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AN OVERVIEW OF TRANSFORMING NIGERIA'S ENERGY FUTURE WITH SOLAR POWER AND HARNESSING THE ENERGY OF THE SUN FOR ELECTRICITY GENERATION.

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ABSTRACT
A brief review of ways of converting solar energy to electricity, directly and indirectly, is made, with a treatment of costs, estimates, viability and prospects. Nigeria's geographical location between 4°and 14° N latitude endows it with substantial solar resources. Depending on the region, the country receives between five and seven hours of daily sunlight, translating to high technical potential for photovoltaic energy generation. Data from global atlases confirms significant Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI) across the territory, providing a solid foundation for solar PV power potential (PVOUT). The case of Nigeria is analyzed with such factors as her resources, finances and geography in mind. Reasonable paths of implementation are then suggested in the light of the foregoing.

1. INTRODUCTION

The last decade has witnessed the drastic worsening of the energy supply situation worldwide, and the accompanying flurry of frantic activities at various levels to secure alternative sources of energy to replace traditional ones that had become dear and scarce. Several truly substantial amounts of fiscal and human resources to this cause, and their determination seems to be so high in that they regard themselves as just starting in their pursuits. One type of energy that has attracted all and sundry is that from our sun, for its apparent freeness for the taking, and its cleanliness. Technologies for utilizing solar energy in diverse applications have accordingly been multiplying and are being perfected daily (Mumah et al., 2025).

Now, solar energy is being applied to air heaters, coolers, furnaces, space travel, refrigeration and air conditioning, desalination of water, generation of electricity, etc. The cost of solar energy for these different purposes do vary and depend on the geographical locations of such places as where the applications are to be made. It is therefore necessary to make a comprehensive analysis of relevant factors in deciding upon what, and on what scale a

particular application of solar energy would be beneficial. The objective of this overview, however, addresses itself particularly to the conversion of solar to electrical energy.

2. SOLAR TO ELECTRICAL ENERGY

Apart from nuclear energy (and geothermal energy which is due to residual heat from radioactive decay of some rocks), all forms of energy now known ultimately derive from the sun as source. Wind, tidal, hydro, and ocean-derived energies are generated by the sun's heating of the earth and its atmosphere, as are any forms of bio-derived energies since plants depend on the sun for growth. These processes may therefore be classified as indirect generation of energy from the sun. On the other hand, solar radiation can be changed directly into electricity by making it impinge upon such materials as having the property of being excited by such radiation to initiate electron flow. This is a direct conversion of solar energy. Solar radiation can also be made to heat up fluids that are then passed through both conventional or novel turbo-generators. Despite the lack of spontaneity of transformation of radiation to electric current, here it is still reasonable to classify this group as direct when compared to the indirect class.

From another point of view, electricity derivation from the sun may be considered with respect to the scale of operation. Thus we may consider solar generation of electricity on the scale of conventional power stations as large-scale (above 1 MW), for neighbourhood, household or farmstead use (conventionally requiring movable generating machines) as medium-scale (100 kW to 1 MW), and for such localized uses as in charging electric car batteries for motive power and accessory functions, or for operating other small appliances, as small-scale (below 100 kW).

2.1. Prospects of Solar Irradiance and Solar PV in Nigeria: The Dual Mandate of Nigerian PV

Solar Photovoltaic (PV) deployment in Nigeria represents a strategic lever for national development, driven by the dual mandate of resolving an acute energy crisis and fulfilling global decarbonization commitments. Nigeria holds the distinction of having the world's largest electricity access deficit , with the centralized national grid chronically unable to meet demand, operating production at often only one-third of its 16 GW installed capacity.

In this environment, solar PV has emerged as an economic imperative, not merely an environmental option. Decentralized solutions—Commercial & Industrial (C&I) rooftop solar, mini-grids, and Solar Home Systems (SHS)—are already cost-competitive, with lifetime Levelized Cost of Electricity (LCOE) for solar plus storage estimated at around $0.20/kWh, significantly lower than the $0.30/kWh to over $0.60/kWh cost of diesel generation. This cost advantage establishes a robust business case rooted in superior reliability (epub.wupperinst.org)

However, realizing Nigeria's immense solar potential is constrained by systemic friction. While ambitious policy frameworks like the Energy Transition Plan (ETP) and instruments like Feed-in Tariffs (FiTs) exist to structure private investment , policy instability and contradictory fiscal measures, such as high duties on imported solar components, increase investment risk and drive up the Weighted Average Cost of Capital (WACC) (Osinowo et. al,2015)

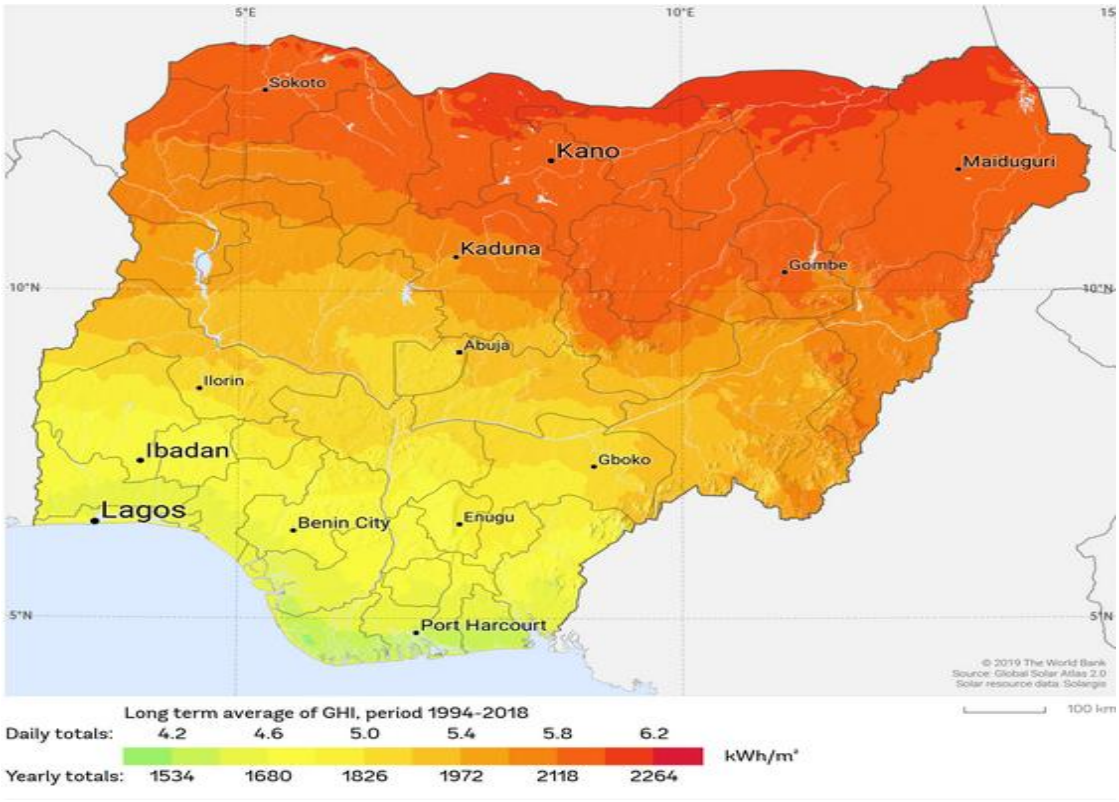

Figure 1. Solar irradiation in Nigeria (SOLARBUY, 2024)

This solar resource is spread across the country. The amount of solar radiation received by each country's zones is displayed in Figure 1. The annual average of total solar radiation in Nigeria's coastal region is estimated to be between 3.5 kWh/m^2/day to 5.2 kWh/m^2/day (Green), whereas in the northern region it ranges between 5.2 kWh/m^2/day to 7.0 kWh/m^2/day (Red).

2.2. Direct Solar to Electrical Energy Conversion

2.2.1. Direct Photoconversion

Kettani (1976) has listed four feasible ways in which the photon energy of incident solar radiation may be converted directly into electricity. These ways are the photovoltaic, in which incident light initiates electron diffusion (and therefore power flow) across the junctions of doped semi-conductors; the photo emissive, in which incident light ejects electrons from the surface of suitable materials; the photo galvanic in which light incident upon a suitable solution of a dye and a reducing agent excites the agent to transfer electrons to the dye, thus reducing it chemically and in electric potential; and the photomagnetic where a suitable material at appropriate temperatures is placed in a magnetic field, and develops a potential difference upon insolation. However, only photovoltaic power generation has had extensive development and application so far.

The development of the photovoltaic source of electrical power came from the space projects of the U.S. and U.S.S.R., and today PV units find ready applications in all sizes of power requirements from proposed giant orbiting power stations to solar powered wrist watches. Although solar cells can be made from a good number of semiconductors, silicon cells are the most established in the field, perhaps because silica, the base material, is extremely abundant upon the earth. The cost of these cells has been one key problem in the competitiveness of solar-derived power with conventionally generated power (Parker & Tipton, 1978). Silicon

cells have sold for about 10-15 $peak watt (or 1000-1500 $m²), whereas they must cost about 10-20 cents/peak watt to compete with coal and nuclear power. Two examples of comparative cost analysis for solar cells/PV plants and other energy sources are given in Fig. 1 (Marfakis, 1976) and Table 1, the latter being more pessimistic than the former. Furthermore, solar cell utilization in power generation has been indicated as being rather too costly in energy to produce system components, so much so that unless technological advancement makes component production less energy-intensive, we might in fact be using more energy than we eventually get back from the sun through these appliances (Baron, 1978). With developments upon present technology however, solar cells are envisaged to have a 25-fold decrease in price to about 0.5 $peak watt around 1986 (Marfakis, 1976; National Research Council, 1979). Besides this, a different manufacturing approach shows far more promise, from commercial development of amorphous-glass semiconductors. These materials ably solve both problems of high cash and manufacturing-energy costs of present-day solar cells and are envisaged to sell for about 5 cents/peak watt in the 1990s when they are more likely to make their debut (Panati, 1980). In the light of these developments, photovoltaic power production is attractive and shows long-term promise too.

(i) Large Scale (above 1 MW) PV Power Generation

(a) Solar Power Satellites (SPS)

Ever since 1968 when Glaser (1968) proposed a geosynchronous satellite directly intercepting solar radiation and beaming it to earth as microwaves, much work has been done to translate the idea to practice, especially in the U.S.A. where, by an ongoing $16 million program, an experimental SPS is expected to be launched about 1990 (Dorf, 1978). The proposal is for a satellite, approximately 12 km by 4.5 km, weighing 10,000 tonnes to stay in orbit at an altitude of about 36,000 km in parallel to the earth's equatorial plane (Glaser, 1968). PV cell banks on the satellite will convert solar radiation directly to electricity and a transducer will convert this electricity to microwaves for transmission to a station on earth where a re-conversion to electricity will be effected. A single SPS could produce about 3-15 GW (i.e. about 1.5 to 7.5 times the total installed capacity of all Nigerian generating stations in 1982). The cost of the necessary research and development is estimated at about $60 billion. A system such as that detailed above is expected to cost $10 billion, thus generating power at about $2/watt (NSF/NASA Solar Energy Panel, 1972). Solar energy is 15 times more available in asynchronous orbit than on earth, and some cost estimates, after taking several factors like availability, storage elimination, efficiency, and others into account, estimate that SPS power cost would be about 2-15 cents/kWh, which is cheaper than conventional (Dorf, 1978). In any case, SPS systems will also benefit from any downturn in solar cell costs.

(b) Terrestrial Power Generation

Rather few proposals worldwide have been made for power stations based purely on PV action, perhaps on account of cell costs, low efficiency, and area requirement. However, Japan, through its national solar energy blueprint "Project Sunshine" inaugurated in 1974, intends to produce 10 MW of PV power by 1986 and 100 MW by 1991. The United States expects to produce 5 GW by 1990 and 20 GW by 2000 A.D. (McVeigh, 1977).

(ii) Medium Scale (100 kW to 1 MW) PV Power Generation

There has been quite little attention so far devoted to this middle class. Most available solar plants of this grade tend to be solar thermal or other systems. However, since it is possible to use PV systems to generate power from the watt to the gigawatt range, development is only a question of time.

(iii) Small Scale (below 100 kW) PV Power Generation

There is a marked abundance of devices using PV power in the lower bracket of this range, but not very many in the higher bracket. Application to isolated- and hostile-environment, portable units as well as to permit virtually maintenance-free use are very common. Thus for example unmanned marine lights, automatic weather stations, portable traveler's power packs, highway telephones, fire alarms, seismographs, radio transmitters, television systems, calculators, etc. Solar power pumps and other equipment have been demonstrated even right here in Nigeria (Noli, 1981). A good number of experimental domestic units are already installed in houses around the world (especially in Europe and U.S.A.) wherein PV power from building-mounted arrays augments power from the utilities.

2.2.2. Solar-Thermal Power Generation

By this approach, solar energy is made to heat up a substance or system. Electricity may then be derived from the heated substance system in a few ways. The more important ways are the direct, in which the nature of the system is such that electricity is instantaneously produced once the appropriate part of the system is insulated; the thermodynamic, in which a fluid is insulated and its expansion works a turbogenerator; and the so-called Solchem system whereby the working fluid absorbs heat from solar collector and discharges it to the heat engine by a change in chemical composition.

(i) Direct Heat-Electric Conversion

There are many ways in which heat may be converted into electricity. The more important ones are by magnetohydrodynamics in which ionised gas is passed through a magnetic field to produce electricity; thermoelectricity whereby a thermal gradient imposed between two connected dissimilar conductors (or semiconductors) produces a potential difference; and thermionic emission whereby electrons are ejected from heated metallic surfaces. Of all these methods, magnetohydrodynamics is the only one to have become a practical reality at present. Solar Magnetohydrodynamic (MHD) Power Generation.

Since definite successes have been recorded with the operation of solar furnaces up to about 3000°C and MHD systems can work well in the range 2000°C to 2500°C, it is expected that solar furnace heat will be profitably employed in ionising the gas stock for MHD systems (Bigdan, 1976). A joint U.S.-U.S.S.R. non-solar MHD plant prototype entered service in Moscow in 1977 and the Soviet Union expects to commission a 500 MW MHD plant in 1984, while the U.S. also has similar plans (Panati, 1980). Having no moving parts and operating at such high temperatures, MHD power generation is distinctly more efficient than all other present alternatives, and there is enthusiasm all around about its future widespread use.

(ii) Thermodynamic Conversion

By this process a solar-heated fluid directly works a turbo-generator to produce power. Differences in plant styles seem to arise from what best suits the intended plant output.

(a) Large Scale (above 1 MW)

This category of solar power plants seems to be enjoying much attention, perhaps because it ranks closely with conventional power plant sizes. The design pattern almost universally involves concentration of solar radiation and quite often involves tracking the sun for maximum effect. Accordingly, such plants are labelled central-receiver, solar tower, helio-electric, etc. However, some other novel approaches are also being evolved.

(b) Medium Scale (100 kW to 1 MW) Plants
This category seems to be quite similar to the large-scale versions especially as regards the use of concentrating collectors, and even a tower arrangement (e.g. INTI 800). This is because of the high temperature of steam needed to generate this much power.

(c) Small Scale (below 100 kW) Plants
There are also many small scale thermodynamic solar thermal plants under development. It has been shown that organic Rankine-cycle solar power plants are feasible even with flat-plate collectors and turbine inlet temperatures as low as 90°-95°C, although use of concentrators severely reduces the collector area requirement for the same power output, but is costlier (Samtel et al., 1978). Much recent work has gone into improvement upon earlier designs and these plants are expected to be widely available in a few years' time (Lorenz et al., 1973).

(iii) Solchem Systems
In this system, sunlight is converted to chemical energy in a field of solar furnaces. The products are piped to a central station where energy is stored as heat-of-fusion, and heat pipe boilers provide steam for a conventional power plant. This approach has been viewed both as a direct competitor/hybrid supplement to the solar power tower concept. Sulphur trioxide (SO_3) and steam-methane have figured as suitable fluids. However, the solchem method is still in its infancy (Chubb et al., 1976; Yarman, 1978).

Solar Towers
Ever since the French commissioned a small-scale (60kwe) experimental plant at Odeillo in 1967, numerous large scale pilot plants have sprung up around the world and several national and international (e.g. E.E.C.) agencies have undertaken such projects (Hurwood, 1978). The U.S. was the first to embark on an actual full-scale plant, a 10 MWe unit at Barstow in the Mojave desert. Most analysts expect the cost of power from such plants to be much cheaper than from conventional plants very soon, and have made estimates that already compare favourably. For a 100 MWe unit contractors to the Energy Research and Development Agency of the U.S. estimated about $100 million- $170 million costs in 1976 (Eicker & Bruno, 1976), while Smith (1978) estimated $175 million. It is certain that commercial production is going ahead (Gervais et al., 1976; Blake, 1976; Powell, 1976; Rizk & Gun, 1976; Easton et al., 1976; Pourakis et al., 1976; Smith et al., 1976).

Updraft Power Plants
These are derived from a new idea that uses ordinary air as the working fluid. A giant, chimney-shaped vertical funnel is surrounded by a plastic covered area that is directly insolated. The green-house effect heats up the confined air, which, being now lighter, rises through the funnel driving a wind-turbine in the latter. West Germany seems to be in the development forefront. A two-year pilot testing is scheduled to be carried out on a plant in Spain (Aroni, 1981). Sufficient data is not yet available to permit economic assessment.

2.3 Indirect Solar to Electrical Energy Conversion
The only basic difference between the "direct" and "indirect" conversion system is in the time scale of conversion, since both ultimately derive from the same source – the sun. Four important indirect sources of sun-derived electrical energy can be identified. viz; wind power, where unequal solar heating of the earth's atmosphere sets up density gradients and therefore current that are utilized in wind turbines, water power where the energy (potential or kinetic) of water is utilized in running turbo-generators:

2.3.1 Wind Power

Wind power is not new. Wind utilization probably started in Egypt about five millennia ago, and many countries of the East, West, and Middle East have long traditions of the use of wind machines. Theoretically, 1% of the world's total wind energy will meet world wide energy need, but the wind's spread and highly unsteady nature set a practical limit on the extractable proportion of this energy (McVeigh, 1977). Wind-utilization technology has been advancing rapidly. Only a few years back a 500 MW wind power plant would have required 100 km² and bigger plants would require disproportionately larger land areas. Innovations like diffuser augmentation, vertical orientation, composite bearingless arrangement, blade-ducting, and many other component improvements have made wind power more attractive, and there are several experimental and working units around the world (Foreman et al., 1976; Kadlec, 1976; Spierings & Cheney, 1976).

The archetype of large-scale wind generators was the 1.25 MW Putnam machine of about 40 years ago, in Vermont, U.S.A. However, several developed nations have been fervently conducting research and development studies into large-scale utilization (Gore, 1981). The U.S. in 1980 passed a Wind Energy Systems Act which launched an 8-year, $900 million program to develop cost-effective wind-power systems in the U.S.A. The projection is for about 30,000 large wind turbines to supply 10% of the nation's energy needs by 2000 A.D. The Scandinavian,countries, U.K. and others also seem to have similar plans. By size, the whole range is in existence round the world as of now. The U.S. has a working 2 MW wind plant at Boone, Northern Carolina, besides a host of smaller units (Smith et al., 1976). Although present wind power costs (for smaller plants) is about thrice that of oil-generated power, extensive and detailed studies have indicated that with new-breed 1 MW plants the cost is likely to fall to about a third (at most) that of oil-generated power at an investment cost of about £400 to £800 per kW installed (Pelser, 1976).

One interesting application for domestic or small-community use is the hybrid wind-solar combination integrated into the architecture (Environmental Design Group, 1975). In fact, there are many imaginative ways in which the wind can supplement our traditional energy sources. Normally, electricity can be generated in winds of about 8-35 mph (3.58 to 15.65 m/sec).

2.3.2. Water Power

The energy in bodies of water could be utilized in many ways. In traditional hydro-electric plants, the flow of a river is dammed to create an artificial head of fall. On the other hand, a turbo-generator is turned by waves-pumped water in a waves-electric plant, by water from a dam on a partially enclosed coastal basin filled by tides in a tidal power plant, by movement of cold water from the depths to the warm surface in an ocean-thermal-energy conversion (OTEC) plant, and by the movement of sea water down to a natural depression in a helio-hydroelectric plant.

(i) Hydroelectric Power Plants

In the context of this paper, hydroelectric power is so much an indirect form of solar energy that it does not really merit discussion. It has also been said that NEPA being unable to guarantee sufficient year-round river flow (naturally), other forms (mainly natural gas-fired) of generation are now being developed side-by-side with hydro. However, since hydroelectricity is still a major component of the Nigerian power supply, Fig. 2 and Table 2 give statistics of the power demand and supply, including hydro (Noli, 1981).

(ii) Tidal Power Plants

This again is an old method of power extraction. The semi-diurnal tides of the seas are produced by the solar and lunar motions and gravitational pulls with respect to the earth. Suitable sites are partially enclosed basins with small (below 80) length to area ratios and high tidal ranges (difference between maximum and minimum heights of the tide). Several hundred suitable sites are believed to exist worldwide. If the quality (the smallness of the ratios L/A and L/power generated) of the basin is good enough, a lot of power can be generated by a tidal plant. Existing plants and those under construction (USSR, Canada, France, U.S.A., Britain, etc.) include units that produce up to 6 GW, and the investment cost has been about £600 to £800 per kW (McVeigh, 1977).

(iii) Waves-Power Plant

Several technical approaches have been taken by different developers of this power source. These include buoys connected to cranks that rotate the generator blades (U.S.A.), floating air chambers that force pressurised air to work a turbine (Japan), "butterfly" rafts that force pistons to pump water to work turbines, and rocking "ducks" that drive generators (both British). Although an experimental unit off Honshu Island began producing 125 kW in 1978, the development of wave power is still in its infancy and cannot for now be assessed in detail (Panati, 1980).

(iv) Ocean-Thermal-Energy Conversion (OTEC) Power Plants

These plants utilise the temperature difference of about 19–25°C (30–40°F) difference in the temperature of ocean water at the surface and at a depth of 609.6–914.4 meters (2000–3000ft). The warm surface water is made to heat a suitable working fluid to pressurised vapour which works a turbine, and is then cooled by the cold, bottom water back to liquid. Much work, worldwide, has gone into the development of OTEC technology and even the "factories-at-sea" that can be sited on and powered by OTEC plants. In the U.S., a substantial development of OTEC is taking place with a test stage of OTEC-1 now off the coast of Hawaii. 25 MW are expected by this year and 100 MW by the full-sized plant in 1984. Yearly increases are contemplated up to about 400 GW by 1996. At the same time, it has been estimated that potentially, OTEC power is roughly about a third (approximately $1000 per kW installed) as expensive as even new nuclear power stations (Zener, 1976).

(v) Helio hydroelectric (HHE) Power Plants

Wherever there are coastlines near the ocean or other large bodies of water in arid zones, a dam could be built across a valley fairly near the sea and water can be pumped behind the dam by using solar energy (the natural version of HHE relies on solar evaporation to take water back to the body of water) and the resulting difference in head utilized by a conventional hydroelectric plant. This system is still in its infancy with the Gulf of Bahrain as the first trial location (Sayigh, 1977).

2.3.3. Synthetic Fuels

These are fuels synthesized from sources other than crude oil or natural gas and used in place of them or their derivatives. They further fall into two broad subdivisions, viz. fossil-derived and bio-derived. The latter derive from living matter or their wastes.

(i) Fossil-derived

The sources are mainly coal, shale, tar-sands and so-called "heavy oil" deposits. Nations with insufficient petroleum resources (U.S.A., South Africa, W. Germany, etc.) but with coal and adequate finance have been the sole developers of fossil-derived synthetic fuels. As of now,

such fuel is costlier than OPEC's petroleum, but costs are expected to tumble, especially with new methods of extraction.

(ii) Bio-derived

These are mainly ethyl alcohol (ethanol), methanol, gaseous fuels (propane gas, methane from natural gas, sewer gas or gasified coal, and hydrogen), and the broad group of "oil-yielding plants." Many nations are already running vehicles on blends of petrol containing 10–20% of alcohol and efforts are on both for large scale production of methanol and even the production of vehicles to run 100% on methanol and still yield the same mileage per litre as with petroleum (the compression ratio is increased to compensate for the lower calorific value of methanol, its high octane number facilitates this). Similarly, a number of plants whose sap, latex or seed oil have been found suitable as lubricants and petroleum substitutes are being cultivated. Examples are the milk weed, the gopher plant, linseed, rapeseed, the Brazilian coibá feralangsdorffii tree, and the California jojoba. The alcohol fuels are the most developed in this group with Brazil as the leading adopter, but methane production is also showing promise. Methane production by anaerobic fermentation of algae has also been suggested (Seifert et al., 1973).

2.3.4. Indirect Photochemical Systems

Some novel approaches have been suggested for indirect solar energy conversion. The more important ones are photolysis wherein free radicals are formed by photon excitation, and photoionization in which light energy initiates ionization. The application of these processes to nitrosyl chloride and caesium respectively are believed to be potentially viable solar energy conversion methods.

Table 2.1. Solar Energy prospects Estimates (Baron, 1978)

S/No	Category	Prospects and Estimates
1	Fossil/Nuclear plant	0.6-0.8 actual power factor and Cost $1100/kwe
2	PV system	Feasible now in isolated plants in institution, hotels, apartment houses, office buildings, amusement parks, etc.
3	Wind and biomass	Were feasible and obtainable
	OTEC	Will be feasible at the turn of the century

3. MATERIAL AND METHOD

3.1. The Nigerian Resource Base

Lying between the latitudes 4° and 14° of the equator, with an entire boundary washed by the Atlantic Ocean and vegetation varying from rain forest to sub-Sahara Desert conditions, it is clear that in the light of all the foregoing geographical requirements for the diverse ways of profitably harnessing solar energy, Nigeria is particularly blessed. She has a land area of almost a million square kilometres and is distant by about 30 km (Lagos/Badagry) to 140 km (Oron coast) from 2 km deep ocean.

3.2. Demand and Supply Trends in Nigeria's Power Sector

Nigeria's electricity sector, dominated by existing power plants (primarily gas-fired thermal plants accounting for approximately 80% of generation, with hydropower contributing the remainder), continues to face a persistent supply-demand imbalance. Installed capacity exceeds 13,000 MW, but actual generation is constrained by gas shortages, infrastructure limitations, and transmission losses, typically operating at 30-40% of potential. Demand has grown steadily due to population increases and economic activity, while supply has shown modest gains but remains insufficient, leading to widespread reliance on self-generation.

Table (1) below summarizes yearly trends for electricity supply (generation) and demand (consumption) from 2019 to 2024, based on data from the International Energy Agency (IEA), Enerdata, Statista, and Our World in Data. Values are in terawatt hours (TWh). Note that 2024 data reflect preliminary estimates as of late 2025.

Table 1. The Demand and Supply Trend and the Existing Power Plants Respectively

Year	Supply (Generation, TWh)	Demand (Consumption, TWh)	Gap (Demand - Supply, TWh)	Status
2019	32.0	30.0	-2.0	Supply exceeded demand slightly due to exports and losses; per capita consumption ~145 kWh.
2020	28.0	26.0	-2.0	COVID-19 reduced demand; generation dipped amid economic contraction.
2021	31.0	28.0	-3.0	Recovery in demand; supply grew modestly via improved gas utilization.
2022	35.0	32.0	-3.0	Peak supply growth; residential demand dominant (~61% of total).
2023	40.7	40.0	-0.7	Strong demand surge; generation hit record high, but access remains at ~60%.
2024	38.0	33.0	+5.0	Demand dipped 3% amid economic slowdown; supply constrained by outages. Per capita ~140 kWh.

This table above illustrates an average annual supply growth of ~3.7% versus demand growth of ~2.7%, yet the structural gap persists due to inefficiencies (e.g., 20-30% transmission losses). Projections for 2025 suggest demand rising to ~41 TWh, necessitating urgent investments in existing plants' maintenance and gas supply to bridge the deficit.

Nigeria is also largely a single-resource (oil) country, whose financial fortunes depend on the market price of crude petroleum. The last budget for 2024 shared an expected oil-sourced revenue. She currently produces crude petroleum at the rate of 1.4 million barrels per day and crude reserves are projected to last at least 25 years and probably more. She has even more natural gas and coal. As a proper start for systematic energy research, millions was voted, of which some amount has recently been disbursed towards nuclear and solar energy research.

The required research and development personnel are believed to exist throughout the research institutes, universities and polytechnics of the land, for the purposes of creation, adaptation or commercialization of solar energy technology.

3.3. Nigeria's Options for Solar-derived Electricity

It is clear that for any nation, a solution of the energy problem must be in the form of using an energy mix. Although the well sung energy crisis has been simply dissected into two—overconsumption in the developed world and underconsumption in the third world, yet it is clear that Nigeria does have an energy crisis with peculiarities of its own. The supply of power is yet very inadequate. Home oil consumption is growing (the 4th national development plan estimates it to be 440,000 barrels/day in 1985) and it has even suggested that by 1990, Nigeria may be consuming about 50% of her oil output. By that time too, if large reserves are not discovered, the resulting revenue downturn would have serious effects on the nation's

development. In short, the country increasingly needs the oil revenue to finance development, but she also needs increasingly more of the oil for her own use, and in any case has progressively less to draw upon. Also, Nigeria has borrowed for the past 17 years to finance her electric power development, so it is not as if we had so much money to provide energy.

Again, it has been observed that there is a 20:1 economic advantage in processing our crude to petrochemical end-products rather than selling as mined. At the same time it is well known that the developed nations already see the third world as a rich market for all grades of solar devices. In the light of these facts, it is essential that alternative energy sources be developed quickly both to directly improve the quality of life, especially in the rural areas, and also to take the heat off our dwindling fossil reserves, and to help us prevent, wherever possible, needless waste of money on importation of appliances and technology that we can wholly or partially supply. We may consider the solar-electric conversion methods reviewed to see what the country can do about them.

3.3.1. Photovoltaic Conversion

If the expectations of cheap solar cells materialise, then large-scale PV power production will be desirable. For now, medium- and small-scale units are very useful for domestic, institutional and rural-community needs in many forms. Solar cell research, product development and integrated architectural applications suggest themselves. Solar power satellites cannot be considered as we have neither the money nor the technology.

3.3.2. Solar Thermal

The solar tower system can be kept in mind for the very highly insulated parts (e.g. Sokoto State) of Nigeria. The updraft system is very attractive for an even wider area of northern Nigeria, and it seems most desirable to develop it. Small and medium size plants can be of immediate use but it is suggested that a careful selection be made to ensure that in their class, other approaches are not in fact better. Magnetohydrodynamics also seems, at least for commercial purposes, to be beyond our grip at the moment, considering the required finance and technology.

The Solchem system is not really complicated and since it is deemed competitive with solar thermal, it should not be ignored for adoption and development.

3.3.3. Wind Power

There is great potential in wind power development, especially along the coastline, and for smaller units all over the rest of the country. This with direct-solar, is an energy source that can help much in the rapid transformation of our rural and isolated areas.

3.3.4. Water Power (Hydro)

River Niger has been dammed in many places, and the Benue is now being similarly dammed. We shall soon be left with the ocean only, if we want water power. It appears that if non-hydro water resources are considered, more serious attention should be given to waves and tides than OTEC and HHE on account of the larger sizes the former plants tend to generate. However, it is possible that economical OTEC plants may soon be on the market.

3.3.5. Synfuels

It is clear that sooner or later our petroleum stock will be finished. It is therefore not out of place for us to start serious work on alternative fuels research and use. If synfuels (especially bio-derived ones) are available cheaply in remote places, we save on premium petroleum, transportation and distribution costs, etc., by using them instead.

3.4. Overview of Renewable Energy Initiatives in Nigeria

Nigeria, facing a significant electricity access gap affecting over 85 million people, has prioritized renewable energy to enhance energy security, reduce emissions, and support economic development. With an installed capacity dominated by gas-fired plants, the country aims to leverage its abundant renewable resources—estimated at over 68,000 MW from solar, wind, biomass, and hydro sources—to meet growing demand and achieve sustainable goals. Key frameworks include the Nigeria Energy Transition Plan (ETP), which targets net-zero emissions by 2060 across sectors such as power, cooking, transport, industry, and oil and gas. This plan emphasizes renewables-backed electrification, with solar playing a pivotal role in replacing gas as a transition fuel, aiming for nearly 100% emissions reduction in the power sector.

3.5. Major Policies and Frameworks

Nigeria's renewable energy landscape is guided by several policies and agencies:

- National Renewable Energy and Energy Efficiency Policy (NREEEP, 2015): Establishes targets for renewable integration, including 23% renewable energy in the total energy mix by 2025 and 36% by 2030.
- Nigeria Electrification Project (NEP): Focuses on off-grid solutions, having established 125 mini-grids and distributed over a million solar home systems.
- Rural Electrification Agency (REA): Implements decentralized renewable projects, including mini-grids, solar home systems, and productive use programs, impacting over 7.8 million people and supporting 11,400 micro, small, and medium enterprises (MSMEs).
- Energy Transition Plan (ETP): Projects a total installed capacity of 277 GW by 2060, with renewables driving decarbonization in cooking (via electric stoves and biogas), transport (electric vehicles), and industry (zero-emission fuels).

3.6. Key Initiatives and Projects

Table (2) shows Prominent Renewable Energy Initiatives, Including Objectives, Scope, And Achievements as of Late 2025. (energytransition.gov.ng).

4. RESULTS, CHALLENGES AND OPPORTUNITIES

a. Firstly, the governments and private industries of this country need to know that much more money than recently voted for energy research and development is needed, on a continuing basis, for the good of all.
b. A centralised, single although multifaceted government national energy policy is necessary. The taking of our energy inventory, assessment of our position in a world context and projections for our future safety and prosperity shall be reflected in such a policy. It is desirable that all plans, research and development and other contracts have set and monitored objectives.
c. Joint development, both with technically advanced partners on one hand, and our O.A.U. and ECOWAS brothers on the other should be preferred to the "perpetual purchaser" role, as much as possible.
d. Eight new, small and medium scale, state-of-the-art solar products exist that can be bought and utilized. Such applications, with concerted local or joint research and development especially for photovoltaic, solar thermal and wind energies are perhaps most relevant.

Table 2. Renewable Energy Initiatives, Objectives, and Some Achievements

Initiative	Description	Key Objectives and Scope	Achievements/Status
Distributed Access through Renewable Energy Scale-up (DARES)	A World Bank-financed project ($750 million IDA credit, plus over $1.3 billion in additional funding) to deploy distributed renewables like standalone solar and mini-grids.	Provide new or improved electricity access to 17.5 million Nigerians; replace 280,000 polluting generators; prioritize gender inclusion and MSMEs.	Builds on NEP; expected to benefit 237,000 MSMEs with clean power; ongoing implementation since 2023.
Rural Electrification Agency (REA) Programs	Includes Distributed Energy (DE) program, National Public Sector Solarisation Initiative (NPSSI), and African Mini-Grid Program; focuses on private sector-led mini-grids and solar systems.	Address rural electrification gap in 700,000 communities; tie energy to productive uses in agriculture and businesses; deploy 94 MW of PV capacity.	Over 1.1 million connections; $400 million in grants disbursed, with $900 million in pipeline; examples include 250 kW and 200 kW mini-grids.
Katsina Wind Farm	A 10 MW pilot wind project in northern Nigeria.	Demonstrate wind energy viability; contribute to diversified renewable mix.	Operational since 2020; part of broader wind pilots.
Stand-Alone Solar for Productive Use	REA-led program providing solar systems for off-grid areas.	Enhance access for dispersed settlements; support livelihoods and MSMEs.	Integrated into NEP; over a million systems distributed.
Investments to End Poverty Initiative	Government-led effort to expand renewable access as a poverty reduction tool.	Reduce poverty through reliable electricity; target 100 million Nigerians with modern energy services.	Aligns with ETP; projected to create 340,000 jobs by 2030 and 840,000 by 2060.

5. CONCLUSION

Despite progress, barriers persist, including financing gaps, policy fragmentation, high costs, and skills shortages. Opportunities lie in untapped resources like biomass and geothermal, with renewables potentially meeting 60% of demand by 2050 if plans are executed. International partnerships, such as with the World Bank and SEforAll, are crucial for scaling investments. In summary, Nigeria's renewable initiatives represent a strategic shift towards sustainability, with a focus on decentralized solutions to bridge the energy access divide while aligning with global climate commitments. Continued investment and policy coherence will be essential for realizing these goals.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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