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Comparative Analysis of Solar, Wind, Geothermal and Nuclear Energies in Solving Nigeria's Perennial Problem of Inefficient Electric Power Supply

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Abstract- Report from World Bank quoted that about 43 per cent of Nigeria's population of more than 200 million people continues to lack access to grid electricity due to gas supply shortages, grid constraints, water shortages, poor equipment maintenance, unskilled personnel, among others. Businesses in the country reportedly lose about USD 29 billion annually as a result of unreliable electricity supply. The national power grid is in a state of disrepair. Although Nigeria's generation capacity is at around 13,000 MW (mostly from thermal and hydropower sources), the national grid is only able to wheel about 4,000MW or less to consumers. By the end of July 2022, the grid has experienced its seventh system collapse for the year. In addition, due to insufficient generation and grid constraints, the majority of households and businesses generate their own electricity with diesel/ petrol generators. The combined capacity of small gasoline generators in Nigeria has been estimated to be 42,000 MW.

Keywords: Thermal, Electricity, Grid, Power supply, Constraints

I. INTRODUCTION

Reports have shown that over the years, poor infrastructural maintenance, fuel supply shortages, seasonal fluctuations in water levels, unpredictable weather changes, corruption, mismanagement, inefficient electronic devices, generation, transmission and distribution equipment malfunction are the major factors bedeviling or contributing to Nigerian's perennial problem of inefficient electric power supply. Undeniably, several efforts have been made by Federal Government through Federal Ministry of Power in restoring the dilapidated state of infrastructures and incessant power outage in Nigeria; but yet prove abortive. It is on this note, the paper aimed to study comparative analysis of solar, wind, geothermal and nuclear energies in solving Nigerian's perennial problem of inefficient electric power supply. This current work will foster a solution as regards to the best energy source(s) that will bring the state of the system revived and sustainable. In addition, the work will look into the current electric power potentials of the various energy sources, with their relative generation and running costs, operational performances and finally suggest way forward.

(Tarek, 2017) Highlighted that energy required to sustain the society are in the form of heat, light, mechanical, sound and it is known as basic energy forms that is sourced from primary energy sources such as coal, wood, natural gas, crude oil, geothermal, wind, Uranium, solar radiation. Secondary energy sources are gotten technologically from primary energy sources and they include electricity, gasoline, methanol, shaft work, fuel oils, and Hydrogen. Final energy is attributed to both primary and secondary energy sources after transportation losses have been subtracted.

Solar energy is energy gotten from sun radiation when it is converted into thermal (heat energy) or electrical using solar thermal collectors or photovoltaic panels.

Wind energy is energy gotten by converting the kinetic energy of wind into mechanical energy using wind turbine requiring the use of blades and rotor assembly.

Geothermal energy is energy extracted from the earth crust due to formation of magma and radioactive decay. The heat from these processes can be captured and harnessed for electrical power generation.
Nuclear energy is energy from fission reaction (chain reaction) of heavy elements such as Uranium, Thorium, etc, with nucleus bombardment. The heat liberated during the reaction can be harnessed for driving steam power turbines that generate electricity.

Table 1: Access to Electricity in the World (% Population)

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S/N	Name	(% Population)
1	Sub Sahara Africa	35.31
2	East Asia and pacific	96.12
3	Middle east and north America	96.12
4	South Asia	74.4
5	China	100
6	India	78.7
7	Malaysia	100
8	Central Africa republic	10.8
9	South Africa	85.4
10	Brazil	99.5
11	Nigeria	55.6
12	World	84.58

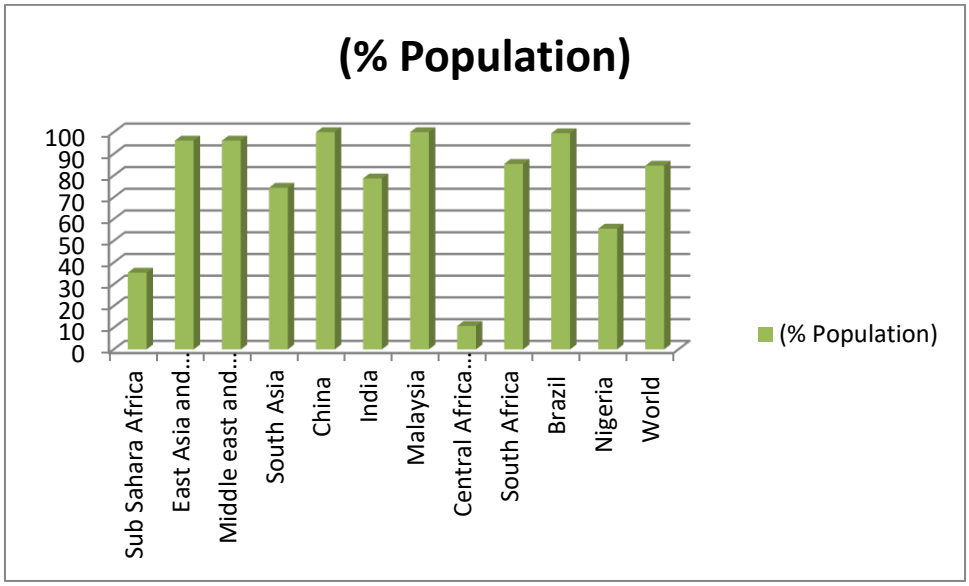

Fig 1.0: Bar chart of Access to Electricity in the World (% Population)

Table 1.0 and Fig 1.0 had shown that only 55.6% percentages of Nigeria's population of more than 200 million people continues to lack access to grid electricity.

ALTERNATIVE ENERGY SOURCES

Most frequently mentioned alternative energies in Nigerian's electric power sector include:

1) Wind power
2) Water power
3) Solar power
4) Nuclear power
5) Geothermal power
6) Tidal power

This alternative energy sources are also known as renewable energy sources and are limited only by their rate of production unlike non-renewable energy sources limited by their rate of consumption.

The following factors should be considered in any comparative analysis of alternative energy sources.

- Availability
- Rate of energy production
- Characteristics of energy produced
- Environmental and safety considerations
- Economic competitiveness
- Political considerations
- Psychological barriers for change.

SOLAR, WIND, GEOTHERMAL AND NUCLEAR ENERGY POTENTIALS IN NIGERIA

Obviously, Nigeria is blessed by abundant renewable/alternative energy resources such as solar, wind, geothermal and nuclear but the harnessing of these energies have been on a slow rate.

Table 2.0: Nigerian's Energy Resources and their Electric Power Potentials

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Energy Resource	Potential
Solar	4.0 to 6.5kW/m^2/day
Wind	520Kw/m^2/year
Geothermal	130.28MW/m^2
Nuclear	2400MW
Hydro	11,250 MW

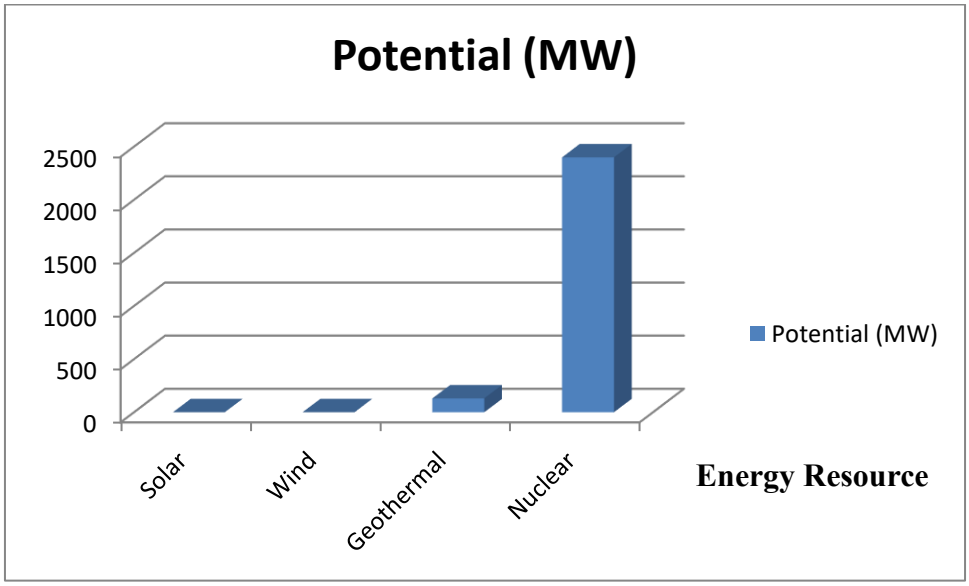

Fig 2.0: Bar Chart of Nigerian's Energy Resources and their Electric Power Potentials

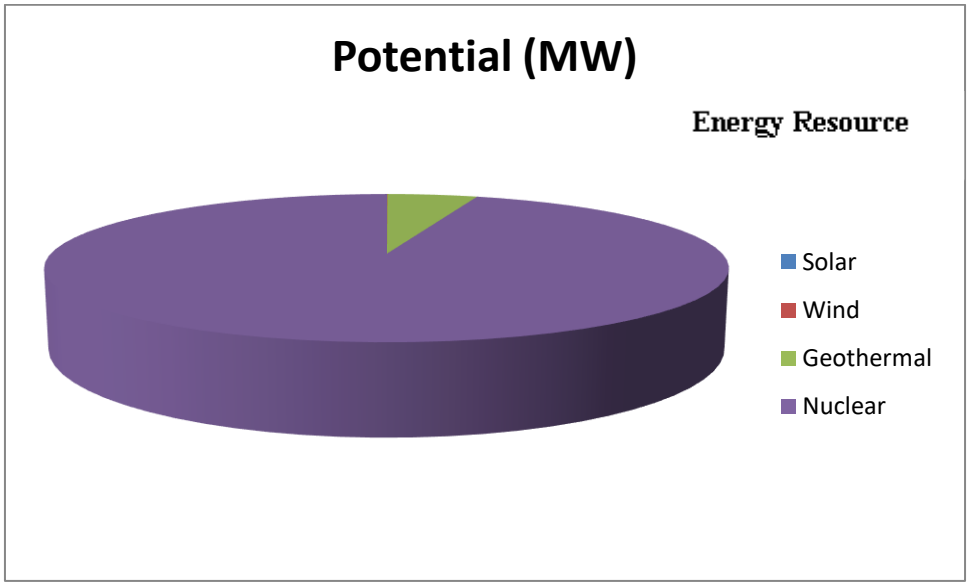

Fig 3.0: Pie Chart of Nigerian's Energy Resources and their Electric Power Potentials

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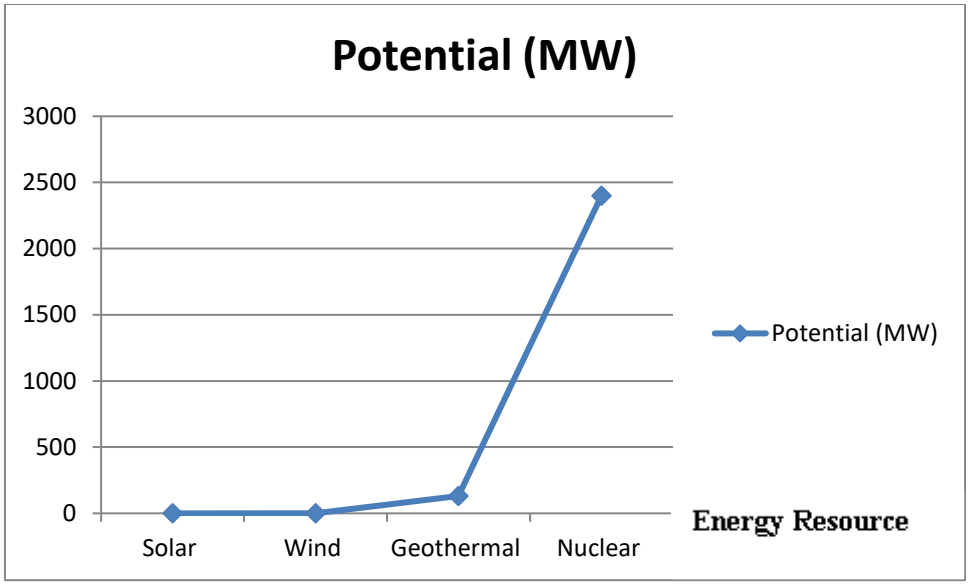

Fig 4.0: Line Graph of Nigerian's Energy Resources and their Electric Power Potentials

According to the fig 2.0 to Fig 4.0, maximum electric power generation in Nigeria will be achieved when nuclear energy resource is used followed by geothermal energy as a second choice. The use of wind and solar energy resources can be adopted for domestic and light industrial activities or can be used as an auxiliary to conventional electric power generation systems.

COST MODELS OF ENERGY SYSTEM

1) Cost of continuous operation of a conventional system
This is mostly based on the operational cost only as the conventional system has to be purchased. Therefore, the cost of operating a conventional energy system per year is given below:

$$CCS_j = CE \times E \times (1+R)^{j-1} \ldots\ldots (1.0) \text{ (Tarek, 2017)}$$

Where $CCS_j = cost\ of operating\ conventional\ \ system\ for\ year, j\ in\ \#/year$

$E = amount\ of\ energy\ required\ per\ year\ in\ thermal\ unit/Btu$

$CE =$ Cost of conventional energy in #/ Btu

$R = average\ percentage\ increase\ of\ conventional\ \ prices$

$during\ a\ specific\ period\ of\ \ operation\ in\ a\ year$

2) Engineering cost model
The engineering cost model for the operation of solar energy system must consider the system expenditure in addition to the conventional system.

$$CSS_j = A + CCS_j(1-N) + CESS_j + MC \ldots\ldots (2.0) \text{ (Tarek, 2017)}$$

Where $CSS_j = cost\ of operating\ solar\ \ system\ for\ year, j\ in\ \#/year$

$$A = Annual\ payment = (C-D)(CRF_{\frac{A}{P}.n.r})$$

$$C = cost\ of\ the\ solar\ system$$

$$D = down\ payment\ of\ the\ solar\ system$$

$$CRF = capital\ recovery\ factor\ to\ find\ the\ annuity$$

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$P = present\ cost, = (C - D), r = interst\ rate\ of\ loan, n = length\ of\ loan\ in\ a\ year$

$CCS_j = cost\ of\ conventional\ system\ in\ year\ j$

$CESS_j = cost\ of\ conventional\ energy\ to\ operate\ the\ system\ in\ year\ j$(when solar is used as a backup)

$MC = average\ maintenance\ cost\ of\ solar\ system\ in\ year\ j$

$N = percentage\ of\ time\ the\ solar\ system\ is\ in\ operation$

LEVELISED COST OF ENERGY (LCOE)

(Heinrich, 2017) defined levelised cost of energy as the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using a discount rate that captures the cost of finance (in our Nigerian case, the Weighted Average Cost of Capital or WACC).

LCOE = (overnight capital cost × CRF + FOM/ (8760 ×capacity factor) + (specific fuel cost × heat rate) + VOM ….(3.0)

CRF (capital recovery factor) = $\frac{r\times(r+1)^i}{((r+1)^i-1)}$ …(4.0)

Where r is the WACC and *i* is the investment life (in the case of this study this is 11% as defined by NERC).

FOM = annual fixed operation and maintenance costs

VOM = variable operation and maintenance costs

SOCIETY'S COST OF ELECTRICITY (SCOE) AS CALCULATED WITHIN THIS STUDY

SCOE = LCOE + cost of climate change damage + cost of air pollution damage +

System integration costs

According to the cost models presented above, wind energy is most favorable resource, followed by geothermal energy resource. Operational and maintenance cost of nuclear and solar are moderately high.

Table 3.0: Energy Resource and their Negative Impact to the Environment

Energy Resource	Negative Impact to the Environment	Rating (%)
Solar	Climate and pollution damages	-
Wind	Climate and pollution damages	-
Geothermal	Climate and pollution damages	Moderately high (25)
Nuclear	Climate and pollution damages	Very high (50)

According to the table 3.0 above, wind and solar energy resource are known for zero environmental negative impact. Geothermal energy resource environmental hazard such as land slide and earthquake are major factors limiting its adoption as a sources electric power. Nuclear energy resource being the highest, owing to its radiation tendencies due to spillage as well as genetic mutations of ecosystem and humans at large. Therefore, adoption of unclear energy for electric power generation must required improved environmental safety and quality assurance guidelines that must be sustainable.

Table 4.0: Energy Resources and their Cost of on-Grid Energy

Energy Resource	Cost of on-Grid Energy USD/(kWhr)
Solar	0.157
Wind	0.13
Geothermal	0.053
Nuclear	0.12

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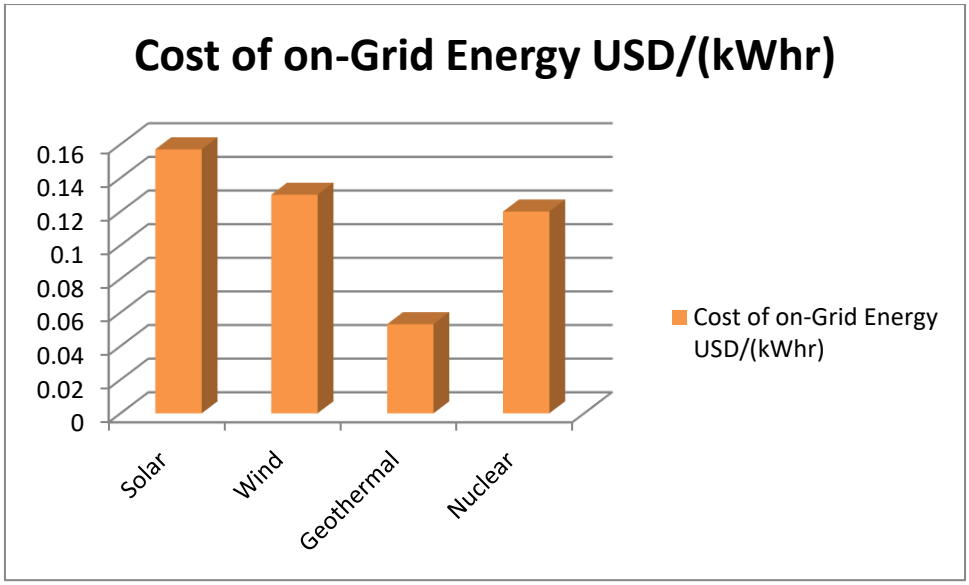

Fig 5.0: Bar Chart of Energy Resources and their Cost of on-Grid Energy

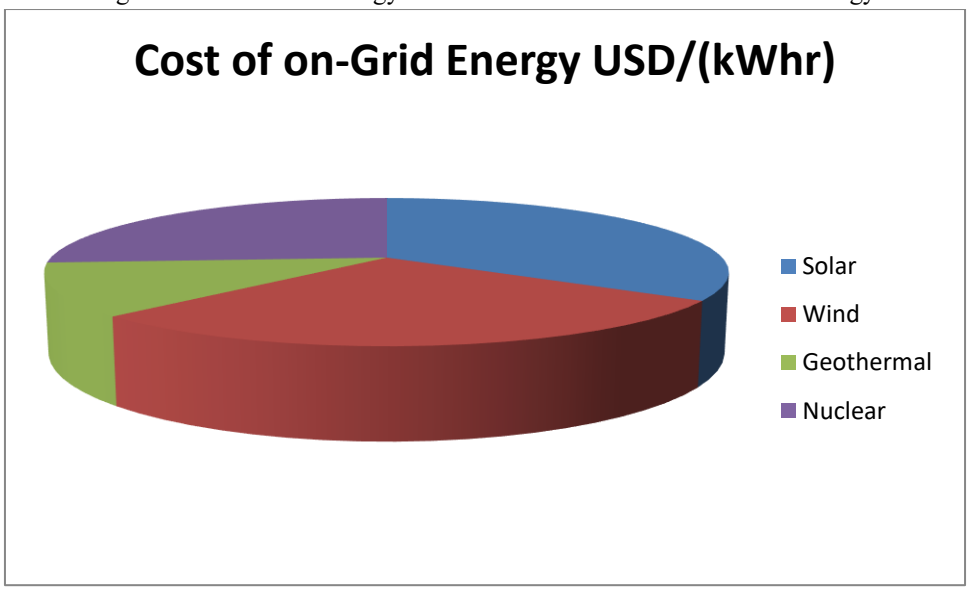

Fig 6.0: Pie Chart of Energy Resources and their Cost of on-Grid Energy

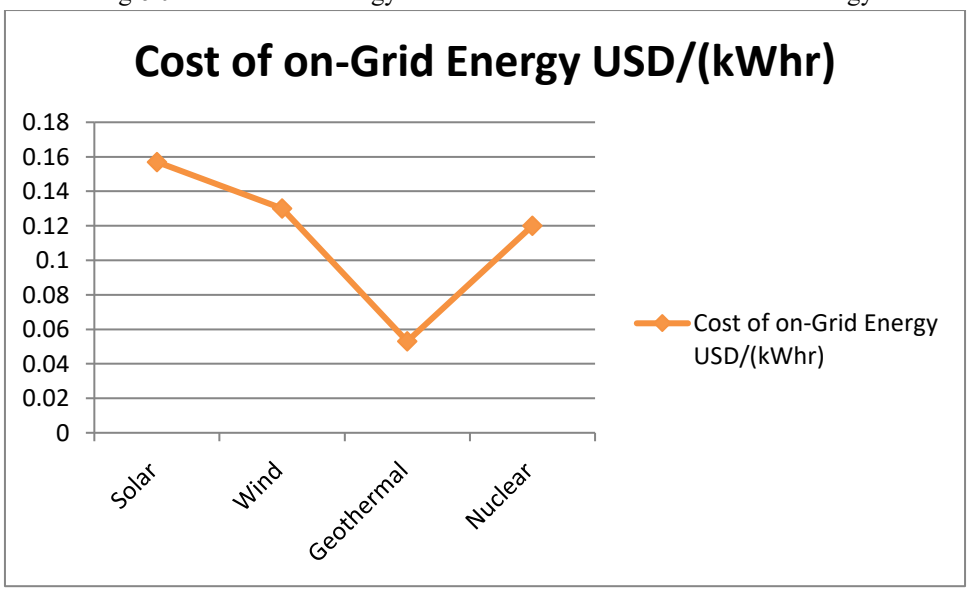

Fig 7.0: Line Graph of Energy Resources and their Cost of on-Grid Energy

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According to the table 4.0 above, Fig 5.0 to Fig 7.0, solar and wind energy resources are seen to have the highest on-grid connection cost of and therefore, may not be sustainable as a choice of energy resources for on-grid electric power generation in Nigeria. Geothermal energy resource was found to have least on-grid cost followed by nuclear energy resource. Since Nigeria is found with abundance of geothermal potentials, it can be adopted as an energy resource for on-grid connection owing to its lowest cost. The adoption of nuclear energy for on-grid connection demands a moderate investment higher than that of geothermal but can be sustainable when compared with solar and wind energy systems.

Table 5: Cost of Uranium 308 for Nuclear Energy Operation

Year	Cost $/IbU308
1963	180
1968	160
1970	140
1987	120
1999	100
2001	80
2000	60
2002	40
2003	20

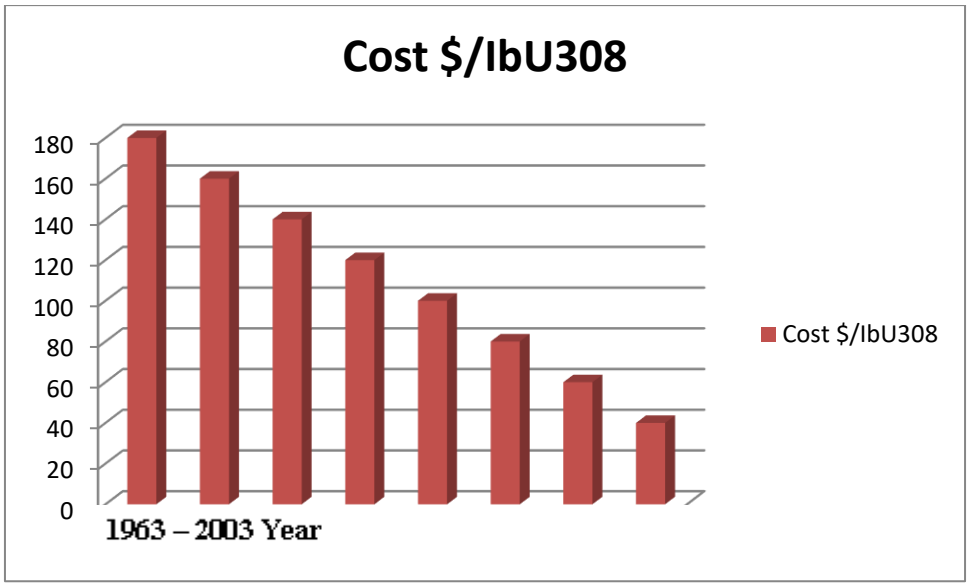

Fig 8.0: Bar Chart of Cost of Uranium 308 for Nuclear Energy Operation

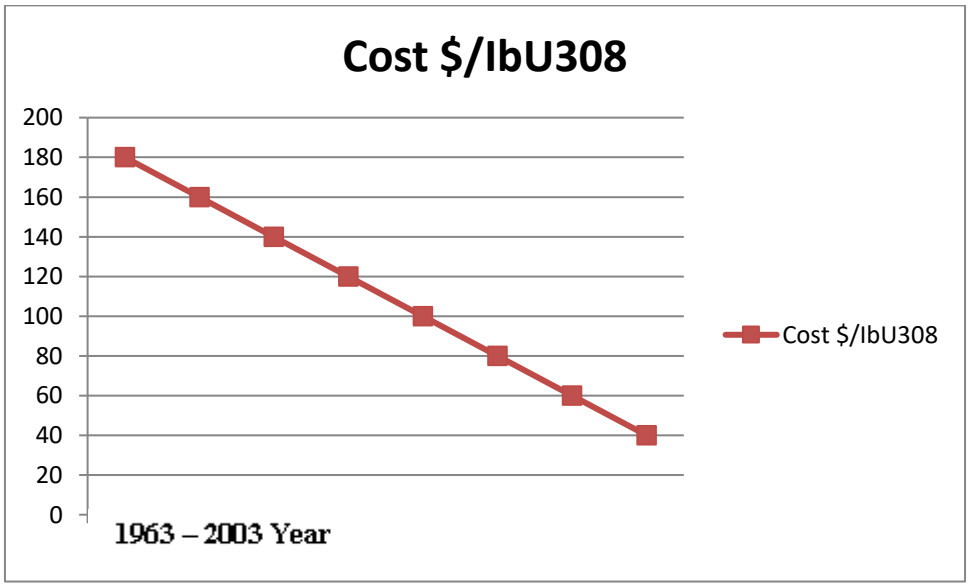

Fig 9.0: Line Graph of Cost of Uranium 308 for Nuclear Energy Operation

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According to table5.0, Fig 8.0 and Fig 9.0, the cost of Uranium 308 required for nuclear energy on-grid connection demands high investment at the introduction of nuclear power plant around 1963. But the prices of Uranium decreases with increase in availability of nuclear power plant worldwide. From this data, one can unarguably said that the cost of adopting/operating electric power supply in Nigeria using nuclear energy resource may likely drop further in future.

Table 6: Percentage increase in Average Energy Availability of Nuclear Power Worldwide

Year	Average Energy Availability of Nuclear Power (%)
1990	71
1992	73
1997	75
1999	78
2000	80
2001	82
2002	83
2003	85

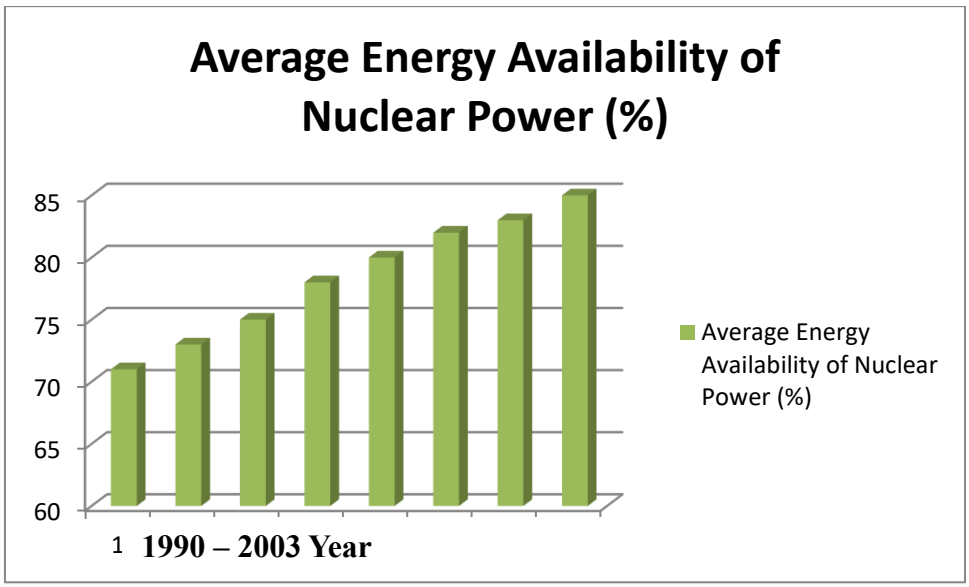

Fig 10.0: Bar Chart of Percentage increase in Average Energy Availability of Nuclear Power Worldwide

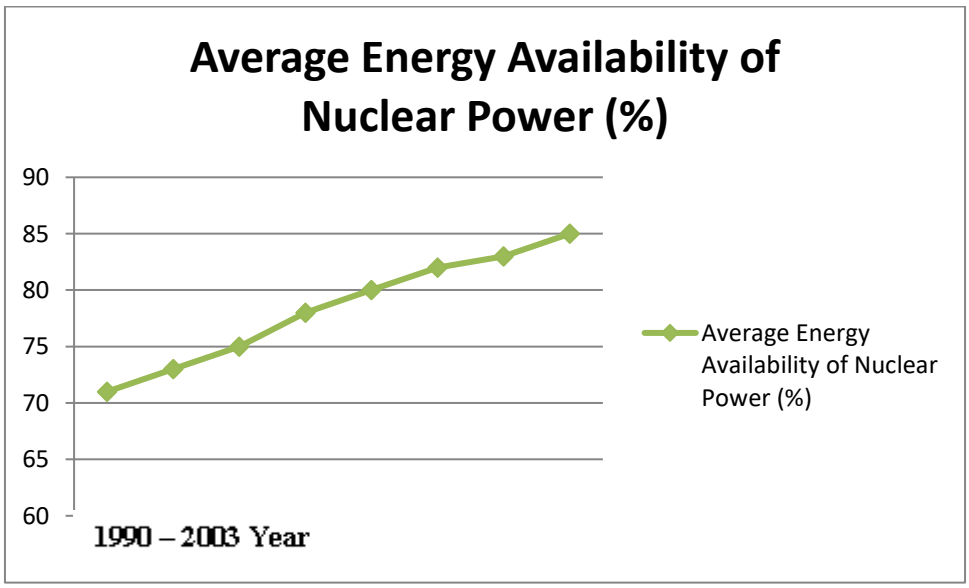

Fig 11.0: Line Graph of Percentage increase in Average Energy Availability of Nuclear Power Worldwide

According to table 6.0, Fig 10.0 and Fig 11.0, the Percentage increase in Average Energy Availability of Nuclear Power Worldwide is obviously encouraging. Decrease in Uranium 308 prices per year, together with increased average energy availability of nuclear power plant, will definitely bring to an end the Nigerian's perennial problem of inefficient electric power supply if nuclear power plant can be adopted as an option.

As the Nigerian's perennial problem of inefficient electric power supply is alarming, embracing reliable and long term energy sources such as geothermal and nuclear energies will leverage/optimize the Nigerian on-grid capacity. It is on this note, that the comparative analysis study of solar, wind, geothermal and nuclear energies in solving Nigerian's perennial problem of inefficient electric power supply is justified on the basis of climate damages, environmental pollution, operating/ running cost, etc.

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