

# Renewable Energy Optimisation for Electricity Generation in Nigeria: Lessons from Leading Countries



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**ABSTRACT:** Nigeria is faced with a persistent electricity crisis that has crippled most sectors of the economy. This paper reviewed the strategies deployed by five leading countries in renewables, the status of renewable energy in Nigeria and ways to optimise it to generate a large amount of electricity in Nigeria and other developing countries. Relative Importance Index (RII) was used to analyse the collected data to achieve the study objectives. Wind power, solar power and hydropower were ranked the highest sources of renewable energy in China, the USA, India, Germany and Brazil. The major findings are (i) the various strategies deployed to develop the renewable energy industry in leading countries will also be effective in Nigeria; (ii) solar energy is considered to have the highest potential for Nigeria, and hydropower is the next potential. This study recommends that the Nigeria government should (i) target electricity generation capacity of 200 GW by the year 2035 and target fifty percent of the capacity i.e. 100 GW from renewable energy; (ii) adopt combined strategies used by leading countries which includes diversification of renewable sources, investment in research and development, international cooperation, financial incentive, subsidies and ambitious targets to optimise the development of renewable energy; (iii) focus on solar and small hydropower to kick start increase in electricity generation capacity from renewable sources; (iv) focus on building both large-scale plants and many small-scale plants.

**KEYWORDS:** Climate change, Energy poverty, Energy security, Net zero, Renewable energy.

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## I. INTRODUCTION

The global energy demand keeps growing because of the increasing population, industrialisation, and the movement of people and goods across the world. The current primary sources of energy are coal, oil, gas, nuclear, and other fossil fuels, which emit carbon dioxide into the atmosphere that are believed to be responsible for climate change. However, there is a shift in most countries towards the use of renewable energy for electricity generation, heating, cooling, and transportation, such as in electric cars, to reduce harmful emissions from fossil fuels. The global capacity to generate electricity from solar panels, wind turbines, and other renewable technologies is forecasted to increase rapidly over the coming years. Capacity addition to almost 280 GW in 2020, the highest increase in the last two decades, is reported to be propelled by policy deadlines in many countries (International Energy Agency, 2021). According to Statista (2026), the leading countries in installed renewable energy capacity worldwide in 2024 are China, the USA, Brazil, India, and Germany. China has an

installed capacity of 1,827 gigawatts (GW), the USA has 428 GW, Brazil has 214 GW, India has 204 GW and Germany has an installed capacity of 179 GW. Although developing countries such as Nigeria subscribed to measures to reduce global warming, power generation and utilisation of renewable energy are currently sub-optimal.

Nigeria, with an estimated population of 242 million people (World Population Review, 2026), has a substantial national energy need. The electricity generation, transmission, and distribution capacities are very low compared with her needs. Poor electricity supply with power outages, surges, brown-outs, poor voltage profiles, and load shedding remain common features (Dunmade, 2016, cited in Dodo *et al.*, 2021) for less than 60% of the population connected to the national grid. The country's total power generation capacity is estimated at 14.1 GW and delivers only an average of 4.0 GW to homes, businesses, and industries because of poor transmission and distribution capacity. Brazil, with a population of about 213 million people, has a total electricity generation capacity of about 240 GW and South Africa, with a population of 65

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million people, has a power generation capacity of over 66 GW (Country Economy, 2026). In the year 2023, Brazil generated 56.1% of its electricity from hydropower, 14.3% from wind, 9.4% from solar, 8.2% from biofuels and 6.4% from natural gas. South Africa generated 82% from coal, 7% from nuclear and 5.1% from wind, while Nigeria generated 77.2% from natural gas and 22.2% from hydropower (IEA, 2026). The rule of thumb is at least one gigawatt of electricity consumption for every one million population in a developed industrial nation. This rule provides a useful indicator of the scale of the investments that must be made in the Nigerian electricity supply industry over the coming decades (Obuka *et al.*, 2014). Nigeria is therefore estimated to need about 200 GW of electricity generation, as against the current 14.1 GW capacity, for the economic development of the country.

The International Energy Agency (IEA) anticipates a rapid increase in the global capacity to generate electricity from solar panels, wind turbines, and other renewable technologies in the coming years. By the end of year 2026, the global renewable electricity capacity is projected to grow by more than 60% from 2020, reaching over 4800 GW. This surge is driven by stronger governmental support and more ambitious clean energy goals announced at United Nations climate change conferences (International Energy Agency, 2021). Nigeria is faced with a persistent electricity crisis that has crippled most sectors of the economy. Renewable energy is believed to have the potential to solve the power generation and consumption crisis in the country, and the availability of renewable energy sources in all parts of Nigeria has been demonstrated in several studies (Aliyu *et al.*, 2015). Leading countries have developed large capacities to generate electricity from renewable energy. Nigeria is believed to possess significant potential in renewable energy sources such as hydropower, wind, solar, and biomass. Several studies are available on renewable energy opportunities in Nigeria, for example, Aliyu *et al.* (2015), Akorede *et al.* (2017), Dodo *et al.* (2021) and Ismaila *et al.* (2022). However, little is known about the application of operations management principles to optimise renewable energy in Nigeria. This paper seeks to combine knowledge from operations management and various literature on renewable energy to find strategies that will help make the best use of renewable energy for electricity generation in developing countries like Nigeria.

## II. REVIEW OF RENEWABLE ENERGY

Renewable energy is produced from a source that is not depleted when used. Sources such as water, sunlight, and wind are considered renewable because they naturally replenish and do not run out. Energy derived from these sources is utilised for generating electricity, as well as for heating, cooling, and transportation. Globally, scientists from diverse regions, including Asia, Europe, North America, South America, Australia, and Africa, are actively engaged in researching and exploring renewable energy solutions (Tutak *et al.*, 2021). Although, there is considerable literature on renewable energy in Africa, Ismaila *et al.* (2022) noted that more research is conducted in Asia compared to Africa, despite Africa having a larger population without electricity access. Therefore, increased research is necessary to advance renewable energy development in Africa. Beyond the significant advantage of

being clean, renewable energy also holds the potential to address energy poverty in Africa by supplying electricity to those currently without access. Why and how leading countries develop large-scale renewable energy are discussed in this section to show action plans (strategies) deployed by each country to achieve set goals.

### A. Renewable Energy in China

Chiu (2017) highlighted that China is the leading global producer of wind and solar energy and the top investor in renewable energy. The nation excels in generating electricity from renewable sources, boasting a capacity three times greater than that of the second-ranked USA. As of early 2017, China is home to five of the six largest solar panel manufacturers and the world's largest wind turbine manufacturer. The author pointed out that the primary motivation for the Chinese government to promote renewable energy is to reduce air pollution, with energy security being a secondary reason. By increasing the share of renewable energy in its electricity consumption, China aims to reduce its dependence on fossil fuels from volatile regions, thus minimising the need for extensive military protection of oil and gas transportation routes. China's strategy is to lead in attracting renewable energy investments, addressing its air and water pollution issues, and securing its energy needs without relying on imported fossil fuels.

China has made substantial strides in solar electricity generation. The country is home to some of the world's largest solar farms and the government has implemented policies and initiatives to support the expansion of solar energy capacity (Zhong & Leung, 2019). Provinces like Xinjiang, Inner Mongolia and Qinghai have vast expanses of land used for large-scale solar projects. Wind power is another significant contributor to China's renewable energy portfolio. The country has witnessed substantial growth in its wind energy capacity with both onshore and offshore wind farms (Wang & Chen, 2021). Coastal regions and areas with high wind potential, such as the Gansu and Xinjiang provinces, have seen extensive wind farm developments. China has a long history of utilising hydropower for electricity generation. The country boasts some of the largest hydropower plants globally, including the Three Gorges Dam. Hydropower continues to play a crucial role in China's renewable energy mix providing a reliable and consistent source of electricity. China has also been exploring the potential of biomass for electricity generation, including the use of organic materials such as agricultural residues, municipal solid waste, and forestry residues to produce bioenergy. Biomass projects contribute to both energy generation and waste management. The Chinese government has implemented various policies like feed-in tariffs, subsidies, and targets for renewable energy capacity expansion. The commitment to such policies has encouraged both domestic and international investment in the renewable energy sector.

### B. Renewable Energy in the USA

In 2020, renewable energy constituted 12.6% of total energy consumption and 19.8% of electricity production in the United States, as reported by the US Energy Information Administration (EIA). The U.S. EIA (2022) noted that the

expansion of renewable energy is largely fuelled by significant federal incentives, such as the Investment Tax Credit, which reduces upfront costs by 10 to 30%. Numerous state incentives also exist, including tax credits, grants, and rebates. Additionally, 39 states have implemented net metering programs, allowing customers to sell surplus electricity back to the grid, thus eliminating the need for on-site storage and encouraging the installation of renewable energy systems. Approximately 850 utilities in the U.S. offer consumers the option to purchase renewable or green power (Center for Sustainable Systems, University of Michigan, 2022).

Wind energy has experienced substantial growth in the United States, with vast wind farms dotting landscapes, particularly in regions with strong and consistent winds. States like Texas, Iowa and California are leaders in wind power generation (AWEA, 2020). Advances in turbine technology and favourable government policies have facilitated expansion in electricity generation from wind energy. Solar energy has witnessed a remarkable increase in deployment driven by declining costs of photovoltaic technology and supportive government incentives. States like California, Arizona, and Texas, with abundant sunlight, have become hubs of solar power installation both in utility-scale projects and residential solar panels (DOE, 2020). Hydropower has a long history in the USA, with many hydroelectric dams providing a stable source of electricity. Large-scale hydropower has been in operation for decades, but there is a growing interest in smaller, low-impact hydropower projects and marine energy technologies (NHA, 2019). Biomass sources for electricity generation include agricultural residues, wood, and other biological matter. The contribution of biomass is comparatively smaller than wind and solar, but it plays a role in certain regions and industries providing a reliable and renewable source of power (EIA, 2020). Geothermal power plants tap into the Earth's heat to generate electricity. The western part of the USA, including California and Nevada, has significant geothermal resources. The source is reliable and offers a continuous baseload power supply. Transition towards renewable energy in the United States has been driven by a combination of factors, including environmental concerns, technological advancements, declining costs of renewable technologies and supportive government policies (NREL, 2020). Federal and state-level initiatives, tax credits and renewable portfolio standards have played pivotal roles in promoting the adoption of clean energy.

### C. Renewable Energy in India

Large hydropower and other renewable energy sources account for over 30% of India's electricity generation. As of 2017, the utility electricity sector in India had an installed capacity of 330.26 GW, with hydropower contributing about 13.5% and other renewable sources nearly 17.33%. Coal accounts for 59.2% of the installed capacity, natural gas for 7.6%, diesel for 0.25%, and nuclear power for approximately 2.05%. Wind power represents around 8.6% of the total installed power generation capacity, producing 28,000 MW in 2016. India ranks among the top five countries globally in wind and solar power generation. The country offers attractive incentives to both local and international investors. Through its Ministry of New and Renewable Energy, the Indian

government promotes the extensive use of biomass and other renewable energy sources (Raghuwanshi and Arya, 2019).

India stands as a global leader in solar energy utilisation, largely due to its advantageous geographical positioning. The government has launched several initiatives and policies to boost solar power production, including the Jawaharlal Nehru National Solar Mission. Significant contributions to the country's solar power capacity come from large-scale solar parks, rooftop installations, and solar-wind hybrid projects (Sharma & Ghosh, 2021). Wind power also plays a crucial role in India's energy mix, with onshore and offshore wind farms established in states such as Gujarat, Tamil Nadu, Karnataka, and Maharashtra (Rao & Das, 2019). India has a long tradition of harnessing hydroelectric power, particularly in the Himalayan region and other hilly areas, which offer excellent opportunities for hydroelectric projects. Both small and large-scale hydroelectric plants are integrated into the nation's renewable energy portfolio (Kumar & Bhattacharya, 2017). Additionally, agricultural residues, organic waste, and dedicated energy crops are utilised in biomass projects to generate power. Solid biomass sources like sugarcane bagasse, forestry pulp, livestock dung, biogas, liquid biofuels, and municipal waste are employed to produce electricity and provide heating, cooking, and lighting in rural areas. Geothermal power projects, which aim to harness the earth's internal heat for electricity generation, are still in the early development stages. Kumar and Majid (2020) argue that to reduce the cost of renewable products, India must increase its manufacturing capabilities for these products. Another significant challenge is the unreliable grid infrastructure, which hampers the development of renewable energy technologies. To achieve a reliable system, they suggest the hybrid installation of multiple renewable resources alongside conventional sources and storage devices.

### D. Renewable Energy in Brazil

Brazil is a global leader in electricity generation from renewable energy. The country takes advantage of its abundant natural resources to have a diverse mix of renewable energy sources. Brazil has long been recognised for its extensive use of hydropower. The country is home to the vast Amazon River, which provides opportunities for the construction of hydroelectric dams. The Itaipu Dam is one of the largest hydropower plants in the world. While hydropower has been crucial to Brazil's energy mix, the concern of environmental impacts such as deforestation and the displacement of indigenous communities has led to increased exploration of alternative renewable sources (Abreu *et al.*, 2011). Over the last decade, Brazil has seen significant growth in wind energy capacity for electricity generation. The country's extensive coastline and favourable wind conditions in the north-eastern states have attracted substantial investments in wind farms in Brazil. The country has implemented various policies and incentives to encourage the development of wind energy projects and contribute to the diversification of the country energy mix. Solar is also used for electricity generation because Brazil receives abundant sunlight throughout the year. The government has introduced initiatives such as tax incentives and net metering programs to promote solar photovoltaic installations.

Government initiative like auctions for the development of renewable projects with fixed-price contract is instrumental in attracting investment and promoting competition in the sector (Pingelli-Rosa, 2007). Brazil has a long-standing tradition of using bioenergy, particularly from sugarcane for electricity generation. The country has a well-established bioenergy sector producing biofuels and using biomass for power generation. The country has been implementing energy efficiency measures to optimise electricity use. They promote energy efficient technologies, encourage conservation practices and adopting smart grid technologies. The country actively participates in international initiatives and collaborations to share knowledge and expertise in the use of renewable energy. As of 2018, renewable energy accounted for 79% of the domestically produced electricity in Brazil, of which 65% is from hydroelectricity, 11% from wind energy and solar energy accounted for about 2.5% (da Souza *et al.*, 2018).

#### E. Renewable Energy in Germany

Germany has made significant strides in electricity generation from renewable energy. The country's energy transition program, known as "Energiewende," aims to reduce greenhouse gas emissions, enhance energy security and foster economic growth through the widespread adoption of renewable energy technologies (Morris & Pehnt, 2016). Germany has invested heavily in wind power, both onshore and offshore wind farms. The offshore wind farms in the North and Baltic Seas contribute significantly to the country's renewable energy capacity (Agora Energiewende, 2020). Solar energy also plays a crucial role in Germany's energy mix. The country has been a pioneer in promoting solar photovoltaic technology by encouraging widespread adoption through financial incentives and feed-in tariffs. Rooftop solar panels on residential and commercial buildings, as well as large-scale farms, contribute significantly to the country's electricity generation (Schmidt and Schneider, 2016). Hydropower remains an important component of Germany's renewable energy portfolio, although to a lesser extent than wind and solar. Small-scale hydropower plants are spread across Germany, utilising the energy generated from flowing water to produce electricity (Schlömer *et al.*, 2014). Biomass also plays a role in Germany's renewable energy mix. Biogas plants, anaerobic digesters and biomass power plants generate electricity by utilising organic material such as agricultural residues, organic waste and dedicated energy crops. The bioplants contribute to the country's efforts to diversify its renewable energy sources (Scarlat *et al.*, 2015).

One of the notable achievements of the Energiewende is the rapid decline in the costs of renewable technologies. Economies of scale, technological advancement and competitive market forces have driven down the costs of generating electricity from renewable sources. Renewable energy is increasingly competitive with conventional sources as the deployment of wind and solar installations has increased, contributing to advancements in technology and efficiency. The Renewable Energy Act is a key legislative framework that facilitated the integration of renewable energy into the German electricity grid. It mandates grid operators to prioritise

renewable energy sources and ensure fair access to the grid. Germany actively participates in international collaborations to share experiences and best practices in renewable energy. Smart grids and energy efficiency measures are other strategies deployed by the country for the development of electricity from renewable sources (Klobasa *et al.*, 2014). Smart grids were implemented to allow for better management and integration of renewable energy into existing infrastructure. Germany implemented various energy efficiency measures, which include building standards, energy-efficient appliances and awareness campaigns to reduce overall energy consumption.

#### F. Renewable Energy in Nigeria

A substantial amount of research on renewable energy in Nigeria indicates that nearly all regions have the potential to generate electricity using at least two types of renewable energy technologies. Aliyu *et al.* (2015) highlighted that, despite this potential, the development of renewable energy in Nigeria lags significantly behind that of developed and emerging countries. Solar, wind, and biomass resources for electricity generation remain underutilised, and the electricity grid needs to be prepared for integrating renewable energy technologies. They suggested that the many years of electricity crisis and the imperative to reduce greenhouse gas emissions should be the primary motivations for advancing renewable energy options in Nigeria.

Ismaila *et al.* (2022) concluded that Nigeria has extensive renewable energy resources, which, if fully harnessed, could meet the country's electricity demands and significantly reduce the environmental impact of fossil-fuel-based generators. They argue that Nigeria is well-positioned for investment in renewable energy technologies, especially given the ongoing efforts to ensure a reliable and sustainable electricity supply, including power plants currently under construction or undergoing upgrades, and the privatisation of the electricity distribution and generation sectors since 2013. Their research indicates a predominant focus on off-grid renewable-based rural electrification, particularly hybrid solar PV-diesel and hybrid solar PV-wind-diesel systems, due to the accessibility of solar and wind resources in the study locations.

There has been limited research on commercial or industrial-scale hybrid renewable energy systems in Nigeria. Apart from the conventional large hydropower from the Kainji, Jebba, and Shiroro dams, which contribute to the grid, most other renewable energy projects are off-grid, either as standalone solar PV systems or hybrid solar PV-diesel generators. Energy security, economic benefits, and clean energy integration should drive significant research and investment in renewable energy for rural areas and urban and industrial sectors. According to Ismaila *et al.* (2022), the abundance of renewable energy resources across Nigeria necessitates expanding research to include municipal and industrial areas, as well as incorporating biomass and small hydropower into the energy mix. The government must demonstrate greater commitment by establishing the necessary framework to encourage robust investments in renewable power generation.

A study conducted by Dodo *et al.* (2021) revealed that Nigeria has an abundance of solar, wind, small hydro, and biomass energy resources. They mentioned that the Energy Commission of Nigeria (ECN) estimates renewables are capable of generating up to 1,182.4 GWh of energy daily if fully utilised. Biomass is identified as the most significant contributor with a potential yield of 933.6 GWh, followed by solar (120.3 GWh), hydro (84.0 GWh), and wind energy (44.4 GWh). Research was focused on renewable energy for rural electrification, particularly hybrid systems combining solar photovoltaic, diesel generators, and wind power. The National Renewable Energy and Energy Efficiency Policy (NREEEP) aims to integrate solar, wind, biomass, and small hydro schemes into the energy mix and expand research and deployment to urban and industrial areas. The study highlights Nigeria's vast renewable energy potential, which can meet the country's electricity demands and significantly reduce harmful greenhouse gas emissions from fossil fuels.

To promote renewable energy in Nigeria, Aliyu *et al.* (2015) suggest public-private partnerships, research investment, and government incentives through policies and legislation. New market-driven policies and laws can enhance incentives for renewable energy development. Continuous promotion and encouragement of renewable energy for both on-grid and off-grid generation is crucial through research, training, operation, maintenance culture, and local manufacturing. An integrated power solution combining centralised and decentralised renewable energy technologies can overcome the electricity crisis and drive economic prosperity. These strategies can also apply to other sub-Saharan African countries, where a lack of policies and economic viability are major barriers. Ismaila *et al.* (2022) found that hybrid fossil fuel-renewable energy systems are the most economical and reliable option for electricity generation in Nigeria, reducing carbon dioxide emissions and offering long-term profits. In their study, Akorede *et al.* (2017) emphasised that Nigeria's abundant renewable energy resources and existing energy policies position the country to scale up renewable energy use, reduce dependence on fossil fuels, and overcome the energy crisis, but effective implementation is crucial.

The reviewed literature all agree that Nigeria has an abundance of renewable energy potential that can be used to provide an adequate electricity supply for the economic development of the nation. The studies, however, contradict on whether government policies are adequate to scale up renewable energy use. Ismaila *et al.* (2022) and Akorede *et al.* (2017) concluded that policies are okay to develop renewables, but Dodo *et al.* (2021) and Aliyu *et al.* (2015) wrote that policies need to be improved to encourage private sector participation in renewables. It is imperative that the Nigerian government continuously refines its energy policy frameworks to facilitate the expansion of electricity capacity, including from renewable energy sources. The maps of solar and wind sources are shown in Figures 1 and 2.

G. Gap in the Literature

Several studies reviewed in the current study were mainly concerned with different forms of renewable energy and silent on strategies to optimise renewable energy in Nigeria.

Considering this, Ismaila *et al.* (2022) point out that a significant gap is the scant attention paid to commercial or industrial-scale hybrid renewable energy systems, with the majority of studies focusing on off-grid rural electrification.

Furthermore, biomass and tiny hydropower are understudied and require further investigation (Aliyu *et al.*, 2015). As reviewed in the existing studies, regulations should be altered to promote further private individual participants and investment in renewables, as the literature also indicates that current policies are not sufficient to scale up the usage of renewable energy (Aliyu *et al.*, 2015; Dodo *et al.*, 2021). Considering this, the study contributes to knowledge through a methodological gap by applying the Relative Importance Index (RII) to select the suitable strategies that would maximise the use of renewable energy for electricity generation in Nigeria.

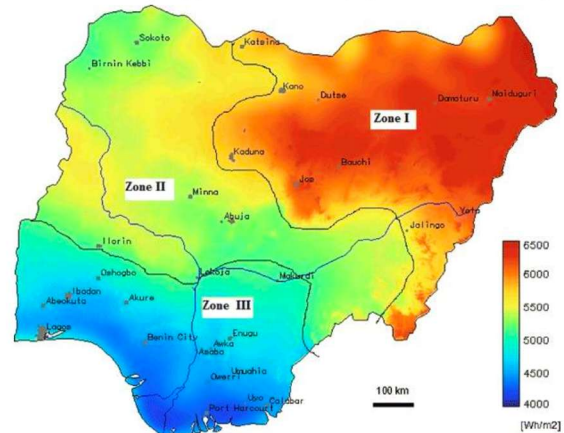


Figure 1 Solar Radiation Map of Nigeria (Kehinde *et al.*, 2018)



Figure 2 Average wind speed distribution map of Nigeria (Dodo *et al.*, 2021)

### III. RANKING OF RENEWABLE ENERGY SOURCES USED BY LEADING COUNTRIES

The Author’s ranking of renewable energy sources used by leading countries is shown in Table 1. China was rated as the highest amongst the sampled countries because the country is identified as the world’s largest producer of wind and solar energy for electricity generation. According to Chiu (2017), China is currently the biggest investor in renewable energy and the world’s biggest generator of solar and wind energy. Hydropower also scored 5 for China because hydro has long been used to generate electricity, and the country is home to some of the biggest hydroelectric dams in the world, notably the Three Gorges Dam (Han and Chang, 2022). China’s renewable energy mix still heavily relies on hydropower as a constant and dependable source of electricity.

In the USA, the use of solar energy has increased dramatically, mostly due to favourable government incentives and the falling cost of photovoltaic technology. As such, studies have shown that due to the abundance of sunshine, states like California, Arizona, and Texas have emerged as major hubs for the installation of solar power systems, including both residential and utility-scale units (Han and Chang, 2022). Tesla Inc. was noted as the main supplier of solar energy through its massive investment in clean energy by installing over 500,000 solar systems across various counties in the US (EIA, 2022). The USA scored 5 for solar power installation. In the case of Wind, the US is still lagging behind China when compared with the rate of their respective annual output. In 2021, for instance, China produced 656.7 gigawatt hours; that of the USA was 378.2 gigawatt hours (Han and Chang, 2022; EIA, 2022). Although the USA is behind China in wind power, the USA was also rated 5 for wind energy usage. In addition, biomass was ranked 4, while hydropower and geothermal power were assigned 5 in the USA. Given this,

relatively high usage in India. India’s market for biomass-based gasification is expected to grow to  $2.24 \times 10^7$  MW per hour by 2022, with a compound annual growth rate of 3.7% predicted for the years 2023–2028 (Bhuiyan *et al.*, 2022). Geothermal power usage was found to be minimal when compared with other sources. Electricity generation from geothermal is rated 3 for India. A rating of 4 is assigned for hydropower because the sector comprises over 100 plants and 9 pumped storage stations with capacities exceeding 25 MW. Despite this significant infrastructure, hydropower’s contribution to the country’s electricity mix has been declining, currently accounting for approximately 10%, while thermal generation dominates with an 80% share. India aims to reduce its emissions intensity by 45% and achieve a target of 50% of its cumulative electric power installed capacity from non-fossil fuel sources by 2030, indicating a shift towards cleaner energy sources (Hydropower.org, 2023).

Germany is rated 5 for wind and solar energy for electricity generation since both sources are highly used. According to Eduardo *et al.* (2020), through financial incentives and feed-in tariffs, the nation has been at the forefront of promoting solar photovoltaic technology, encouraging its wider adoption. Large-scale solar farms and rooftop solar panels on residential and commercial buildings both make major contributions to the production of power. Given this, studies have shown that the reason for this is that Germany has set an ambitious aim to achieve a specific amount of energy from solar power by a given year, which demonstrates its commitment to solar energy. Germany produced 125.3 terawatt hours of power in 2022 from onshore and offshore wind farms, with 100.2 terawatt hours coming from onshore farms and 25.1 terawatt hours from offshore locations (Hernández *et al.*, 2023). Aside from this, it was revealed that in 2022, onshore wind power had grown by around 11% over the previous year (Ferriani and

**Table 1** Ranking of Renewable Energy Sources in Leading Countries (Author’s ranking)

Renewable energy	China	USA	India	Germany	Brazil
	Rank	Rank	Rank	Rank	Rank
Wind Power	5	5	5	5	5
Solar Power	5	5	5	5	5
Hydropower	5	5	4	4	5
Biomass	5	4	4	4	5
Geothermal Power	3	5	3	3	3

5: Strongly agreed; 4: Agreed; 3: Undecided; 2: Disagreed 1: Strongly disagreed

studies have shown that geothermal resources are abundant in the western US, which includes California and Nevada (Han and Chang, 2022).

India was rated amongst the top five countries that produce solar energy and wind power in the world as of 2023. The country has a capacity of 40 GW for wind turbines and 63.17 GW for Solar in 2022. India was rated 5 points for solar and wind energy. Biomass was also assigned a rating of 4 due to its

Gazzani, 2023). The country used less biomass, hydropower, and geothermal power when compared with other forms of renewable energy. For instance, in 2022, biomass accounted for 7.7% of Germany’s energy consumption, and the hydropower output of energy of 17.5 terawatt hours in 2022 decreased to 7.5 terawatt hours in 2023 (Hernández *et al.*, 2023). This justified the rationale for assigning 4 to biomass and hydropower, and 3 for geothermal for Germany.

Wind and solar power are rated 5 for Brazil. According to de Macedo and de Alencar Nääs (2023), South American wind energy capacity has grown significantly during the last ten years, but is still below full capacity when compared with other developed countries. The nation produced more than 80 terawatt-hours of wind energy in 2022, 12% of Brazil's total power output (EIA, 2022). As of February 2024, Brazil's installed solar power accounted for around 38.4 GW, or 17.0% of the nation's total electrical grid (EIA, 2024). For biomass and hydropower, the country is rated 5, due to the high usage of these two renewable sources in the country. Hydropower has long been the mainstay of its renewable energy industry, providing 65% of the nation's domestic electricity production in 2020, followed by wind at 8.6% and biomass at 8.4% (Drumond *et al.*, 2021). Lastly, geothermal power in Brazil was scored 3. De Macedo and de Alencar Nääs (2023) reveal that due to low temperatures, geothermal systems that are economically exploited are expected to have a total capacity of 365 MWt, and their annual energy consumption is anticipated to be around 6,540 TJ.

#### IV. RANKING OF STRATEGIES FOR RENEWABLE ENERGY DEVELOPMENT IN LEADING COUNTRIES

The findings on the strategies deployed by leading countries in the development of renewable energy for electricity generation and distribution are presented in Table 2. The strategies ranked are (i) Diversification of renewable sources; (ii) Investment in research and development; (iii) International cooperation with other countries; (iv) Financial incentives and subsidies like tax credits; (v) Infrastructure development such as new transmission line and smart grids; (vi) Government initiatives and ambitious targets; (vii) Decentralising electricity production to building many small-scale plants; and (viii) Energy efficiency measures. Each country was ranked from 1 to 5 to show whether or not each strategy was deployed. The highest score of 5 for "Strongly Agreed" was assigned when

the literature review completely agrees that a strategy was deployed by a country. Score 4 for "Agreed" was assigned when the literature agrees with minor reservations. Score 3 for "Undecided", score 2 for "Disagreed" with minor agreement and score 1 for "Strongly Disagreed" when the literature completely does not mention that a strategy was implemented by the country.

Diversification of renewable sources was established as one of the top strategies adopted in China, India, the US, Germany, and Brazil to develop renewable energy for electricity generation. These countries use different renewable sources, including solar, wind, hydropower, and biomass, for electricity generation to transition from conventional fossil fuel sources to more sustainable renewable sources. The primary reasons for the ambitious targets of renewables in the energy mix are to reduce climate change and for energy security to provide a 24/7 electricity supply to consumers at affordable prices. China, the USA and Brazil were ranked 5 in Table 2, because they have deployed more than three renewable sources on a large scale for electricity generation. China is using wind, solar, hydroelectric, and biomass. The USA generates from solar, wind, hydro, and geothermal. Brazil maintains a strong energy mix centered on hydropower, wind, and biomass. India and Germany were rated 4, reflecting slightly less diversification. India is a leader in solar, hydro, and wind, while Germany's renewable output is primarily concentrated in wind and solar power.

China, USA and Germany were ranked 5 for investment in research and development (R&D). These countries invested funds for R&D in renewable energy technologies to improve the efficiency and cost-effectiveness of renewable solutions. This investment has improved existing technologies and provided energy storage solutions to address the intermittent nature of renewables like solar. They have encouraged collaboration between research institutions, industry, and international partners to accelerate innovation and technology

**Table 2** Ranking of Strategies for Renewable Energy Development in Leading Countries (Author's ranking)

Identified Strategies	China	USA	India	Germany	Brazil
Diversification of renewable sources	5	5	4	4	5
Investment in research and development	5	5	3	5	3
International cooperation	5	4	5	5	4
Financial incentives and subsidies	5	4	4	5	3
Infrastructure development	5	4	3	4	3
Government initiatives and ambitious targets	5	4	5	5	4
Decentralised electricity production	4	4	4	5	4
Energy efficiency measures	4	4	3	5	3

5: Strongly agreed; 4: Agreed; 3: Undecided; 2: Disagreed; 1: Strongly disagreed

transfer. India and Brazil were scored 3 because of limited research funding relative to deployment needs (IEA, 2026).

International collaboration is another strategy deployed by leading countries. Sharing knowledge, technology, and expertise with other nations has contributed to global efforts to combat climate change. Three countries, China, India and Germany were ranked 5 points for active participation in international collaborations and agreements related to renewable energy. They collaborate with other nations on renewable energy research, development, and deployment to accelerate progress and make clean energy solutions more globally accessible. With a score of 4, the United States and Brazil agreed that they collaborated less in international climate initiatives because of the variation in policies by administrations.

The countries deploy financial incentives and subsidies. India introduced innovative financing mechanisms like green bonds to attract capital for renewable energy projects and facilitate easy access to loans and financial support for small and medium-sized enterprises involved in renewables. The USA provides incentives and subsidies for businesses and individuals to adopt renewable energy technologies, including tax credits, grants, and other financial mechanisms to make renewable energy more competitive with traditional sources. The Chinese government provides incentives like feed-in tariffs, tax credits, and subsidies to encourage investment in renewable energy projects. Germany has historically employed feed-in tariffs to promote the adoption of renewables with guaranteed fixed premium prices for electricity generated from renewable sources. Brazil scored 3 points due to an indecisive report on the use of financial incentives. The government conducts regular auctions to attract investments and help drive competition, lower the cost and increase the share of renewable energy in the electricity generation mix (De Macedo and de Alencar Nääs, 2023).

The leading countries were also ranked for infrastructure development to support the injection of electricity from renewable sources. Infrastructure development, like the expansion and upgrade of the electricity grid, is required to accommodate the decentralised nature of renewable sources. Development of smart grids that can efficiently manage and distribute electricity from diverse sources. India and Brazil were ranked 3, because the transmission grid is still a challenge.

Other strategies, including legislative frame and policy support for renewable energy, decentralised electricity

production, and energy efficiency measure ranking, are shown in Table 2. Energy efficiency measures include efficient appliances, encouraging conservation practices, adopting smart grid technologies, and awareness campaigns to reduce overall electricity consumption. Germany is doing a lot to improve energy efficiency. China has also implemented measures to improve energy efficiency across industries, buildings and infrastructure to complement the transition to renewable energy and reduce overall electricity demand. China and the USA were assigned a rank of 4 for their energy efficiency initiatives. Brazil and India received a 3, as their existing efficiency standards and programs are considered less exhaustive and still in the developing stages. Decentralised energy production encourages small-scale renewable energy projects at the local level. The approach fosters community engagement and reduces transmission losses, making the energy system more efficient. Germany emphasises decentralised energy production and was ranked 5.

**V. STRATEGIES FOR OPTIMISATION OF RENEWABLE ENERGY IN NIGERIA**

The Relative Importance Index (RII) is a tool commonly used in research to prioritise or rank factors based on their importance. RII is particularly useful in fields like construction management, project management, and social sciences, where it is essential to understand the relative significance of various factors (Chan & Kumaraswamy, 1997). Equation 1 was used to estimate the Relative Importance Index for strategies identified as deployed in leading countries for Nigeria. The rankings in Table 2 were used to calculate the weight in the equation.

$$R\Pi = \frac{\sum W}{A * N} \tag{1}$$

where

$R\Pi$  = Relative Importance Index

$\sum W$  = Total summation of weight

W = is the weight from ranking (ranking score x frequency)

A = Highest weight identified (it is 5 in this case)

N = Number of countries used (5 countries were ranked)

For example, diversification of renewable sources achieved an RII of  $(3*5 + 2*4 + 0*3 + 0*2 + 0*1) / (5*5) = 0.92$ , since three countries were ranked 5 and two countries ranked at 4.

**Table 3** Relative Importance Index for identified strategies (Author’s calculation)

Items		SA(5)	A(4)	U(3)	SD(2)	D(1)	Total	N	A*N	RII	Rank
Diversification of renewable sources	F	3(5)	2(4)	0(3)	0(2)	0(1)					
	Total	15	8	0	0	0	23	5	25	0.92	1st
Investment in research and development	F	3(5)	0(4)	2(3)	0(2)	0(1)					
	Total	15	0	6	0	0	21	5	25	0.84	2nd
International cooperation	F	3(5)	2(4)	0(3)	0(2)	0(1)					
	Total	15	8	0	0	0	23	5	25	0.92	1st
Financial incentives and subsidies	F	2(5)	2(4)	1(3)	0(2)	0(1)					
	Total	10	8	3	0	0	21	5	25	0.84	2nd
Infrastructure development	F	1(5)	2(4)	2(3)	0(2)	0(1)					
	Total	5	8	6	0	0	19	5	25	0.76	3rd
Government initiatives and ambitious targets	F	3(5)	2(4)	0(3)	0(2)	0(1)					
	Total	15	8	0	0	0	23	5	25	0.92	1st
Decentralised electricity production	F	1(5)	4(4)	0(3)	0(2)	0(1)					
	Total	5	16	0	0	0	21	5	25	0.84	2nd
Energy efficiency measures	F	1(5)	2(4)	2(3)	0(2)	0(1)					
	Total	5	8	6	0	0	19	5	25	0.76	3rd

The outcome of RII estimates clustered the eight strategies into three priority groups, as shown in Table 3. The top-tier strategies, all scoring RII of 0.92, the second and third groups followed with scores of 0.84 and 0.76, respectively. The first-tier strategies identified include: (1) diversification of renewable sources, (2) international cooperation, (3) government initiatives and ambitious targets. This suggests that a combination of these strategies would optimise the use of renewable energy for electricity generation in developing countries. Nigeria's favourable geographical location strongly supports the diversification of its renewable energy portfolio. As noted by Akorede et al. (2017), the nation is well-positioned to leverage solar, wind, hydro, and biomass resources. However, achieving government targets such as the Electricity Vision 30:30:30 goal of 30GW with a 30% renewable share by 2030 (NREAP, 2016) requires realistic, targeted policies for grid rural electrification and grid integration. The success will also depend on international partnerships to secure the necessary technology transfer and specialised expertise.

The three second-tier strategies from RII calculations are (1) investment in research and development, (2) financial incentives and subsidies, and (3) decentralised electricity production. Adoption of this second group of strategies would produce results, but the first-tier strategies are considered relatively more important than this group. There should be significant investment in research and development for renewable energy in research institutes and universities. To advance Nigeria's electricity sector, the government must find innovative, low-cost financing models, and the decentralising of power, especially through off-grid renewable projects, must be prioritised.

The analysis ranks infrastructure development and energy efficiency measures as third-tier strategies, lower in immediate priority than the other two groups but still vital. A successful transition will require a multi-level approach of focusing heavily on the top-tier strategies while grid upgrades and efficiency measures, such as smart grid adoption, energy conservation practices and awareness campaigns to reduce electricity wastage, will ensure long-term supply stability.

This result shows that Nigeria should diversify utilisation of its renewable energy by developing electricity plants from solar, hydro, wind and other sources. Nigeria should relate with leading countries to develop renewable technologies, and the government should set a very ambitious target to generate a large amount of electricity from renewables.

## VI. RECOMMENDATIONS

Wind power, solar power, hydropower, biomass and geothermal power were the identified renewable energies available in China, the USA, India, Germany and Brazil; while multi-dimensional strategies applicable in these countries would contribute optimally to the use of renewable energy for electricity generation in Nigeria. The study recommended the under-listed suggestions.

- The government should target an electricity generation capacity of 200 GW by the year 2035 and target fifty percent of the capacity, i.e. 100 GW from renewable energy.
- Adopt combined strategies used by leading countries, which include diversification of renewable sources, investment in research and development, international cooperation,

financial incentives and subsidies, and ambitious targets to optimise the development of renewable energy.

- Focus on solar and small hydropower to kick-start an increase in electricity generation capacity from renewable sources. Focus on building both large-scale plants and many small-scale plants. For example, solar farms can be built near existing transmission lines.

- There should be deliberate efforts by government and private stakeholders to create awareness of the real cost of electricity generation, especially from petrol and diesel self-generation to create the willingness for customers to pay the right price for electricity.

- The country should decentralise electricity production by focusing on community power generation, mini-grids, and off-grid projects that could be integrated into the national grid. The government should ensure that each state is allowed to generate its electricity and encourage large investments in renewable energy equipment like solar panels, wind turbines, inverters, transmission poles, and cables.

- There must be plans to increase electricity access by increasing public and private sector investments in power generation and transmission, facilitating off-grid connections to a cleaner power supply, improving the enabling environment for private sector participation in the power sector, and promoting improved liquidity throughout the Nigerian energy sector.

Nigeria, like many African countries, is seeing the impact of climate change across the country. There is drought in the North, resulting in farmer-herder clashes, flooding, and erosion in the South. There is air pollution, especially from petrol and diesel generation in every part of the country (Launch of Nigeria's Energy Transition Plan, 2022). While climate change is arguably the greatest challenge of the current time, the energy transition to renewable energy is potentially one of the greatest opportunities.

## VII. CONCLUSION

Energy is the bedrock of economic development, and nations cannot grow without an adequate electricity supply. Nigeria needs energy to industrialise, create thousands of jobs, and improve the living standards of its people. The study concluded that first-grade strategies like diversification of renewable sources, investment in research and development, international cooperation, government initiatives, and ambitious targets would optimise the use of renewable energy for electricity generation in Nigeria. Second-grade strategies, including financial incentives and subsidies, infrastructure development, decentralised electricity production and energy efficiency measures, would serve as additional supports. Future analysis into the economic feasibility of renewable energy and potential financing models for Nigeria and other developing countries is recommended. Such insights will help bridge the gap between this study's findings and the practical needs of policymakers and stakeholders.

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