution of Egypt's electricity industry through 2040 is assessed in	Egypt's projected renewable penetration objective is primarily met by wind power technology. It may be an	Wind, PV, and combined cycle are suitable technologies used in Egypt's power generation mix.	Change in carbon emissions is moderate.	• Ubuntu • Retrievability • Reusability • Auditability	[112]

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Table 2 (*continued*)

Country	Objective of study	Significant findings of the study	Pros	Cons	U4RIA criteria employed	Ref.
	terms of its economic and environmental effects.	alternative to balance the country's vast renewable resource endowments.				
Cameroon	The electricity challenges in Cameroon and the potential and practical contributions of renewables to energy difficulties were studied.	Cameroon will achieve future power objectives and ensure considerable growth in the country with appropriate laws, guidelines, policies, information, capacity building, and off-grid RE investment projects.	1. Solves the problem of insufficient power supply. 2. Energy security. 3. Addresses environmental and health challenges.	1. Depends on rainfall. 2. Inadequate financing. 3. Non-availability of funding.	• Ubuntu • Retrievability • Auditability	[113]
	Decentralized PV/wind/diesel hybrid power generating long-term system viability and techno-economic feasibility.	A standard diesel-producing system was hybridized to improve reliability and cost-effectiveness.	1. Achieving a sustainable power supply system. 2. Reduction of emissions. 3. Reduction of costs.	–	• Ubuntu • Retrievability • Reusability • Reconstructability • Interoperability • Auditability	[114]
	The potential of geothermal energy for power generation in the Cameroon Volcanic Line is assessed by geological research.	There is unexplored geothermal potential in Cameroon. Consequently, renewable energy may reduce energy consumption, particularly in rural regions.	1. Energy security 2. Power supply sustainability.	No enthusiasm from the government to exploit the vast geothermal potential of Cameroon.	• Ubuntu • Retrievability • Reusability • Auditability	[115]
Malaysia	This paper suggests policy and industry roadmaps for the long-term viability of Malaysia's grid-connected oil palm biomass renewable energy sector.	According to the paper, synchronizing upstream and downstream palm oil agricultural activities is required to make the waste to energy industry viable.	1. Job creation in the agricultural sector. 2. Saving the environment.	Translating an excellent idea into reality.	• Ubuntu • Retrievability • Auditability	[116]
	This article examines Malaysia's long-term power generating alternatives using the integrated MARKAL-EFOM system (TIMES) model.	According to the report, big hydropower and other indigenous sustainable energy sources can completely replace fossil fuels by 2050.	1. Diversification of the energy mix. 2. Improvement of the economy and wellbeing of the population. 3. A 100% sustainable power generation by 2050. 4. No need to embrace nuclear energy technology.	–	• Ubuntu • Retrievability • Auditability	[117]
Pakistan	To make long-term electrical supply suggestions to close the demand-supply gap.	The study stated that energy efficiency and conservation initiatives would help Pakistan close the supply-demand imbalance and finally balance its energy mix for power generation.	1. Will solve the problem of insufficient power supply. 2. Ensuring energy security. 3. Combatting climate change.	1. Financial constraint. 2. Lack of commitment from policymakers. 3. Need for energy efficiency and conservation measures.	• Retrievability • Auditability	[118]
	This study aimed to see if chicken manure could be used to generate electricity in Pakistan.	Biogas from chicken manure may be used to generate power, and it is both practical and ecologically sound.	1. Saving the environment.	Unavailability of infrastructure.	• Retrievability • Reusability • Reconstructability • Auditability	[119]
	Wind energy is being harnessed for a long-term power source.	Wind energy has the potential to be Pakistan's answer to the country's energy problems.	1. Energy security. 2. Economical 3. Environment friendly. 4. Conservation of conventional energy resources.	1. Financial constraint. 2. Suitable site location. 3. Low-frequency noise. 4. Poor wind output.	• Retrievability • Reusability • Auditability	[120]
India	Examine multiple power demand scenarios for 2015 through 2030, based on publicly accessible data and trends.	Both scenarios highlight the importance of fossils, renewables, and nuclear generation. For such a situation, both energy and environmental policies should be developed.	1. Reduction of high carbon emissions.	High cost of maintenance	• Ubuntu • Retrievability • Reusability • Auditability	[121]
	An hourly resolved model is used to predict a 100% renewable energy transition pathway for India until 2050.	According to the findings, a decarbonized power system will be achieved by 2050.	1. Cost savings. 2. Net zero-emission option. 3. Competitive.	1. Disposal of nuclear waste. 2. Health risks. 3. Constraint of funds for research and development.	• Retrievability • Reusability • Interoperability • Auditability	[122]
	An in-depth look at India's solar energy potential, current development status, and future possibilities.	Various devices can be powered by solar energy, with coal plants providing 70% electricity.	Emissions reduction.	1. Lack of knowledge of renewable energy technologies. 2. Market barrier. 3. Policy barrier.	• Ubuntu • Retrievability • Auditability	[123]

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Table 2 (*continued*)

Country	Objective of study	Significant findings of the study	Pros	Cons	U4RIA criteria employed	Ref.
Iran	The study examines Iran's bio-power generating capability.	The report estimates Iran's annual bio-power potential at 62,808,106 kWh or 27% of total energy consumption. Bio-based power generation reduces CO_2 emissions by 4096 kt/yr or 0.6% of Iran's annual GHG emissions.	1. Practical way of recycling biowaste. 2. Potentials of GHG emissions reduction.	1. Animal waste management challenge.	• Ubuntu • Retrievability • Reusability • Reconstructability • Interoperability • Auditability	[124]
	From 2015 to 2050, the report presents a power planning method for evaluating the long-term feasibility of future energy scenarios.	The results suggest that the most significant scenario is Cl 32, in which non-hydro renewable energy contributes 32% of total power output.	1. Reduction in GHG emissions.	1. Policy barrier.	• Auditability	[125]
Turkey	The effects of nuclear and renewable energy on Turkey's economic development will be examined.	Turkey's dependency on energy generation would be considerably reduced if nuclear power were produced. As a result, renewable and nonrenewable energy sources and nuclear energy must be employed to keep Turkey's development and power consumption in check.	1. Will solve the problem of growing electricity demand. 2. Energy security.	1. Turkey is an earthquake zone, which might be disastrous if a nuclear disaster occurs.	• Ubuntu • Retrievability • Auditability	[126]
	To make sustainable energy decisions, energy generation systems must be compared. Consequently, Turkey's primary seven power-producing methods were given an output score.	Solar PV and wind power, for example, have high ratings and are increasing their generation share. From a sustainability aspect, renewable energy sources should be utilized entirely.	1. Good for the environment. 2. Energy security.	1. Coal is still the primary energy source.	• Retrievability • Reusability • Auditability	[127]
Thailand	This paper investigates the viability of boosting sun photovoltaic (PV) energy in current diesel-based power production systems.	The optimal scenario would reduce COE to $0.374/kWh, CO2 (796.61 tons/yr), and other gas emissions (21.47 tons/yr).	1. Reduction of electricity cost. 2. Reduced emissions 3. Reduction in fuel consumption.	1. Increase in capital cost of the system.	• Ubuntu • Retrievability • Reusability • Auditability	[128]
	This research looked into the advantages of community renewable energy (CRE) programs supported by Thailand's Ministry of Energy.	CRE initiatives may assist communities in various ways, including coexisting with human agricultural operations and forest conservation.	1. Environmental protection. 2. Contribution to the sustainable development of communities.	1. Policy constraint.	• Ubuntu • Retrievability • Reusability • Reconstructability • Auditability	[129]
Mexico	Investigate an alternate scenario for a Mexican Low Carbon Electric Power System from an environmental and economic angle.	By 2020, GHG emissions would have decreased by 33%, and by 2035, they would have reduced by 79%.	1. Positive about the environment. 2. Good for the economy.	1. Cost constraint. 2. Policy barrier.	• Ubuntu • Retrievability • Auditability	[130]
	The temporal energy complementarity of solar and wind energy is illustrated in Mexico.	Mexico has various areas with high energetic complementarity, some presently being used. However, according to the research, there are still places in the country's center, and north that have not been explored and where renewable energy generating systems may be created.	1. Sustainable power supply. 2. Positive about the environment.	1. Policy constraint.	• Ubuntu • Retrievability • Reusability • Interoperability • Auditability	[131]

operations, solvent, and other product usages, agricultural, LULUCF, waste, bioenergy credit, and carbon capture and storage [138]. PLEXOS is simple for computation. MATLAB & MOSEK solves non-linear, quadratic, mixed-integer quadratically constrained, conic and convex problems. The network planner generates precise demand estimates compared to the other modelling tools in the literature. Finally, GAMS has the capability of entering data without changing the algebra.

The challenges being confronted with by utilizing these modelling tools include low resolution as noticed when using TIMES, LEAP does not have optimization capabilities, Network Planner does not consider small hydro, bioenergy plants, small wind turbines, solar household systems, etc., and the remaining modelling tools such as GAMS, PLEXOS, MATLAB, SWITCH and so on. Are free for students only. However, critical sub-sectors, including power generation, gas flaring, and transportation, are included under fuel combustion emissions. As a result, NECAL2050 cannot be utilized to do a more in-depth study of the options for lowering emissions from these primary sources. GAMS, PLEXOS, and MATLAB have optimization capabilities. At various phases of the policy and modeling cycles, the limits of these energy modeling techniques do influence policy decisions. Models' effect on policymaking depends on both how successfully a country has used energy models and the procedures it uses to apply them. Additionally, it appears that variations in the use of models are dependent on broader policy choices. Modeling is more frequently employed as an exploratory,

Table 3
Summary of power modelling software [135–152].

Name	Type (open source or Propriety licenses)	Developer	About	Uses	Shortcoming
The TIMES energy model	Free and open-source software.	IEA's (ETSAP)	TIMES utilizes a bottom-up multi-period optimization model for the most cost-effective energy system.	To assess a country's energy system includes primary energy supply, secondary energy conversion, energy service needs across multiple end-use industries, and the associated infrastructure and technology.	Low resolution.
The EnergyPLAN simulation program.	Freeware	Aalborg University's Sustainable Energy Planning Research Group	It is designed to examine energy systems using various technical and economic methodologies.	It is utilized for RE integration, studying combined heat and power (CHP) production, market exchange analysis, technical analysis, and feasibility assessments, among other things.	Not efficient when modelling non-future energy systems.
Nigerian Energy Calculator 2050-NECAL2050.	Open-source	United Kingdom Department of Energy and Climate Change (UK-DECC) and Nigerian Energy Commission (ECN).	NECAL2050 uses an accounting system to match supply and demand continually. It combines a mix of present and future technologies to fulfill shifting demand.	Evaluating various low-carbon scenarios' energy balance and GHG reduction potential.	Lacks the capability to be utilized for modelling of different countries or regions.
LEAP model	Free use for academic purposes.	Stockholm Environment Institute.	It is a tool for assessing energy strategy and reducing climate change.	It generates different scenarios for projected energy usage and environmental effect depending on residential or industrial unit counts.	Absence of optimization capabilities.
MATLAB & MOSEK	The free version is available for students.	Cleve Moler	The energy system model is a linear optimization tool.	The optimal investment and generating technology combination to fulfill demand.	Open-source available for students only.
PLEXOS	Commercially available.	Energy Exemplar	A modelling tool for the electricity, gas, and water market.	Iterative planning procedures for lower costs and higher returns.	Functions on a static database and does not allow the inclusion of new generators.
SWITCH model	Commercial	Fripp, Johnston & Maluenda	An aggressive expansion model focuses on new generation and transmission assets and end-use and demand-side planning and management to explore system performance under different scenarios.	Examines the most cost-effective energy systems that fulfill particular reliability, performance, and environmental quality requirements.	Versatility is low.
Portfolio approach.	Free	US Department of Energy CCS R & D management.	A model that correctly depicts the decision problem's key characteristics.	Provides a structure for the many forms of data that must be included in resource allocation choices and a systematic and repeatable procedure for assessing options against goals.	Outcome is under-calculated compared to the actual simulation.
GAMS (General Algebraic Modelling System).	Free for students.	Alexander Meeraus, Richard C. Price, and Gary Kutcher.	A mathematical optimization system with a high-level modelling system.	Mixed-integer, linear, and nonlinear optimization problems may all be modeled and analyzed with this tool.	Commercial software is expensive for young researchers.
Network planner	Free	Modi research group, earth institute, Columbia University.	Examining the cost of various electrification methods.	Cost analysis	RE systems such as small hydro, bioenergy plants, tiny wind turbines, solar household systems, and so on are not considered.

auxiliary tool for goal-setting and effect evaluation. Models are often used more frequently as exploratory tools for aim formulation and instrument evaluation in policy processes with lower levels of internal disagreement. It was noted that models were more frequently employed to defend established ideas than to consider other perspectives. It is anticipated that model-based climate and energy policy advice will become more significant over time as policymaking becomes more complicated. Due to the case study nature and complexity of policy making processes, it is impossible to determine the extent to which models affected final policy decisions or to make firm generalizations about the circumstances in which models had a disproportionately positive impact.

The study considered attributes such as low input data requirements, user support, user friendly interface, data set availability, ability to export results, adaptability, distribution capability, optimization capability, power system tracking, fuel availability, cost availability, etc., as shown in Table 5 to compare the various energy modelling tools considered in this study. This would help researchers and policy makers choose the best modelling tool based on the criteria.

6. Existing renewable projects for power generation in developing economies

Power consumption per capita is frequently used to assess a country's technical, social, and economic development [171,172]. In comparison to developing economies, electricity consumption in industrialized economies is relatively high across all sectors of the economy. Electric cars and trains are now the norm, compressors, electric heaters, boilers, refrigerators, and air conditioners are all powered by electricity. These countries' electrical supply mix includes

Table 4
Overview of energy modelling software tools used in the selected developing and underdeveloped countries.

Country	Model	Area of Application	Description of study	Strength	Weakness	Ref.
Brazil	The EnergyPLAN simulation program.	1. Energy Planning	100% (Renewable Energy) RE system was researched.	1. Renewable scenarios were able to be compared for technical, cost, emissions, and risk parameters.	1. Not efficient when modelling non-future energy systems.	[153]
	LEAP model	1. Analyze Energy Policy	100% RE system was researched.	1. Highlights how systematically accounting for health and climate costs in energy planning would economically justify the decarbonization of energy systems.	–	[154]
Argentina	LEAP model	1. Emissions mitigation	Evaluated the impact of a variety of climate change control policies.	1. Based on scenarios and an energy-environment modeling tool, it tracks both energy demand and environmental impacts on the same platform. 2. It contains a TED talk (Technology and Environment Database). 3. It is adaptable in terms of data availability, with a modest initial data need that may be increased if comprehensive data for the study area becomes available.	–	[155]
	LEAP model	1. GHG mitigation	Explored deep decarbonization pathways for the country until 2050 which break with existing more conservative national scenarios.	–	–	[156]
Chile	LEAP model	1. Energy planning and analysis	Generated an energy and environmental model	–	–	[157]
	LEAP model	1. Energy modelling	Examined different CO_2 emission baseline scenarios	1. It is simple to use and ideal for measuring energy demand and transformation in underdeveloped nations.	–	[158]
Mexico	The EnergyPLAN simulation program.	1. Energy planning	Evaluates several scenarios of renewables incorporation into the Mexican electricity system.	1. It allows for applying various energy methods in energy system analysis.	1. Not efficient when modelling non-future energy systems.	[159]
	LEAP model	1. Environmental analysis	Presented three scenarios relating to the environmental futures of Mexico	–	–	[160]
	LEAP model	1. GHG mitigation	Analyzed the potential contributions of Carbon Capture and Storage (CCS) systems on the electrical sector, as well as the participation of the cement, metal and chemical industries.	–	- -	[161]
Nigeria	The TIMES energy model	1. Energy planning	100% RE system was researched.	1. Over the whole modelling horizon, simultaneous operation and investment optimization across the entire energy system. 2. Explicit portrayal of the economy's most important sectors. 3. Modular framework with the option of connecting to a quantifiable equilibrium model for an extra model to get insight into.	1. Low resolution	[135]
	The EnergyPLAN simulation program.	1. Energy system analysis 2. Analyzing Combined Heat and Power (CHP) production.	This report proposes how electricity will be 100% available in all parts of the country.	1. It is a deterministic model that can do RES calculations using data that is both stochastic and intermittent. 2. Different systems are optimized in different ways. 3. With an hourly time-step, it may undertake an annual study of an entire innovative system. 4. It models a RE system by taking losses and other	2. Not efficient when modelling non-future energy systems.	[136]

(continued on next page)

Table 4 (*continued*)

Country	Model	Area of Application	Description of study	Strength	Weakness	Ref.
				technical factors into account. 5. It may analyze district cooling and heating, electric car integration, RE integration, electricity import/export, etc. 6. It allows for applying various energy methods in energy system analysis. 7. Analytic programming, rather than dynamic, sophisticated mathematical tools, or iterative programming, is used for analysis.		
	Nigerian Energy Calculator 2050-NECAL2050.	1. Energy modelling 2. GHG emissions 3. Land use	Using the Nigerian Energy Calculator 2050, the researcher developed four scenarios; their energy balances and emissions were compared.	1. The model's paths were created utilizing Nigerian data and economic and technological options.	1. Under the heading "emissions from fuel burning," a more detailed examination of methods for reducing emissions from power generation, gas flaring, and transportation is gathered. As a result, it is impossible to achieve.	[137]
	LEAP model	1. Analyze Energy Policy 2. Mitigation of climate change	Leap compared predicted emissions, demand, and supply from 2010-to 2040.	1. It is simple to use and ideal for measuring energy demand and transformation in underdeveloped nations. 2. Based on scenarios and an energy-environment modeling tool, it tracks both energy demand and environmental impacts on the same platform. 3. It contains a TED talk (Technology and Environment Database). 4. It is adaptable in terms of data availability, with a modest initial data need that may be increased if comprehensive data for the study area becomes available. 5. IIt is free to use for researchers in underdeveloped countries.	1. Lacks optimization capability.	[138]
South Africa	MATLAB & MOSEK	1. Engineering 2. Finance 3. Computer science	South Africa's pathways to a completely decarbonized and low-cost power grid are studied.	1. Conic, conic-integer, and convex nonlinear problems.	1. Free for students only.	[139]
	PLEXOS	1. Energy planning	For South Africa, this report advises boosting energy sector capacity to discover the best cost-effective and decarbonized energy mix.	1. Simple computation	1. Functions on a static database and does not allow the inclusion of new generators.	[140]
Ghana	LEAP model	_	The level to which Ghana might rely on biomass was studied.	_	_	[141]
	Network Planner	1. Investigating the costs of various electrification alternatives in un-electrified communities.	Costs for providing electricity were evaluated using Network Planner.	1. The model generates precise demand estimations. 2. Produces cost forecasts. 3. Suggests the most cost-effective method of powering communities.	1. RE systems such as small hydro, bioenergy plants, tiny wind turbines, solar household systems, and so on are not considered.	[142]
	LEAP model	_	The research evaluates Ghana's existing electricity generating growth plan and compares it to potential development paths with increased Renewable Energy Technology adoption.	_	_	[143]
Egypt	The TIMES energy model	_	This article establishes a local TIMES modelling basis for the energy industry.	_	_	[144]
Ethiopia	GAMS	_	Investigated the most cost-effective investment choices for Ethiopia's various integrated energy sources.	_	_	[145]

(*continued on next page*)

Table 4 (*continued*)

Country	Model	Area of Application	Description of study	Strength	Weakness	Ref.
	ARDL model	1. Economic scenario 2. Energy planning 3. Emissions assessment and so on.	Under an improved EKC framework, the research emphasizes the influence of renewables and conventional energy sources in impacting emissions.	1. Adaptable	1. Performs better for a small amount of data.	[146]
Kenya	SWITCH model	1. Planning transitions to low-emission electric power systems.	The research looked at low-carbon growth routes for Kenya's power industry.	1. It allows users to compose customized models.	1. Less versatile	[147]
	LEAP model	_	Three pathways were analyzed based on emissions and costs.	_	_	[148]
China	SWITCH model	_	The financial and technical costs of a decarbonization scenario, from medium to long term, were examined considering extremely short-term renewable variability.	_	_	[149]
	LEAP model	_	Investigations into how to reduce emissions were carried out.	_	_	[150]
	Portfolio approach.	1. Energy planning	The article compared costs, efficient frontiers, diversification, and risk levels under various instances and scenarios.	1. Characterized by having a more comprehensive capacity and conceptual richness.	1. Outcome is under-calculated compared to the actual situation.	[151]
Cameroon	MESSAGE modelling tool	1. GHG mitigation	Identified the energy electricity demand, proposes solutions, and calculates the greenhouse gases emitted in each of the interconnected networks available in Cameroon.	1. Most basic data is only required. 2. Models can be formulated using concise algebraic statements.	1. Commercial software is expensive for young researchers.	[162]
Malaysia	ARIMA	1. Energy forecasting	Fitted the 40 years forecast up to 2053 by assessing 40 years of past data from 1973 until 2013	1. Simple to implement. 2. No parameter tuning.	1. Difficult to predict turning points.	[163]
	LEAP model	1. Energy planning	Developed a few power generation scenarios with various fossil and renewable resource shares for Malaysia.	1. Low data requirements.	–	[164]
Pakistan	LEAP model	1. Energy planning	Four supply side scenarios for the study period (2013–2035) have been developed for power generation.	1. Flexibility	–	[165]
	LEAP model	1. Cost analysis 2. Energy planning	Compared five supply side scenarios to find the best competitor of Business as Usual scenario and technically tries to increase the share of RE in electricity generation.	1. It is free to use for researchers in underdeveloped countries.	–	[166]
India	GAMS (General Algebraic Modelling System).	1. Energy optimization 2. Environment assessment. 3. Transportation and so on.	This report examines the region's power supply status for the year 2018.	1. Models can be formulated using concise algebraic statements. 2. Most basic data is only required. 3. Data can be entered into the model without changing the algebra. 4. Formulate linear, non-linear, and integer problems.	1. Commercial software is expensive for young researchers.	[152]
Turkey	ARDL model	1. GHG mitigation	Examined the potential of renewableenergysources in reducing the impact of GHG emissions in Turkey.	1. Adaptability	1. Performs better for a small amount of data.	[167]
	LEAP model	1. Environmental analysis	Presented the outcomes of the environmental impact assessment of renewable energy scenarios relevant with the sustainable perception in Turkey using energy modelling for the period 2014–2050.	–	–	[168]
Thailand	LEAP model	1. Energy security analysis 2. GHG mitigation	Estimated and analyzes the renewable energy potential in the energy mix in Thailand.	–	–	[169]
Iran	MESSAGE modelling tool	1. Long-term energy planning	Focus was paid to the long-term adoption of renewable electricity technologies and their implications for emissions reductions in Iran.	1. Helps design long term strategies by analysing cost optimal energy mix. Investment needs and other costs for new infrastructure, energy supply security, energy resource utilization, rate of introduction of new technologies (technology learning), environmental constraints.	–	[170]

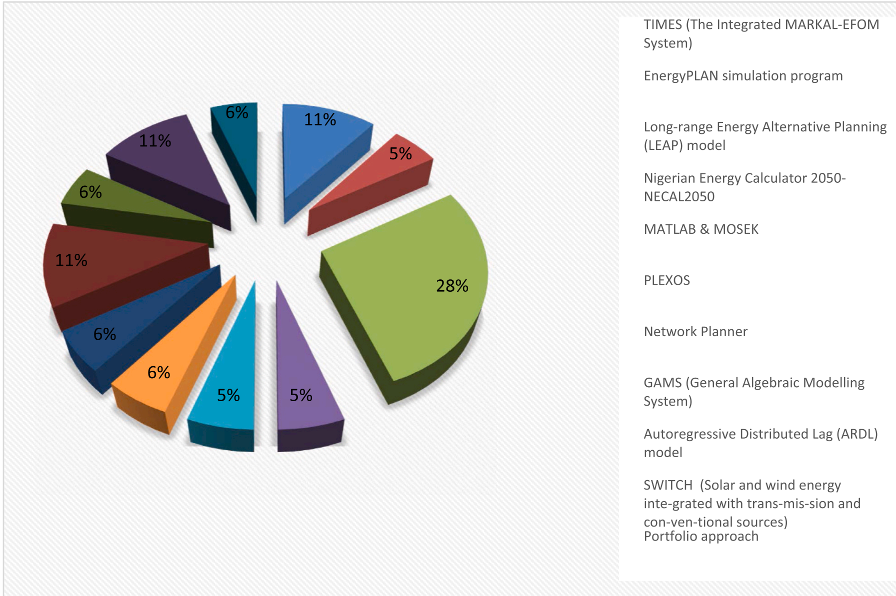

Fig. 1. Software solutions with embedded energy modelling tools used for power generation.

conventional and renewable energy sources [173].

Power outages are a significant issue in underdeveloped and developing countries which rely heavily on diesel and gasoline-powered generators, polluting the environment and producing a lot of noise. RE sources should be adopted for power generation to meet this enormous power supply burden while also ensuring environmental safety, as supported by the literature used for this study [174–178]. An electricity supply mix that includes renewable energy sources and existing energy sources is required to ensure a sufficient, cost-effective, and environmentally friendly power supply system.

This section reviews several studies on renewable energy systems, microgrids, and smart grids for developing economies. This would be highly beneficial because it would allow such countries to design policies that would encourage the deployment of renewable energy sources. At the same time, investors would be able to look into renewable energy investment opportunities.

According to international standards, South Africa has not paid much attention to the extensive deployment of hydropower generation except for a new small-scale plant with a capacity of 7 MW that was built and commissioned in the Sol Plaatjie municipality Free State area, there has been no significant hydropower development in the last three decades. Hydropower electricity accounts for only 5% of the total installed capacity of 45,500 MW [179]. Only around 1930 MW (14%) is generated in Nigeria's three most extensive hydroelectric power facilities, which are located in Shiroro, Kainji, and Jebba [180]. Small hydropower plants (SHPs) were built before Nigeria's independence. Currently, Kano, Sokoto, the plateau, and Ogun have eight SHPs totaling 37 MW. Egypt's hydropower capacity is 3664 MW, with a 15,300 GWh yearly production. Currently, there are five significant hydropower plants [181]. With 280 MW, 85.68 MW, 270 MW, 64 MW, and 2100 MW, Aswan I is the largest hydroelectric facility in Egypt. Egypt has mini/small hydropower potential with a shows the small/mini hydropower potential location, head (m), flow (m^3/sec), and power (MW) [182]. Almost 80% of Brazil's electrical energy consumption (currently 60%) was generated by hydroelectric power facilities [183]. Following Russia and China, Brazil has the third-highest hydroelectricity potential. In terms of installed hydroelectric power by the end of 2021, Brazil was the second-place nation globally (109.4 GW) [184]. According to the Energy Ministry, 17 additional hydroelectric power facilities with a combined capacity of 3517 MW are also being built around the nation. The capacity of Iran's current electricity production is 81 GW, with hydroelectric power accounting for around 16% of that total [185]. About 80% of Mexico's renewable energy supply still comes from hydropower, making it the greatest renewable energy source in the nation. By the end of 2017, hydropower accounted for 10% of all forms of energy generation in the nation, or around 17% of the total installed capacity. The nation's installed hydropower capacity is 12,125 MW, while its potential hydropower output is predicted to be 27,000 MW [186]. With a total installed capacity of over 7000 MW (MW) of hydropower producing capacity in 26 hydroelectric dams around the nation, hydropower in Thailand is the largest renewable energy source in the country, surpassing both solar energy and wind energy. The Bhumibol Dam, which has eight turbines and a combined capacity of 749 MW, is Thailand's largest hydroelectric dam [187]. Sarawak Hidro's 2400 MW Bakun project, which became Malaysia's largest hydropower plant when it was opened in 2011, and Sarawak Energy's 944 MW Murum facility, which started full operations in 2015, are current examples of hydropower plants in Malaysia. Additionally, Sarawak Energy's 1285 MW Baleh project obtained state government clearance in 2016, and there are a number of other hydro projects in the works that may provide an additional 4 GW of capacity [188]. 197 hydropower facilities exist in India. The rise of authority in India began around the end of the 19th century. The Sidrapong Hydropower Facility, a hydroelectricity project in Darjeeling, was inaugurated in 1897. And a hydroelectric power plant was inaugurated in Sivasamudram, Karnataka, in 1902 [189]. The domestic hydropower potential of Cameroon is projected to be 23,000 MW, with 75% of the capacity concentrated in the Sanaga River basin, which lies in the country's north. However today, barely 3% of Cameroon's hydropower potential is being used. The building of the 200 MW Memve'ele hydroelectric project was finished in 2017. The Cameroonian government, the International Finance Corporation, and the EDF Group created the 420 MW Nachtigal hydropower project, the biggest independent hydroelectric project in Sub-Saharan Africa. The 1800 MW Grand Eweng project, which will be finished in 2024 and rank as Africa's fourth-largest hydropower plant, is another significant project now under development [190]. In the Ethiopian state of Beneshangul Gumuz, the Blue Nile River is being developed for the Grand Renaissance Hydroelectric Project (GRHEP), formerly known as the Millennium Project of Ethiopia. With an installed capacity of 6,450MW [191], it will be the greatest hydroelectric project in Africa and one of the largest power plants still under development worldwide.

Photovoltaic (PV) is extensively used in rural South Africa for

Table 5
Evaluation of energy modelling tools.

	Energy Modelling Tool														
		TIMES	Energy PLAN	NECAL2050	LEAP	MATLAB & MOSEK	SWITCH	PORTFOLIO	GAMS	MESSAGE	ARIMA	ARDL	Network Planner	ARDL	PLEXOS
Ranking Criteria	Low input data requirements				✓										
	User support				✓	✓	✓		✓	✓			✓		✓
	User-friendly interface	✓		✓	✓	✓	✓		✓	✓			✓		
	Data set availability			✓	✓				✓	✓					
	Ability to export results			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Adaptability	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Integration with other software				✓					✓					✓
	Online training	✓				✓							✓		
	Simulation	✓		✓	✓	✓	✓		✓	✓			✓		✓
	Unit set points	✓		✓	✓	✓		✓	✓	✓			✓		✓
	Total emission intensity	✓			✓	✓		✓	✓	✓			✓		
	Climate modelling						✓		✓				✓		
	Transmission capability			✓	✓	✓		✓	✓	✓			✓		✓
	Distribution capability			✓	✓	✓		✓	✓	✓			✓		✓
	Optimization capability	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Power system tracking	✓		✓	✓	✓		✓	✓	✓			✓		✓
	Fuel availability			✓	✓	✓		✓	✓	✓			✓		✓
	Cost availability	✓		✓	✓	✓	✓	✓	✓	✓			✓		✓

lighting, household appliances, telecommunications, and water pumps. PV technology will be used up to 14% of the time. Supply will double by 2050 [192]. A French oil company developed one of Nigeria's most significant PV projects to produce 1000 MW of solar electricity. The location is ideal for the project since it gets a lot of solar radiation and has numerous dispersed inhabitants [193]. Private companies from Egypt and abroad have offered to build 20 solar energy projects for $30 billion with a capacity of 20,000 MW (MW) in only two years [194]. Brazil installed 17 GW of solar energy in August 2022. Brazil was the 11th greatest producer of solar energy in the world in 2021 (16.8 TWh), and it ranked 14th globally in terms of installed solar power (13 GW) [195]. Ituverava and the Nova Olinda plants are the two biggest solar power facilities in Brazil. Both the Nova Olinda and Ituverava solar plants have outputs of 254 MW and 292 MW, respectively [196]. Bhumibol Dam Solar PV Park, with a capacity of 778 MW, is being built near Tak by the Electricity Generating Authority of Thailand. The primary project is anticipated to start in 2024 and go into operation commercially in 2026 [197]. In India, one of the most popular and quickly growing industries is solar power. The largest solar parks and electricity producing facilities in India are located in Tamil Nadu, Gujarat, Rajasthan, Telangana, Maharashtra, and Madhya Pradesh. One of the largest solar farms in the world, Shakti Sthala Pavagada Solar Park in Karnataka spans 13,000 acres and has a 2000 MW power producing capacity. Kadaladi Solar Park, located in the Ramanathapuram district, is a projected 4000 MW power station and 500 MW solar park constructed by Tangedco near Naripaiyur Village [198].

Although South Africa's wind energy potential is between 500 and 56,000 MW, the demonstration plant at Klipheuwel owned by ESKOM and the wind farm at Darling have only produced 0.05%. The wind turbines aren't linked to the national grid [199,200]. The 10 MW wind farm near Rimi village, 25 km south of Katsina, is Nigeria's first. The wind farm has 37.55 m tall wind turbines with a 275 kW rated output. The project is sponsored solely by the Federal Ministry of Power and is 98% complete as of May 2015. The mean annual wind speed in Katsina is 6.044 m/s [201]. Egypt's Supreme Council of Energy authorized a proposal to use renewable energy sources to generate 20% of power by 2020. Wind energy may make up to 12% of overall energy usage. Wind farms at Zafarana and the Gulf of El-zeyt can produce 545 MW and 200 MW, respectively [202]. Brazil installed 22 GW of wind energy as of July 2022. Brazil was the fourth-largest producer of wind energy in the world in 2021 (72 TWh), after only China, the United States, and Germany [203]. In terms of installed wind power, Brazil ranked seventh in the world in 2021 (21 GW). Argentina offers a perfect environment for the generation of wind energy, with strong winds covering around 75% of the country's surface. The Argentinian government authorized 6.5 GW of renewable energy projects between 2016 and 2019, bringing in investments totaling about $7.5 billion. Of this capacity, 5 GW are currently in use [204]. The amount of wind energy produced in Mexico is increasing quickly. Its installed capacity was 3527 MW in 2016 and will reach 8128 MW in 2020 [205].

The estimated biomass contribution to Nigeria's power sector is negligible and unavailable [206]. Egypt's biomass resources offer tremendous potential for energy production, despite minimal development. The most prevalent agricultural waste is wheat, maize, rice, and sugar cane. For Suzan Abdelhady and co. (ICAE2014), a year's worth of rice straw may provide 2477 GWh of electricity. According to the FOA, Egypt is Africa's largest rice producer (Food and Agriculture Organization). In South Africa, specific paper and sugar mills burn bagasse to create steam, yielding over 210 GWh of energy each year. The streams in Kwazulu-Natal and Mpumalanga have the most biomass energy. It contains around 4300 km^2 of sugar cane plantations and 13,000 km^2 of forestry farms. A sugar mill annually uses 210 GWh of paper and bagasse [207]. With 15,2 GW installed, Brazil ranked second globally in the production of energy from biomass (electricity from solid biofuels and renewable waste) in 2020 [208].

The South African National Energy Development Institute (SANEDI) says smart grid technologies would help South Africa achieve its desired energy mix. Without smart grids, large-scale renewable energy integration is impossible. In terms of service delivery, smart grid technology enables municipalities to use integrated systems and procedures, resulting in unprecedented efficiency and effectiveness. The South African National Energy Development Institute (SANEDI) says smart grid technologies would help South Africa achieve its desired energy mix. Without smart grids, large-scale renewable energy integration is impossible. In terms of service delivery, smart grid technology enables municipalities to use integrated systems and procedures, resulting in unprecedented efficiency and effectiveness [209]. Johannesburg, the Municipality of Tshwane, and the Nelson Mandela Bay Municipality have all undertaken smart metering programs. The Ethekwini Municipality is trialing smart meters for customers who are small-scale energy generators (SSEG) such as those with roof top solar panels [210]. Smart grid technology paves the path for greater use of green energy from renewable sources. Nigeria's electricity industry has yet to progress to the point where it can accommodate smart grid technology [211]. Egypt's state-owned Egyptian Energy Holding Company (EEHC) will upgrade its electrical system with Schneider Electric's help. Schneider Electric will build four control centers to monitor and improve the electrical network in 18 months. It will also deploy over 12,000 smart ring central units nationwide. They aim to upgrade 1000 distribution points and substations. Hardware-based cybersecurity software will protect the network [212].

In Africa, where the power grid has failed, microgrids and off-grid household solar systems are rapidly adopted. A gas-diesel hybrid microgrid powers the Zwartkop Chrome Mine and the Thabazimbi Chrome Mine in South Africa. ABB is also "drinking their own kool-aid" with a microgrid with a big solar footprint at the ABB Longmeadow Facility in South Africa [213]. Six new microgrids have been built in Nigeria at the same time as part of a World Bank-backed rural electrification scheme. The examples demonstrate the vast potential that can be realized by scaling up microgrid rollout efforts. The solar hybrid microgrid projects in Nasarawa State will supply clean, reliable, and inexpensive electricity to around 5000 families and 500 businesses. Six communities in the Doma and Lafia local government regions will access electricity [214]. The Sakuri Mine Solar Microgrid Project in Egypt, which will utilize smart grid technologies, is now under construction. The project has a 36MW rated capacity. Juwi is in charge of the smart grid initiative [215,216].

7. Conclusion

Power supply is still very much insufficient in underdeveloped and developing economies. Most of these countries depend on coal and natural gas for power generation. Fossil fuels pollute the environment and are responsible for global warming causing harm to people's health. Developed nations like Germany, the UK, Switzerland, the USA, Canada, and others have significantly reduced carbon emissions from fossil fuel power plants. Therefore, as a matter of urgency, there is a need for developing and underdeveloped economies to follow suit. Both developing and underdeveloped nations face the challenge of inadequate power supply, environmental, global warming, and health impacts from their existing power generation mix. All the studies reviewed suggested that having a sustainable power supply mix will address these challenges. Renewable energy sources such as solar, wind, hydro, biomass, tidal, geothermal, and even alternative energy sources such as nuclear energy are insignificant proportion. They should be captured and used for power generation. From literature, it is found that hydropower is the most utilized renewable energy resource, followed by solar power, wind, and then biomass. The slow transition to RE sources in underdeveloped and developing nations is attributed to governments' lack of commitment to significant policies, standards, and regulatory systems, making it difficult for local and foreign investors to invest. Another factor is nonexistent or insufficient energy efficiency and conservation policies, social factors, unavailability of skilled workforce, natural causes such as lack of rainfall, land constraint, grants, and subsidies. To achieve a sustainable power supply system, rapid economic growth, and industrialization, factors such as energy efficiency, conservation regulations, microgrid technologies, and smart-grid systems require urgent attention. Determining the power supply mix of an underdeveloped and developing nation depends on the resources available in the region or the ability to import them, the amount of power to be provided, and historical, financial, societal, demographic, conservational, and geopolitical factors all influence the decision. As a result, the power supply mix varies from one country to another. Energy models incorporate these data to develop a power supply mix specific to the country being studied.

The paper then reviewed various energy modelling tools utilized in developing an optimum power generation mix for these upcoming nations. These models used for power sources mix development include TIMES, EnergyPLAN simulation program, LEAP model, NECAL2050, MATLAB & MOSEK, PLEXOS, Network Planner, GAMS, ARDL model, SWITCH, and Portfolio approach. These models were compared to each other considering factors such as low input data requirements, user support, user friendly interface, data set availability, ability to export results, adaptability, distribution capability, optimization capability, power system tracking, fuel availability, cost availability, etc., for selection criteria. It was found that every power modelling tool has its strength and weakness depending on its application in all the consequences and objectives of planning.

The best way to address insufficient power supply in developing economies while also reducing GHG emissions is to invest in an optimal mix of harnessed sustainable energy sources. As reviewed in this study, developing countries have developed their own optimal power sources mix by utilizing the various energy modelling tools considered in this study. Developing an optimal supply mix involves optimizing various conflicting objectives such as clean and affordable energy (SDG7) that was considered in this study. This is now a multi-objective problem with two objectives (clean and affordable energy) that is solved subject to various constraints such as resource availability, emission factors, costs, etc., to produce the optimal sources mix a developing country. With regards to power modelling tools, a model should be chosen based on energy characteristics and objectives, and these models can be customized in such a way to meet the peculiarities of developing nations' techno-economic considerations. Energy mix optimization modelling and decision support system premised on systems thinking is an immediate future work being considered to foster the mission of power supply sustainability both in the developing and underdeveloped economies.

This would result in the generation of weights for each specific factor. These weights would in turn be deployed into a multi-objective, multi-constraints optimization model for the conduct of simulation trials. Objectives that can be considered apart from those considered in SDG7 are jobs, land utilization, water availability, costs, operation and maintenance, etc., subject to constraints such as: available land, water potential, costs constraint, jobs creation factor, and operation and maintenance factor.

Authorship contributions

Hanif Auwal Ibrahim: Conception and design of study, acquisition of data, analysis and/or interpretation of data, Drafting the manuscript. **Michael Kweneojo Ayomoh**: Conception and design of study, analysis and/or interpretation of data. **Ramesh C. Bansal**: Conception and design of study, analysis and/or interpretation of data.

Intellectual property

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

Research ethics

We further confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

IRB approval was obtained (required for studies and series of 3 or more cases)

Written consent to publish potentially identifying information, such as details or the case and photographs, was obtained from the patient(s) or their legal guardian(s).

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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References

[1] M. Sharifzadeh, H. Lubiano-Walochik, N. Shah, Integrated renewable electricity generation considering uncertainties: the UK roadmap to 50% power generation from wind and solar energies, Renew. Sustain. Energy Rev. 72 (2017) 385–398, https://doi.org/10.1016/j.rser.2017.01.069.
[2] M. Muchlis, D. Adhi, D. Permana, Pengembangan Sistem Kelistrikan Dalam Menunjang Pembangunan Nasional Jangka Panjang Proyeksi Kebutuhan Listrik PLN Tahun, 2003.
[3] T.H. Abreu Kang, A.M. da Costa Soares Júnior, A.T. de Almeida, Evaluating electric power generation technologies: a multicriteria analysis based on the FITradeoff method, Energy 165 (2018) 10–20, https://doi.org/10.1016/j.energy.2018.09.165.
[4] World Energy Outlook 2010 – Analysis - IEA n.d. https://www.iea.org/reports/world-energy-outlook-2010 (accessed March 22, 2022).
[5] G. Najafi, B. Ghobadian, T. Tavakoli, T. Yusaf, Potential of bioethanol production from agricultural wastes in Iran, Renew. Sustain. Energy Rev. 13 (2009) 1418–1427, https://doi.org/10.1016/j.rser.2008.08.010.
[6] Home - UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 n.d. https://ukcop26.org/(accessed March 22, 2022).
[7] R.C. Bansal, A.F. Zobaa, in: "Handbook of Renewable Energy Systems, World Scientific Publisher, UK, 2022.
[8] IEA – International Energy Agency - IEA n.d. https://www.iea.org/reports/%20world-energy-outlook-2019 (accessed March 22, 2022).
[9] 2021 Q1 electricity & other energy statistics | China Energy Portal | n.d. https://chinaenergyportal.org/en/2021-q1-electricity-other-energy-statistics/(accessed March 22, 2022).
[10] Q. Feng, X. Sun, J. Hao, J. Li, Predictability dynamics of multifactor-influenced installed capacity: a perspective of country clustering, Energy 214 (2021) 118831.
[11] Power Africa in Kenya | Power Africa | U.S. Agency for International Development n.d. https://www.usaid.gov/powerafrica/kenya (accessed March 22, 2022).
[12] UNdata | record view | Electricity, the net installed capacity of electric power plants n.d. http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aEC (accessed March 22, 2022).
[13] 2019 detailed electricity statistics (update of Jan 2021) | China Energy Portal | n.d. https://chinaenergyportal.org/en/2019-detailed-electricity-statistics-update-of-jan-2021/(accessed March 22, 2022).
[14] UNdata | record view | Total Electricity n.d. http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aEL#EDATA (accessed March 22, 2022).
[15] Electricity sector in Mexico - Wikipedia. En.wikipedia.org. https://en.wikipedia.org/wiki/Electricity_sector_in_Mexico. Published 2022. Accessed September 30, 2022.
[16] Electricity sector in Pakistan - Wikipedia. En.wikipedia.org. https://en.wikipedia.org/wiki/Electricity_sector_in_Pakistan. Published 2022. Accessed September 30, 2022.
[17] Republic of Turkey Ministry of Energy and Natural Resources - Electricity. Enerji.gov.tr. https://enerji.gov.tr/infobank-energy-electricity. Published 2022. Accessed September 30, 2022.
[18] D. Kidmo, K. Deli, B. Bogno, Status of renewable energy in Cameroon, Renewable Energy and Environmental Sustainability 6 (2021) 2, https://doi.org/10.1051/rees/2021001.
[19] Dosm.gov.my. https://www.dosm.gov.my/v1/uploads/files/6_Newsletter/newsletter%202018/Series%2010_Electricity%20Sector.pdf. (Accessed 30 September 2022).
[20] Electricity sector in Chile - wikipedia. En.wikipedia.org. https://en.wikipedia.org/wiki/Electricity_sector_in_Chile. Published 2022. Accessed September 30, 2022.
[21] Afdb.org. https://www.afdb.org/sites/default/files/2021/11/22/cameroon.pdf. Published 2022. Accessed September 30, 2022.
[22] Electricity sector in Argentina - Wikipedia. En.wikipedia.org. https://en.wikipedia.org/wiki/Electricity_sector_in_Argentina. Published 2022. Accessed September 30, 2022.
[23] BNamericas - Brazil added almost 5GW of generation capaci… BNamericas.com. https://www.bnamericas.com/en/news/brazil-added-almost-5gw-of-generation-capacity-in-2020. Published 2022. Accessed September 30, 2022.
[24] Installed power capacity by source Greece 2020 | Statista. Statista. https://www.statista.com/statistics/1153672/installed-power-capacity-greece-by-source/. Published 2022. Accessed September 30, 2022.
[25] Iran's installed electricity generation capacity at 83.35GW. Tehran Times. https://www.tehrantimes.com/news/445967/Iran-s-installed-electricity-generation-capacity-at-83-35GW. Published 2022. Accessed September 30, 2022.
[26] Adb.org. https://www.adb.org/sites/default/files/linked-documents/49087-001-so.pdf. Published 2022. Accessed September 30, 2022.
[27] D. Fadai, Utilization of renewable energy sources for power generation in Iran, Renew. Sustain. Energy Rev. 11 (2007) 173–181, https://doi.org/10.1016/j.rser.2005.01.011.
[28] C. Augustine, M.N. Nnabuchi, Relationship between global solar radiation and sunshine hours for Calabar, Port Harcourt, and Enugu, Nigeria 4 (2009) 182–188.
[29] S.O. Oyedepo, Energy and sustainable development in Nigeria: the way forward. Energy,, Sustainability and Society 2 (1) (2012) 1–17.
[30] F. Kemausuor, G.Y. Obeng, A. Brew-Hammond, A. Duker, A review of trends, policies, and plans for increasing energy access in Ghana, Renew. Sustain. Energy Rev. 15 (2011) 5143–5154, https://doi.org/10.1016/j.rser.2011.07.041.
[31] Aziz PD. Abd, S.S.A. Wahid, Y.Z. Arief, Aziz N. Ab, Evaluation of solar energy potential in Malaysia, Trends in Bioinformatics (9) (2016) 35–43, https://doi.org/10.3923/TB.2016.35.43.
[32] Kaygusuz K, Sarı A. Renewable Energy Potential and Utilization in Turkey. (n.d).
[33] P. Veeraboina, G.Y. Ratnam, Analysis of the opportunities and challenges of solar water heating system (SWHS) in India: estimates from the energy audit surveys & review, Renew. Sustain. Energy Rev. 16 (2012) 668–676, https://doi.org/10.1016/j.rser.2011.08.032.
[34] S. Pandey, V.S. Singh, N.P. Gangwar, M.M. Vijayvergia, C. Prakash, D.N. Pandey, Determinants of success for promoting solar energy in Rajasthan, India, Renew. Sustain. Energy Rev. 16 (2012) 3593–3598, https://doi.org/10.1016/j.rser.2012.03.012.
[35] N.K. Sharma, P.K. Tiwari, Y.R. Sood, Solar energy in India: strategies, policies, perspectives and future potential, Renew. Sustain. Energy Rev. 16 (2012) 933–941, https://doi.org/10.1016/j.rser.2011.09.014.
[36] B. van der Zwaan, A. Boccalon, F. Dalla Longa, Prospects for hydropower in Ethiopia: an energy-water nexus analysis, Energy Strategy Rev. 19 (2018) 19–30, https://doi.org/10.1016/j.esr.2017.11.001.
[37] International - Laurea-ammattikorkeakoulu n.d. https://www.laurea.fi/en/international/(accessed March 22, 2022).
[38] Sunny Mexico: An Energy Opportunity | Greentech Media n.d. https://www.greentechmedia.com/articles/read/sunny-mexico-an-energy-opportunity (accessed March 22, 2022).
[39] Solar power in Thailand. - Wikipedia n.d. https://en.wikipedia.org/wiki/Solar_power_in_Thailand. (accessed March 22, 2022).
[40] T. Letcher, Future Energy, third ed., Elsevier, 2020, 3rd ed.
[41] U. Aliyu, S. Elegba, Prospects for small hydropower development for rural applications in Nigeria, Nigerian Journal of Renewable Energy 1 (1990) 74–86.
[42] R.C. Bansal (Ed.), "Handbook of Distributed Generation: Electric Power Technologies, Economics and Environmental Impacts", Springer, Cham, Switzerland, 2017.
[43] A. Demirbaş, Sustainable developments of hydropower energy in Turkey, Energy Sources 24 (2002) 27–40, https://doi.org/10.1080/00908310252712280.
[44] T. Adefarati, R.C. Bansal, "Impacts of PV-wind-diesel-electric storage hybrid system on the reliability of a power system", Energy Proc. 105 (2017) 616–621.
[45] P. Sharma, H.D. Mathur, P. Mishra, R.C. Bansal, "A review of energy management strategies for microgrids", Appl. Energy 327 (120028) (2022) 1–25.
[46] L.I. Levieux, F.A. Inthamoussou, H. De Battista, Power dispatch assessment of a wind farm and a hydropower plant: a case study in Argentina, Energy Convers. Manag. 180 (2019 Jan 15) 391–400.
[47] T. Adefarati, R.C. Bansal, "Reliability and economic evaluation of a micro grid power system", Energy Proc. 142 (2017) 43–48.

[48] B. Khan, P. Singh, The current and future states of Ethiopia's energy sector and potential for green energy: a comprehensive study, Int. J. Eng. Res. Afr. 33 (2017) 115–139, https://doi.org/10.4028/WWW.SCIENTIFIC.NET/JERA.33.115.
[49] R.C. Bansal, T.S. Bhatti, Small Signal Analysis of Isolated Hybrid Power Systems: Reactive Power and Frequency Control Analysis, *Alpha Science International, Oxford, U.K*, 2008.
[50] R.G. Sanchez, I. Kougias, M. Moner-Girona, F. Fahl, A. Jäger-Waldau, Assessment of floating solar photovoltaics potential in existing hydropower reservoirs in Africa, Renew. Energy 169 (2021 May 1) 687–699.
[51] R.C. Bansal, "Automatic reactive power control of autonomous hybrid power systems", PhD thesis, IIT Delhi, India (2003).
[52] Turkey | World Energy Council n.d. https://www.worldenergy.org/impact-communities/members/entry/turkey (accessed March 22, 2022).
[53] Final Energy Report South Africa Commissioned by the Netherlands Enterprise Agency. (n.d).
[54] Country Briefs – GET.invest n.d. https://www.get-invest.eu/market-information/country-briefs/(accessed March 22, 2022).
[55] Renewable energy sector in Egypt - Open to Export n.d. https://opentoexport.com/article/renewable-energy-sector-in-egypt/(accessed March 22, 2022).
[56] Renewable Energies in West Africa Regional Report on Potentials and Marktes-17 Country Analyses Energy-Policy Framework Papers, Section »Energy and Transport« Promotion of Renewable Energies, 2009.
[57] N.T. Mbungu, R.C. Bansal, R. Naidoo, "Overview of optimal smart energy coordination for microgrid applications", IEEE Access 7 (2019) 163063–163084.
[58] T. Chidiezie Chineke, C. Theo Chineke, Boosting Electricity Supply in Nigeria: Wind Energy to the Rescue? Spatial and Temporal Characterization and Projections of Aerosol Loading and Impacts over West Africa View Project Boosting Electricity Supply in Nigeria: Wind Energy to the Rescue?, 2009.
[59] T. Adefarati, R.C. Bansal, M. Bettayeb, R. Naidoo, "Optimal energy management of a PV-WTG-BSS-DG microgrid system, Energy 217 (119538) (2021) 1–21.
[60] C.I.OriakuJ.C. Osuwa, A.D. Asiegbu, G.U. Chukwu, C.O. Kanu, Frequency distribution analysis of available wind resources in Umudike, Abia State, Nigeria for Wind Energy Conversion, Syst Des 8 (2) (2007) 203–206.
[61] D.A. Fadare, The application of artificial neural networks to mapping of wind speed profile for energy application in Nigeria, Appl. Energy 87 (2010) 934–942, https://doi.org/10.1016/j.apenergy.2009.09.005.
[62] A. Sujil, R. Kumar, R.C. Bansal, "Multi agent based autonomous energy management system with self-healing capabilities for a microgrid, IEEE Trans. Ind. Inf. 15 (12) (2019) 6280–6290.
[63] Rosnazri Ali, Ismail Daut, Soib Taib. A review on existing and future energy sources for electrical power generation in Malaysia, Renew. Sustain. Energy Rev. 16 (2012) 4047–4055.
[64] Get, invest. Kenya Renewable Energy Potential n.d. https://www.get-invest.eu/market-information/kenya/renewable-energy-potential/. (Accessed 23 March 2022).
[65] S. Gaddada, S.P.K. Kodicherla, Wind energy potential and cost estimation of wind energy conversion systems (WECSs) for electricity generation in the eight selected locations of Tigray region (Ethiopia), Renewables: Wind, Water, and Solar 3 (2016), https://doi.org/10.1186/s40807-016-0030-8.
[66] R. Singh, R.C. Bansal, "Optimization of an autonomous hybrid renewable energy system using reformed electric system cascade analysis", IEEE Trans. Industrial Informatics, vol, 15, no 1 (2019) 399–409.
[67] H.A. Ibrahim, M.K. Ayomoh, Optimum predictive modelling for a sustainable power supply mix: a case of the Nigerian power system, Energy Strategy Rev. 44 (2022 Nov 1) 100962.
[68] C. İlkiliç, Wind energy and assessment of wind energy potential in Turkey, Renew. Sustain. Energy Rev. 16 (2) (2012 Feb 1) 1165–1173.
[69] S. Sharma, S. Sinha, Indian wind energy & its development-policies-barriers: an overview, Environmental and Sustainability Indicators 1 (2019 Sep 1) 100003.
[70] M. Senatla, R.C. Bansal, R. Naidoo, L. Chiloane, U. Mudau, "Estimating the economic potential of PV rooftop systems in South Africa's residential sector: a tale of 8 metropolitan municipalities, IET Renew. Power Gener. 14 (4) (2020) 506–514.
[71] M. Senatla, R.C. Bansal, R. Naidoo, B. Bredenkamp, T. Yusuf, "Increasing deployment of solar PV in the commercial sector in South Africa: past greenhouse gas emissions implications and net-zero implications by 2050", in: 13th International Conference on Sustainable Energy & Environmental Protection, SEEP, Vienna, Austria, 2021.
[72] M. Senatla, R.C. Bansal, R. Naidoo, B. Bredenkamp, T. Yusuf, "Virtual power plants to add market value for the highly distributed solar PV penetration levels from commercial and residential sectors: the case of South African metropolitan cities, in: 13th International Conference on Sustainable Energy & Environmental Protection, SEEP, Vienna, Austria, 2021.
[73] A. Kumar, Y. Deng, X. He, A.R. Singh, P. Kumar, R.C. Bansal, M. Bettayeb, R. Rayudu, "Sustainable rural electrification based on socio-techno-economic-environmental-political (STEEP) microgrid design framework", Energy, Environ. Sci. J. Integr. Environ. Res. 15 (2022) 4213–4246.
[74] A. Kumar, A.R. Singh, Y. Deng, X. He, P. Kumar, R.C. Bansal, "A novel methodological framework for the design of sustainable rural microgrid for developing nation", *IEEE Access*, vol, 6, no 1 (2018) 24925–24951.
[75] A.A. Mas'ud, A.V. Wirba, F. Muhammad-Sukki, I.A. Mas'ud, A.B. Munir, N. M. Yunus, An assessment of renewable energy readiness in Africa: case study of Nigeria and Cameroon, Renew. Sustain. Energy Rev. 51 (2015) 775–784.
[76] A. Laura Chiodi, R. Filipovich, C.L. Agostina, F.E. Rubén, E.L. Carlos, P.H. Abel, et al., Monogenetic Volcanism in the Andes View Project Geothermal Country Update of Argentina: 2015-2020, 2020.
[77] L. Hui, Z. Qingjun, T. Puyuan, H. Wenguang, Technologies and Applications of Geophysical Exploration in Deep Geothermal Resources in China, 2015.
[78] X.G. Zhao, G. Wan, Current situation and prospect of China's geothermal resources, Renew. Sustain. Energy Rev. 32 (2014) 651–661, https://doi.org/10.1016/j.rser.2014.01.057.
[79] H.L. Ferreira, A. Costescu, A. L'Abbate, P. Minnebo, G. Fulli, Distributed generation and distribution market diversity in Europe, Energy Pol. 39 (9) (2011) 5561–5571.
[80] M. Bell, K. Pavitt, Technological accumulation and industrial growth: contrasts between developed and developing countries, in: D. Archibugi, J. Michie (Eds.), Technology, Globalization and Economic Performance vol. 95, Cambridge University Press, 1997, 83-137 & Fatas, A.; Mihov, I. Policy volatility, institutions, and economic growth. Rev. Econ. Stat, 2013, pp. 362–376, 2.
[81] C. Newman, J. Rand, F. Tarp, Industry switching in developing countries, World Bank Econ. Rev. 27 (2) (2012) 357–388.
[82] Z. Hussein, T. Hertel, A. Golub, Climate change mitigation policies and poverty in developing countries, Environ. Res. Lett. 8 (3) (2013) 35009.
[83] R. Pandey, Energy policy modelling: agenda for developing countries, Energy Pol. 30 (2) (2002) 97–106.
[84] D.M. Kammen, C. Kirubi, Poverty, energy, and resource use in developing countries, Ann. N. Y. Acad. Sci. 1136 (1) (2008) 348–357.
[85] B. Jairaj, S. Martin, J. Ryor, S. Dixit, A. Gambhir, A. Chunekar, R. Bharvirkar, G. Jannuzzi, S. Sukenaliev, T. Wang, The future electricity grid, World Resources Institute (2016). https://www.wri.org/sites/default/files/The_Future_Electricity_Grid.pdf. (Accessed 29 September 2022).
[86] World development indicators, 2016, the World Bank, USA 2016. http://databank.worldbank.org/data/download/site-content. (Accessed 10 July 2017).
[87] J.M. Barrett, Challenges and requirements for tomorrow's electrical power grid, in: *Future of the power grid series*, 2, 2016. https://www.cmu.edu/epp/irle/readings/barrett-tomorrows-electrical-power-grid.pdf. (Accessed 29 September 2022).
[88] H.A. Ibrahim, M.K. Ayomoh, Identification and prioritisation of electricity driving factors for power supply sustainability: a case of developing and underdeveloped nations, in: 2021 IEEE Asia-Pacific Conference on Computer Science and Data Engineering (CSDE), IEEE, 2021, pp. 1–6.
[89] Scaling up energy efficiency in developing countries. Usaid.gov. https://www.usaid.gov/energy/efficiency/building-blocks. Published 2022. Accessed October 3, 2022.
[90] Energy technology perspectives 2014 – analysis - IEA n.d. https://www.iea.org/reports/energy-technology-perspectives-2014 (accessed March 23, 2022).
[91] M.V. Barros, C.M. Piekarski, A.C. de Francisco, Carbon footprint of electricity generation in Brazil: an analysis of the 2016-2026 period, Energies 11 (2018), https://doi.org/10.3390/en11061412.
[92] R. Singh, R.C. Bansal, A. Singh, R. Naidoo, "Multi-objective optimization of hybrid renewable energy system using reformed electric system cascade analysis for islanding and grid connected modes of operation", IEEE Access 6 (2018) 47332–47354.
[93] R. de Souza Henriques, R.R. Saldanha, L.M.G. Coelho, An air pollutant emission analysis of Brazilian electricity production projections and other countries, Energies 12 (2019), https://doi.org/10.3390/en12152851.
[94] L.I. Levieux, F.A. Inthamoussou, H. de Battista, Power dispatch assessment of a wind farm and a hydropower plant: a case study in Argentina, Energy Convers. Manag. 180 (2019) 391–400, https://doi.org/10.1016/j.enconman.2018.10.101.
[95] J.L. Aprea, J.C. Bolcich, The energy transition towards hydrogen utilization for green life and sustainable human development in Patagonia, Int. J. Hydrogen Energy 45 (2020) 25627–25645, https://doi.org/10.1016/j.ijhydene.2020.01.246.
[96] C. Rodríguez-Monroy, G. Mármol-Acitores, G. Nilsson-Cifuentes, Electricity generation in Chile using non-conventional renewable energy sources – a focus on biomass, Renew. Sustain. Energy Rev. 81 (2018) 937–945, https://doi.org/10.1016/j.rser.2017.08.059.
[97] C. Gaete-Morales, A. Gallego-Schmid, L. Stamford, A. Azapagic, Assessing the environmental sustainability of electricity generation in Chile, Sci. Total Environ. 636 (2018) 1155–1170, https://doi.org/10.1016/j.scitotenv.2018.04.346.
[98] M.I. Vega, C.A. Zaror, The effect of solar energy on the environmental profile of electricity generation in Chile: a midterm scenario, International Journal of Energy Production and Management 3 (2018) 110–121, https://doi.org/10.2495/EQ-V3-N2-110-121.
[99] E. Pérez-Denicia, F. Fernández-Luqueño, D. Vilariño-Ayala, L. Manuel Montaño-Zetina, L. Alfonso Maldonado-López, Renewable energy sources for electricity generation in Mexico: a review, Renew. Sustain. Energy Rev. 78 (2017) 597–613, https://doi.org/10.1016/j.rser.2017.05.009.
[100] J.J. Vidal-Amaro, C. Sheinbaum-Pardo, A transition strategy from fossil fuels to renewable energy sources in the Mexican electricity system. Journal of Sustainable Development of Energy,, Water and Environment Systems 6 (2018) 47–66, https://doi.org/10.13044/j.sdewes.d5.0170.
[101] I. Rodríguez-Serrano, N. Caldés, Rúa C de la, Lechón Y. Assessing the three sustainability pillars through the Framework for Integrated Sustainability Assessment (FISA): case study of a Solar Thermal Electricity project in Mexico, J. Clean. Prod. 149 (2017) 1127–1143, https://doi.org/10.1016/j.jclepro.2017.02.179.
[102] O. Ogunmodimu, E.C. Okoroigwe, Concentrating solar power technologies for solar thermal grid electricity in Nigeria: a review, Renew. Sustain. Energy Rev. 90 (2018) 104–119, https://doi.org/10.1016/j.rser.2018.03.029.
[103] S.O. Oyedepo, O.P. Babalola, S.C. Nwanya, O. Kilanko, R.O. Leramo, A. K. Aworinde, et al., Towards a sustainable electricity supply in Nigeria: the role of

decentralized renewable energy system, European Journal of Sustainable Development Research 2 (2018), https://doi.org/10.20897/ejosdr/3908.
[104] A.S. Oyewo, A. Aghahosseini, D. Bogdanov, C. Breyer, Pathways to a fully sustainable electricity supply for Nigeria in the mid-term future, Energy Convers. Manag. 178 (2018) 44–64, https://doi.org/10.1016/j.enconman.2018.10.036.
[105] P. Naicker, G.A. Thopil, A framework for sustainable utility scale renewable energy selection in South Africa, J. Clean. Prod. 224 (2019) 637–650, https://doi.org/10.1016/j.jclepro.2019.03.257.
[106] C.G. Monyei, K.E.H. Jenkins, S. Viriri, A.O. Adewumi, Policy discussion for sustainable integrated electricity expansion in South Africa, Energy Pol. 120 (2018) 132–143, https://doi.org/10.1016/j.enpol.2018.05.021.
[107] M. Sakah, F.A. Diawuo, R. Katzenbach, S. Gyamfi, Towards a sustainable electrification in Ghana: a review of renewable energy deployment policies, Renew. Sustain. Energy Rev. 79 (2017) 544–557, https://doi.org/10.1016/j.rser.2017.05.090.
[108] Ghana's electricity supply mix has improved, but reliability and cost are still a challenge n.d. https://theconversation.com/ghanas-electricity-supply-mix-has-improved-but-reliability-and-cost-is-still-a-challenge-161762 (accessed March 23, 2022).
[109] Ahmed A, Gong J. Assessment of the Electricity Generation Mix in Ghana: the Potential of Renewable Energy.
[110] M.A.H. Mondal, C. Ringler, P. Al-Riffai, H. Eldidi, C. Breisinger, M. Wiebelt, Long-term optimization of Egypt's power sector: policy implications, Energy 166 (2019) 1063–1073, https://doi.org/10.1016/j.energy.2018.10.158.
[111] A.O. Abdulrahman, D. Huisingh, The role of biomass as a cleaner energy source in Egypt's energy mix, J. Clean. Prod. 172 (2018) 3918–3930, https://doi.org/10.1016/j.jclepro.2017.05.049.
[112] Y.Y. Rady, Rocco M v., serag-eldin MA, colombo E. Modelling for power generation sector in developing countries: case of Egypt, Energy 165 (2018) 198–209, https://doi.org/10.1016/j.energy.2018.09.089.
[113] E. Muh, S. Amara, F. Tabet, Sustainable energy policies in Cameroon: a holistic overview, Renew. Sustain. Energy Rev. 82 (2018) 3420–3429, https://doi.org/10.1016/j.rser.2017.10.049.
[114] B.E.K. Nsafon, A.B. Owolabi, H.M. Butu, J.W. Roh, D. Suh, J.S. Huh, Optimization and sustainability analysis of PV/wind/diesel hybrid energy system for decentralized energy generation, Energy Strategy Rev. 32 (2020), https://doi.org/10.1016/j.esr.2020.100570.
[115] P.N. Nemzoue, N.A. Keutchafo, J.P. Tchouankoue, Geothermal development in Cameroon, Revista de Engenharia Térmica 19 (1) (2020 Sep 9) 32–41.
[116] M.S. Umar, T. Urmee, P. Jennings, A policy framework and industry roadmap model for sustainable oil palm biomass electricity generation in Malaysia, Renew. Energy 128 (2018) 275–284, https://doi.org/10.1016/j.renene.2017.12.060.
[117] R. Haiges, Y.D. Wang, A. Ghoshray, A.P. Roskilly, Optimization of Malaysia's power generation mix to meet the electricity demand by 2050, Energy Proc. 142 (2017) 2844–2851, https://doi.org/10.1016/j.egypro.2017.12.431. Elsevier Ltd.
[118] G. Valasai, das, Uqaili MA, Memon HUR, Samoo SR, Mirjat NH, Harijan K. Overcoming electricity crisis in Pakistan: a review of sustainable electricity options, Renew. Sustain. Energy Rev. 72 (2017) 734–745, https://doi.org/10.1016/j.rser.2017.01.097.
[119] M. Arshad, I. Bano, N. Khan, M.I. Shahzad, M. Younus, M. Abbas, et al., Electricity generation from biogas of poultry waste: an assessment of potential and feasibility in Pakistan, Renew. Sustain. Energy Rev. 81 (2018) 1241–1246, https://doi.org/10.1016/j.rser.2017.09.007.
[120] M.H. Baloch, S.A. Abro, G.S. Kaloi, N.H. Mirjat, S. Tahir, M.H. Nadeem, et al., A research on electricity generation from wind corridors of Pakistan (two provinces): a technical proposal for remote zones, Sustainability 9 (2017), https://doi.org/10.3390/su9091611.
[121] L.S. Tiewsoh, J. Jirásek, M. Sivek, Electricity generation in India: present state, future outlook and policy implications, Energies 12 (2019), https://doi.org/10.3390/en12071361.
[122] A. Gulagi, D. Bogdanov, C. Breyer, The role of storage technologies in energy transition pathways towards achieving a fully sustainable energy system for India, J. Energy Storage 17 (2018) 525–539, https://doi.org/10.1016/j.est.2017.11.012.
[123] S. Manju, N. Sagar, Progressing towards the development of sustainable energy: a critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India, Renew. Sustain. Energy Rev. 70 (2017) 298–313, https://doi.org/10.1016/j.rser.2016.11.226.
[124] S.M. Safieddin Ardebili, Green electricity generation potential from biogas produced by anaerobic digestion of farm animal waste and agriculture residues in Iran, Renew. Energy 154 (2020) 29–37, https://doi.org/10.1016/j.renene.2020.02.102.
[125] V. Aryanpur, M.S. Atabaki, M. Marzband, P. Siano, K. Ghayoumi, An overview of energy planning in Iran and transition pathways towards sustainable electricity supply sector, Renew. Sustain. Energy Rev. 112 (2019) 58–74, https://doi.org/10.1016/j.rser.2019.05.047.
[126] B. Kok, H. Benli, Energy diversity and nuclear energy for sustainable development in Turkey, Renew. Energy 111 (2017) 870–877, https://doi.org/10.1016/j.renene.2017.05.001.
[127] G. Yilan, M.A.N. Kadirgan, G.A. Çiftçioğlu, Analysis of electricity generation options for sustainable energy decision making: the case of Turkey, Renew. Energy 146 (2020) 519–529, https://doi.org/10.1016/j.renene.2019.06.164.
[128] P. Peerapong, B. Limmeechokchai, Optimal electricity development by increasing solar resources in diesel-based micro grid of island society in Thailand, Energy Rep. 3 (2017) 1–13, https://doi.org/10.1016/j.egyr.2016.11.001.
[129] C. Chaichana, W. Wongsapai, D. Damrongsak, K.N. Ishihara, N. Luangchosiri, Promoting community renewable energy as a tool for sustainable development in rural areas of Thailand, Energy Proc. 141 (2017) 114–118, https://doi.org/10.1016/j.egypro.2017.11.022. Elsevier Ltd.
[130] G. Grande-Acosta, J. Islas-Samperio, Towards a low-carbon electric power system in Mexico, Energy for Sustainable Development 37 (2017) 99–109, https://doi.org/10.1016/j.esd.2017.02.001.
[131] R.P. Gallardo, A.M. Ríos, J.S. Ramírez, Analysis of the solar and wind energetic complementarity in Mexico, J. Clean. Prod. 268 (2020), https://doi.org/10.1016/j.jclepro.2020.122323.
[132] J. Després, N. Hadjsaid, P. Criqui, I. Noirot, Modelling the impacts of variable renewable sources on the power sector: reconsidering the typology of energy modelling tools, Energy 80 (2015) 486–495, https://doi.org/10.1016/j.energy.2014.12.005.
[133] F. Martins, C. Patrão, P. Moura, A.T. de Almeida, A review of energy modelling tools for energy efficiency in smart cities, Smart Cities 4 (2021) 1420–1436, https://doi.org/10.3390/smartcities4040075.
[134] Energy Systems (Chapter 7) - Climate Change 2014: Mitigation of Climate Change n.d. https://www.cambridge.org/core/books/abs/climate-change-2014-mitigation-of-climate-change/energy-systems/EE273BA73944F60FEAF520F2431DD4AE (accessed March 24, 2022).
[135] C.S. Lai, G. Locatelli, A. Pimm, X. Wu, L.L. Lai, A review on long-term electrical power system modelling with energy storage, J. Clean. Prod. (2021) 280, https://doi.org/10.1016/J.JCLEPRO.2020.124298.
[136] I.T. Tambari, M.O. Dioha, P. Failler, Renewable energy scenarios for sustainable electricity supply in Nigeria, Energy and Climate Change 100017 (2020) 1, https://doi.org/10.1016/j.egycc.2020.100017.
[137] O. Bamisile, Q. Huang, X. Xu, W. Hu, W. Liu, Z. Liu, et al., An approach for sustainable energy planning towards 100 % electrification of Nigeria by 2030, Energy 197 (2020), https://doi.org/10.1016/j.energy.2020.117172.
[138] M.O. Dioha, Emodi N v., Dioha EC. Pathways for low carbon Nigeria in 2050 by using NECAL2050, Renewable Energy Focus 29 (2019) 63–77, https://doi.org/10.1016/j.ref.2019.02.004.
[139] N.V. Emodi, C.C. Emodi, G.P. Murthy, A.S.A. Emodi, Energy policy for low carbon development in Nigeria: a LEAP model application, Renew. Sustain. Energy Rev. 68 (2017) 247–261, https://doi.org/10.1016/j.rser.2016.09.118.
[140] A.S. Oyewo, A. Aghahosseini, M. Ram, A. Lohrmann, C. Breyer, Pathway towards achieving 100% renewable electricity by 2050 for South Africa, Sol. Energy 191 (2019) 549–565, https://doi.org/10.1016/j.solener.2019.09.039.
[141] J.G. Wright, T. Bischof-Niemz, J.R. Calitz, C. Mushwana, R. van Heerden, Long-term electricity sector expansion planning: a unique opportunity for a least cost energy transition in South Africa, Renewable Energy Focus 30 (2019) 21–45, https://doi.org/10.1016/j.ref.2019.02.005.
[142] F. Kemausuor, I. Nygaard, G. Mackenzie, Prospects for bioenergy use in Ghana using long-range energy alternatives planning model, Energy 93 (2015) 672–682, https://doi.org/10.1016/j.energy.2015.08.104.
[143] F. Kemausuor, E. Adkins, I. Adu-Poku, A. Brew-Hammond, V. Modi, Electrification planning using Network Planner tool: the case of Ghana, Energy for Sustainable Development 19 (2014) 92–101, https://doi.org/10.1016/j.esd.2013.12.009.
[144] A.K. Awopone, A.F. Zobaa, W. Banuenumah, Techno-economic and environmental analysis of power generation expansion plan of Ghana, Energy Pol. 104 (2017) 13–22, https://doi.org/10.1016/j.enpol.2017.01.034.
[145] S. Bouckaert, E. Assoumou, S. Selosse, N. Maïzi, A prospective analysis of waste heat management at power plants and water conservation issues using a global TIMES model, Energy 68 (2014) 80–91, https://doi.org/10.1016/j.energy.2014.02.008.
[146] D. Guta, J. Börner, Energy security, uncertainty and energy resource use options in Ethiopia: a sector modelling approach, Int. J. Energy Sect. Manag. 11 (2017) 91–117, https://doi.org/10.1108/IJESM-04-2015-0005.
[147] A Mulali Usama, S.A. Solarin, M. Salahuddin, The prominence of renewable and non-renewable electricity generation on the environmental Kuznets curve: a case study of Ethiopia, Energy 211 (2020), https://doi.org/10.1016/j.energy.2020.118665.
[148] J.P. Carvallo, B.J. Shaw, N.I. Avila, D.M. Kammen, Sustainable low-carbon expansion for the power sector of an emerging economy: the case of Kenya, Environ. Sci. Technol. 51 (2017) 10232–10242, https://doi.org/10.1021/ACS.EST.7B00345.
[149] R. Singh, R.C. Bansal, A. Singh, "Optimization of an isolated PV generating unit and BESS system using electric system cascade analysis, Elec. Power Syst. Res. 164 (2018) 188–200.
[150] O.N. Nobela, R.C. Bansal, J. Justo, "Power quality compatibility of wind energy conversion systems with the South African utility grid", Renewable Energy Focus 31 (2019) 63–72.
[151] W. Cai, C. Wang, K. Wang, Y. Zhang, J. Chen, Scenario analysis on CO2 emissions reduction potential in China's electricity sector, Energy Pol. 35 (2007) 6445–6456, https://doi.org/10.1016/j.enpol.2007.08.026.
[152] S. Zhang, T. Zhao, B.C. Xie, What is the optimal power generation mix of China? An empirical analysis using portfolio theory, Appl. Energy 229 (2018) 522–536, https://doi.org/10.1016/j.apenergy.2018.08.028.
[153] D. Howard, R. Soria, J. Thé, R. Schaeffer, J. Saphores, The energy-climate-health nexus in energy planning: a case study in Brazil, Renew. Sustain. Energy Rev. 132 (2020) 110016, https://doi.org/10.1016/j.rser.2020.110016.
[154] N. Di Sbroiavacca, G. Nadal, F. Lallana, J. Falzon, K. Calvin, Emissions reduction scenarios in the argentinean energy sector, Energy Econ. 56 (2016) 552–563, https://doi.org/10.1016/j.eneco.2015.03.021.

[155] F. Lallana, G. Bravo, G. Le Treut, J. Lefèvre, G. Nadal, N. Di Sbroiavacca, Exploring deep decarbonization pathways for Argentina, Energy Strategy Rev. 36 (2021) 100670, https://doi.org/10.1016/j.esr.2021.100670.

[156] Y. Simsek, H. Sahin, Santika W. Lorca Á, T. Urmee, R. Escobar, Comparison of energy scenario alternatives for Chile: towards low-carbon energy transition by 2030, Energy 206 (2020) 118021, https://doi.org/10.1016/j.energy.2020.118021.

[157] R. O'Ryan, S. Nasirov, A. Álvarez-Espinosa, Renewable energy expansion in the Chilean power market: a dynamic general equilibrium modeling approach to determine CO2 emission baselines, J. Clean. Prod. 247 (2020) 119645, https://doi.org/10.1016/j.jclepro.2019.119645.

[158] J. Vidal-Amaro, C. Sheinbaum-Pardo, A transition strategy from fossil fuels to renewable energy sources in the Mexican electricity system. Journal of sustainable development of energy,, Water and Environment Systems 6 (1) (2017) 47–66, https://doi.org/10.13044/j.sdewes.d5.0170.

[159] F. Manzini, Reduction of greenhouse gases using renewable energies in Mexico 2025, Int. J. Hydrogen Energy 26 (2) (2001) 145–149, https://doi.org/10.1016/s0360-3199(00)00042-2.

[160] D. Castrejón, A. Zavala, J. Flores, M. Flores, D. Barrón, Analysis of the contribution of CCS to achieve the objectives of Mexico to reduce GHG emissions, Int. J. Greenh. Gas Control 71 (2018) 184–193, https://doi.org/10.1016/j.ijggc.2018.02.019.

[161] Meukam Pierre and Kouer, Joel Placide, Contribution of Biomass to the Mitigation of Greenhouse Gas Emissions During Electricity Production by 2050 in Cameroon. Available at SSRN: https://ssrn.com/abstract=4024958 or https://doi.org/10.2139/ssrn.4024958.

[162] R. Haiges, Y. Wang, A. Ghoshray, A. Roskilly, Forecasting electricity generation capacity in Malaysia: an auto regressive integrated moving average approach, Energy Proc. 105 (2017) 3471–3478, https://doi.org/10.1016/j.egypro.2017.03.795.

[163] M.S.N. Samsudin, M.M. Rahman, M.A. Wahid, Sustainable power generation pathways in Malaysia: development of long-range scenarios ", J. Adv. Res. Appl. Mech., vol. 24, no 1 (2020) 22–38.

[164] A. Mengal, N.H. Mirjat, G.D. Walasai, S.A. Khatri, K. Harijan, M.A. Uqaili, Modeling of future electricity generation and emissions assessment for Pakistan, Processes 7 (4) (2019) 212, https://doi.org/10.3390/pr7040212.

[165] M. Shahid, K. Ullah, K. Imran, I. Mahmood, A. Mahmood, Electricity supply pathways based on renewable resources: a sustainable energy future for Pakistan, J. Clean. Prod. 263 (2020) 121511.

[166] G. Bölük, M. Mert, The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach, Renew. Sustain. Energy Rev. 52 (2015) 587–595.

[167] H. Saygın, H.V. Oral, S. Kardaşlar, Environmental assessment of renewable energy scenarios for a sustainable future in Turkey, Energy Environ. 31 (2) (2020) 237–255.

[168] S. Kumar, Assessment of renewables for energy security and carbon mitigation in Southeast Asia: the case of Indonesia and Thailand, Appl. Energy 163 (2016) 63–70.

[169] V. Aryanpur, E. Shafiei, Optimal deployment of renewable electricity technologies in Iran and implications for emissions reductions, Energy 91 (2015) 882–893.

[170] J. Calitz, R.C. Bansal, "The system value of optimized battery electric vehicle charging: a case study in South Africa",, Electr. Eng. 104 (2022) 843–853.

[171] U.B. Akuru, A.O. Animalu, Alternative means of energy sector investments in Nigeria, African Journal of Physics Vol 2 (2009) 161–171.

[172] M.Z. Jacobson, M.A. Delucchi, Z.A.F. Bauer, S.C. Goodman, W.E. Chapman, M. A. Cameron, et al., 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world, Joule 1 (2017) 108–121, https://doi.org/10.1016/j.joule.2017.07.005.

[173] M.O. Dioha, A. Kumar, Rooftop solar PV for urban residential buildings of Nigeria: a preliminary attempt towards potential estimation, AIMS Energy 6 (2018) 710–734, https://doi.org/10.3934/energy.2018.5.710.

[174] G. Ali, M.K. Bashir, H. Ali, M.H. Bashir, Utilization of rice husk and poultry wastes for renewable energy potential in Pakistan: an economic perspective, Renew. Sustain. Energy Rev. 61 (2016) 25–29, https://doi.org/10.1016/j.rser.2016.03.014.

[175] M. Senatla, R.C. Bansal, "A review of planning methodologies used for determination of optimal generation capacity mix: the cases of high shares of PV and wind, IET Renew. Power Gener. 12 (11) (2018) 1222–1233.

[176] D. Harrache, A. Mir, Miguel de la Guardia, Fatima-Zahra Benhachem. Bioaccumulation of trace metals by red alga Corallina elongata in the coast of Beni Saf, west coast, Algeria, Chem. Int. 3 (2017) 220–231.

[177] J. Nisar, R. Razaq, M. Farooq, M. Iqbal, R.A. Khan, M. Sayed, et al., Enhanced biodiesel production from Jatropha oil using calcined waste animal bones as catalyst, Renew. Energy 101 (2017) 111–119, https://doi.org/10.1016/j.renene.2016.08.048.

[178] CSIR SS, Lennard -UCT C. Project Overview and Status. (n.d).

[179] U.O. Aliyu, S.B. Elegba, Prospects for small hydropower development for rural application in Nigeria, Niger J Renew Energy 1 (1990) 8658.

[180] A. Ibrahim, Renewable energy sources in the Egyptian electricity market: a review, Renew. Sustain. Energy Rev. (16) (2012) 216–230, https://doi.org/10.1016/J.RSER.2011.07.149.

[181] Elshennawy T. 2 Th International Conference on the Role of Engineering towards A Better Environment (RETBE'21) Can Egypt Achieve its Target of 20% of Electric Energy from Renewables by 2022? (n.d).

[182] Hydropower made up 66% of Brazil's electricity generation in 2020. Eia.gov. https://www.eia.gov/todayinenergy/detail.php?id=49436. Published 2022. Accessed October 2, 2022.

[183] Renewable Capacity Statistics, Irena.org, 2022. https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022. (Accessed 2 October 2022).

[184] Iran's 9-month hydropower output up over 200%. Tehran Times. https://www.tehrantimes.com/news/444445/Iran-s-9-month-hydropower-output-up-over-200. Published 2022. Accessed October 2, 2022.

[185] Mexico. Hydropower.org. https://www.hydropower.org/country-profiles/mexico. (Accessed 2 October 2022).

[186] Hydroelectricity in Thailand - Wikipedia. En.wikipedia.org. https://en.wikipedia.org/wiki/Hydroelectricity_in_Thailand. Published 2022. Accessed October 2, 2022].

[187] Malaysia. Hydropower.org. https://www.hydropower.org/country-profiles/malaysia#:~:text=There%20is%20a%20further%201%2C700%20MW%20of%20hydropower.the%20country%E2%80%99s%20electricity%20supply%2C%20especially%20in%20rural%20areas. Published 2022. Accessed October 2, 2022.

[188] List of Hydroelectric Power Plants in India - UPSC Notes. BYJUS. https://byjus.com/free-ias-prep/hydroelectric-power-plants-in-india-for-upsc-prelims/. Published 2022. Accessed October 2, 2022.

[189] Cameroon. Hydropower.org. https://www.hydropower.org/country-profiles/cameroon. Published 2022. Accessed October 2, 2022.

[190] The Grand Renaissance Hydroelectric Project. Power Technology. https://www.power-technology.com/projects/the-grand-renaissance-hydroelectricproject/#:~:text=The%20Grand%20Renaissance%20Hydroelectric%20Project%20%28GRHEP%29%2C%20formerly%20known.the%20world%20with%20an%20installed%20capacity%20of%206%2C450MW. Published 2022. Accessed October 2, 2022.

[191] H.A. Ibrahim, M.K. Ayomoh, Identification and prioritization of factors affecting the transition to renewables in developing economies, Energy Rep. 8 (2022 Nov 1) 94–104.

[192] Total targets 1,000mw solar power project in Nigeria - Nigeria Business News n.d. https://businessnews.com.ng/2014/09/10/total-targets-1000mw-solar-power-project-nigeria/(accessed March 24, 2022).

[193] Egypt aims to produce 20% of power from renewables by 2020 n.d. https://www.egypt-business.com/web/details/1441-xg-Egypt-aims-to-produce-20-of-power-from-renewables-by-2020/9961 (accessed March 24, 2022).

[194] Ritchie H, Roser M, Rosado P. Energy. Our World in Data. https://ourworldindata.org/renewable-energy. Published 2022. Accessed October 2, 2022.

[195] Enel Starts Operation of South America's Two Largest Solar Parks in Brazil. WebWire. https://www.webwire.com/ViewPressRel.asp?aId=213780. Published 2022. Accessed October 2, 2022.

[196] Thai Solar Energy Market Size, Share | 2022-27 | Industry Growth. Mordorintelligence.com. https://www.mordorintelligence.com/industry-reports/thailand-solar-energy.market#:~:text=The%20Electricity%20Generating%20Authority%20of%20Thailand%20is%20developing,expected%20to%20enter%20into%20commercial%20operation%20in%202026. Published 2022. Accessed October 2, 2022.

[197] Top 15 biggest solar power projects in India. Walkthroughindia.com. http://www.walkthroughindia.com/walkthroughs/top-15-biggest-solar-power-projects-in-india/#:~:text=Jalaun%20Solar%20Power%20Project%20is%20another%20solar%20photo-voltaic.railways%20also%20launched%20first%20solar%20powered%20DEMU%20train. Published 2022. Accessed October 2, 2022.

[198] Banks D, Consulting R, Schäffler J, Energy N. The Potential Contribution of Renewable Energy in South Africa (n.d).

[199] J. Artin, A. Valizadeh, M. Ahmadi, S.A. Kumar, A. Sharifi, Presentation of a novel method for prediction of traffic with climate condition based on ensemble learning of neural architecture search (NAS) and linear regression, Complexity (2021), 1-13.

[200] Katsina State will be home to First Nigerian wind farm | ECOWREX n.d. http://www.ecowrex.org/pt-pt/node/14309 (accessed March 24, 2022).

[201] H.A. Ibrahim, G. Kirkil, Electricity demand and supply scenario analysis for Nigeria using long range energy alternatives planning (LEAP), J. Sci. Res. Rep 19 (2) (2018 May) 1–2.

[202] Ritchie H, Roser M, Rosado P. Energy. Our World in Data. https://ourworldindata.org/renewable-energy. Published 2022. Accessed October 2, 2022.

[203] Top five wind power producing countries of South America. Nsenergybusiness.com. https://www.nsenergybusiness.com/features/top-five-wind-power-countries-south-america/. Published 2022. Accessed October 2, 2022.

[204] Solar Stuns in Mexico's First Clean Energy Auction: 1,860MW Won at $50.7 per MWh. Greentechmedia.com. http://www.greentechmedia.com/articles/read/Solar-Stuns-in-Mexicos-First-Clean-Energy-Auction-1860-MW-Won-at-50.7-P. Published 2022. Accessed October 2, 2022.

[205] S.O. Oyedepo, On energy for sustainable development in Nigeria, Renew. Sustain. Energy Rev. 16 (2012) 2583–2598, https://doi.org/10.1016/j.rser.2012.02.010.

[206] Banks D, Consulting R, Schäffler J, Energy N. The Potential Contribution of Renewable Energy in South Africa (n.d).

[207] Renewable Capacity Statistics 2022. Irena.org. https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022. Published 2022. Accessed October 2, 2022.

[208] Energy mix: Smart grid development in South Africa–The real story n.d. https://www.smart-energy.com/magazine-article/energy-mix-sanedi-south-africa/ (accessed March 24, 2022).

[209] S. Barsali, M. Ceraolo, R. Giglioli, D. Poli, Storage applications for Smart grids, Elec. Power Syst. Res. 120 (2015 Mar 1) 109–117.
[210] O. Patrick, O. Tolulolope, O. Sunny, O. Patrick, O. Tolulolope, O. Sunny, Smart grid technology and its possible applications to the Nigeria 330 kV power system, Smart Grid Renew. Energy (4) (2013) 391–397, https://doi.org/10.4236/SGRE.2013.45045.
[211] Egyptian state utility to create Middle East's first-ever smart grid n.d. https://www.smart-energy.com/industry-sectors/smart-grid/egyptian-state-utility-to-create-middle-easts-first-ever-smart-grid/(accessed March 24, 2022).
[212] Africa Microgrids | Microgrid Projects n.d. http://microgridprojects.com/africa-microgrids/(accessed March 24, 2022).
[213] M.S. Thopil, R.C. Bansal, L. Zhang, G. Sharma, "A review of grid connected distributed generation using renewable energy sources in South Africa", Energy Strategy Rev. 21 (2018) 88–97.
[214] Sakuri Mine Solar Microgrid Project, Egypt n.d. https://www.power-technology.com/marketdata/sakuri-mine-solar-microgrid-project-egypt-2/(accessed March 24, 2022).
[215] R.D. Prasad, R.C. Bansal, A. Raturi, Multi-faceted energy planning: a review, Renew. Sustain. Energy Rev. 38 (2014) 686–699, https://doi.org/10.1016/j.rser.2014.07.021.
[216] R. Shah, N. Mithulananthan, R.C. Bansal, V.K. Ramachandaramurthy, A review of key power system stability challenges for large-scale PV integration, Renew. Sustain. Energy Rev. 41 (2015) 1423–1436, https://doi.org/10.1016/j.rser.2014.09.027.