

# A KEY PERFORMANCE INDEX APPROACH FOR ASSESSMENT OF GLOBAL SOLAR RADIATION IN NIGERIA

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**Abstract-** Global solar radiation is the sum of direct, diffuse and reflected solar radiation. Direct solar radiation passes directly through the atmosphere to the earth surface. Diffuse solar radiation is scattered in the atmosphere and deflected solar radiation reaches a surface and is reflected to adjacent surface. This paper presents a key performance approach for assessment of global solar radiation in Nigeria. The mathematical modeling of the system Cost Of Energy (COE) in #/kWh was formulated subject to the reliability condition for the computation of the energy contributions of the PV source, wind source and the grid source. The performance characteristics of the system are characterized in terms of its reliability in providing a cost- effective energy solution for satisfying the energy demand within the entire period. The results of the work shows that the percentage PV contributions of Abuja, Benin City, Katsina, Lagos, Nsukka and Yola are 32.63%, 34.58%, 55.84%, 55.32%, 39.12% and 42.02% respectively, thus ranking Katsina as the highest and Abuja as the least due to the thick population of Katsina and the percentage variation of the renewable energy contribution in the Northern part of the country. The percentage energy contribution of wind for Abuja, Benin city, Katsina, Lagos, Nsukka and Yola are 70.69%, 66.71%, 38.84%, 22.08%, 34.92% and 22.83% respectively while that of grid are 8.88%, 10.71%, 17.32%, 34.68%, 37.96% and 48.175% respectively thus ranking Abuja as the city with the highest percentage wind energy contribution of 70.69% and Lagos as the city with the least percentage wind energy contribution of 22.01%. In the same vein, Yola emerged as the city with the highest percentage grid energy contribution of 48.178% with Abuja having the least percentage grid energy contribution of 8.88%. This is because the contribution of wind energy is largely limited by the sharp decrease in the annual average wind speed in the Southern part of the country. The percentage of the wind energy conversion system varies from about 22.18% in Yola to 70.69% in Abuja because a large fraction of solar energy is required to compensate for the available grid electricity supplied. Abuja and Yola recorded the highest and least energy throughput of 8.10kWh/N and 5.22kWh/N respectively while the energy throughput, for Benin city, Katsina, Lagos and Nsukka are 7.47kWh/N, 6.62kWh/N, 5.74kWh/N and 5.58kWh/N respectively. The highest and least costs of 0.168 #/kWh and 0.111 #/kWh were recorded by Yola and Abuja because the Northern part of the country has significant improvement in the overall system cost of energy supplied. The implementation of the stand-alone PV- wind energy system is a more viable option. This will reduce the larger land area needed for the stand-alone hybrid renewable energy system.

**Keywords::** Key Performance Index (KPI), Solar Radiation, Photovoltaic, Cost of Energy, Loss of Supply Probability, Loss of Power Supply Probability, Energy Throughput, Energy Contribution.

## 1.0 Introduction

Electricity is the most desirable form of energy, which plays a vital role in the socio-economic and technological development of a country. With an increase in the population and economic development, the electricity demand of the country multiplies. If the rise in demand is not met satisfactorily, this can lead to a shortage in electricity supply with adverse socio-economic and environmental implications [7],[10],[12],[16].

The renewable energy system design integrates renewable energy mix, such as biomass, wind and solar energy. Large area of land, water and social impacts characterize the electricity production from biomass and this requires further study to verify the techno-economic viability of its power generation. However, it may be required to shift demand to other energy sources such as wind and solar. These are useful sources for renewable energy generation because they are both technically and environmentally viable options [15],[16],[18].

Wind energy is one of the most viable and promising sources of renewable energy. Accurate estimate of wind speed distribution, selection of wind turbines and the operational strategy and management of the wind turbines are essential factors affecting the wind energy potential. The adjustment of the wind profile is necessary to account for the effects of the wind shear inputs. Accurate assessment of wind power potential at a site requires detailed knowledge of the wind speeds at different heights [2],[3],[7],[8],[9].

### Photovoltaic Conversion system

The performance of the photovoltaic conversion system (PVCS) depends majorly on its orientation and period of services. The orientation of the PV sources is described with its tilt angle and the azimuth, both relate to the horizontal. Temperature affects crystalline cells and their performance decreases as cell temperature rises. A significant issue of concern is the heat built-up under the PV modules, resulting in the possible structural damage of the panel. Generally, there are two steps in determining the available solar energy when supplying a remote load. The first step involves the determination of the solar radiation that arrives on the earth at the PV panel's location. The next step is modeling of the panel itself, considering its efficiencies, losses and physical orientations. Each step requires a model that deals with many variables and inputs into the second stage of the model and utilizes the result of the first step [[1],[4],[5],[6]].

### Hybrid Energy System

The fluctuating renewable energy supplies load demands and non-linear characteristics of some components complicate the design of hybrid systems. The overall assessments of autonomous hybrid energy system depends on economic and environmental criteria, which are often conflicting. The technical constraints in hybrid energy systems relate to system reliability. Several reliability indices have been employed for the evaluation of generating systems. The most technical approaches used for the evaluation of power system reliability are the loss of load probability, loss of load power supply and loss of power supply probability. Several other factors, which constitute to the expected probability of renewable energy system influence the economic stability[[11],[17].

### Energy Storage System

Power fluctuations can be incurred since the renewable energy is highly dependent on weather conditions. The use of batteries in medium and high power application is remarkable. The required energy storage capacity can be reduced to a minimum when there is optimal sizing of the energy system at a given site. The rate of prediction at which the energy storage unit charges/discharges when generated power is more or less than the demanded power requires accurate energy storage model[13],[14],[16],[18].

## 2.0 Materials and Method

The major key performance indices (KPI) namely: energy contributions of the PV, wind and grid, the energy throughput of the system and the cost of energy were computed using the mathematical relations below:

The systems cost of energy (COE) in #/kWh is defined by:

$$COE = \frac{C_{ann.sys}}{E_{ann.sys}} \quad 1$$

Subject to the reliability condition:

$$\left. \begin{aligned} S_{imin} \leq S_i \leq S_{imax} \\ LPSP = 0 \end{aligned} \right\} \quad 2$$

Where

$S_i$  = size of each system component i

$S_{imin}$  and  $S_{imax}$  are the minimum and maximum acceptable values for  $S_i$

LSP = loss of power supply probability of the system and  $E_{ann.sys}$  is the total annual energy demand to be served by the system (kWh/yr). The systems annualized cost ( $C_{ann.sys}$ ) is defined by:

$$C_{ann.sys} = \frac{1}{LN} \sum_{i=1}^n (C_{Li} + C_L) \quad 3$$

In terms of the percentage contribution of the individual sources, the energy contributions of the system can be expressed as:

$$EC_{es} = \frac{100 \times \eta_{es} \sum_{i=1}^n E_{cs}(t)}{\sum_{i=1}^n E_{hs}(t)} \quad 4$$

Where  $E_{cs}$  and  $E_{hs}$  are the energy production of each source and the hybrid system respectively for a simulation period N.

The performance characteristic of the system is determined in terms of its reliability in providing a cost-effective energy solution for satisfying the energy demand within the entire period N. The reliability of the energy supply defined in terms of the ratio of the total deficit energy supplied to that of the total load required during the period N is:

$$\eta_{rel} = 1 - LOSP \quad 5$$

and the loss of power supply probability (LPSP) is:

$$LPSP = \frac{\sum_{i=1}^n E_{det}(t)}{\sum_{i=1}^n E_d(t)} \quad 6$$

Where  $E_{det}(t)$  and  $E_d(t)$  are the deficit energy supplied and energy demand respectively at time 't', both expressed in kWh. The energy throughput the system is defined as:

$$K_t = \frac{\eta_{rel}}{COE} \quad 7$$

Equation (7) above expresses the techno- economic stability of the system per unit cost of energy supplied. A higher energy throughput is an indication of a more superior system performance.

### 3.0 Discussion of Results

Observation of the system's key performance indices shows that the renewable energy contribution increases with increasing latitude. The percentage of the grid electricity purchased decreases from the southern to the Northern parts of Nigeria as shown in Figure 1 This is due to the dependence of renewable resources on climatic conditions. Renewable source contributed largely throughout the studied locations due to the vast resource availability and the economic and technical viability of the renewable resources for sustainable electricity supplied. The energy contribution of the PV sources is illustrated in Figure 1. Katsina recorded the highest PV energy contribution of 55.84 while Abuja had the least PV energy contribution of 32.63 due to the percentage variation of the renewable energy contribution in the Northern part of the country which are compensated for through grid electricity purchase.

The percentage PV contribution of Benin City, Lagos, Nsukka and Yola are 34.58%, 55.32%, 39.12% and 42.02% respectively as illustrated in Figure 1

Figure 2 shows the percentage energy contribution of wind source. Abuja recorded the highest percentage wind energy contribution of 70.69% while Yola with a percentage wind energy contribution of 22.81% is the least in this range. This is because the operating hours of the wind turbine generator in Abuja are large compared to Yola.

Solar has a higher contribution of 55.84% compared to the 38.84% of wind energy, which is an indication that Katsina is densely populated. The percentage energy contribution of wind for Benin City, Katsina, Lagos and Nsukka are 66.71%, 38.34%, 22.01% and 34.92% respectively.

Figure 3 shows the energy contribution of the grid for selected cities used as case studies in this research paper. The percentage grid contribution of Abuja, Benin City, Katsina, Lagos, Nsukka and Yola are 88.88%, 10.71%, 17.32%, 34.68%, 37.96% and 48.17%

respectively. From this list, Abuja appeared as having the highest percentage grid contribution of 88.88% and Benin City had the least percentage grid contribution of 10.71%.

The contribution of wind energy is largely limited by the sharp decrease in the annual average wind speed in the southern part of the country. The performance of the wind energy conversion system varies only from about 22.18% in Yola to 70.69% in Abuja. This is because a large fraction of solar energy is required to compensate for the available grid electricity supplied. This increase is an indication of the presence of the southwest trade wind that blows from the Atlantic Ocean in this region. The performance of solar conversion system is almost evenly distributed with peak values of about 55.84% and 55.32% for Katsina and Lagos respectively.

The renewable source contribution is about 67% of the total energy requirement of base station cities and compared to the Northern part of the country. Figure 4 shows the energy contribution of PV, wind and grid, out of the six selected cities used as case studies in this research paper, Benin City recorded the highest energy contribution of 44.96% while Lagos recorded the least percentage energy contribution of 37.39%. This is because the implementation of the system will eliminate the need for the fossil fuel generators and reduce the dependence of the base station loads on the erratic grid supply from about 37.39% to as low as 17.12% in Lagos. This will mean a reduction in the pollutant emission released into the atmosphere as a result of consumption of electricity produced by the grid and fossil fuel generators.

The energy throughput of the selected cities is illustrated in Figure 5. The energy throughput of Abuja, Benin City, Katsina, Lagos, Nsukka and Yola are 8.10kWh/N, 7.47kWh/N, 6.62kWh/N, 5.74kWh/N, 5.58kWh/N and 5.22kWh/N respectively. Abuja and Yola recorded the highest energy and least energy throughput of 8.10kWh/N and 5.2kWh/N respectively.

Figure 6 shows the economic loss of the selected cities used as case studies in the research paper. The variation in the cost of grid diesel produced electricity which results from the cost variation per litre of diesel consumed due to the additional cost of transportation from one part of the country to another.

Yola recorded the highest economic cost of 0.168N/kWh, while Abuja with an economic cost of 0.111N/kWh is ranked the least of all the selected cities used. The larger percentage renewable contribution within the northern part of the country has significant improvement on the overall system cost of energy supplied.

In Yola, the grid system tends to provide a higher economic performance of about 73 % and a technical cost of about 62% at a power supply probability of about 43%

The energy throughput of the grid system is lower, 5.22kWh for Yola as compared to the highest value of 8.10kWh/N for Abuja. This implies that the cost of the supply decreases with a percentage improvement of about 66.34% and percentage of grid electricity purchase decreases from southern to Northern Nigeria. The corresponding energy throughput varies from about 5.22kWh/N in Yola to 8.10kWh/N in Abuja with an average value of 6.66kWh/N.

The average energy throughput of the grid connected renewable energy system is equivalent to an annual cost of electricity consumption of about N3.8 billion. The results of this research paper indicate that the implementation of the stand-alone PV-wind energy system is a more viable option. Even though, remote cell site expansion may be feasible, the expansion possibilities in most cities in the country are a difficult task. This may reduce the larger land area needed for the larger optimal operational site of the stand-alone hybrid renewable energy system.

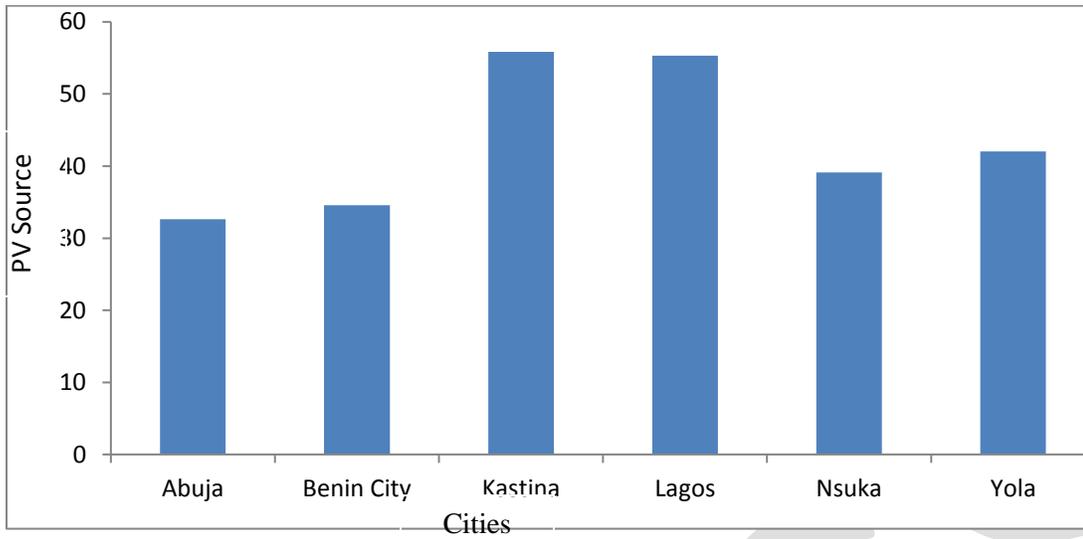


Figure 1: Energy Contribution of PV Source.

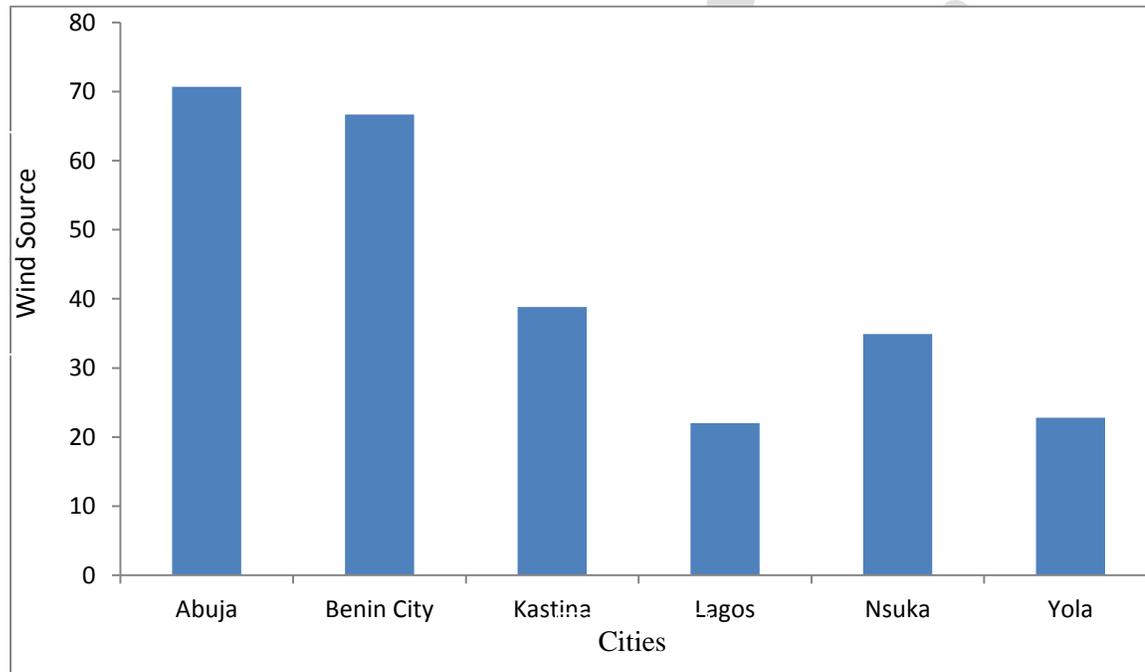


Figure 2: Energy Contribution of Wind Source

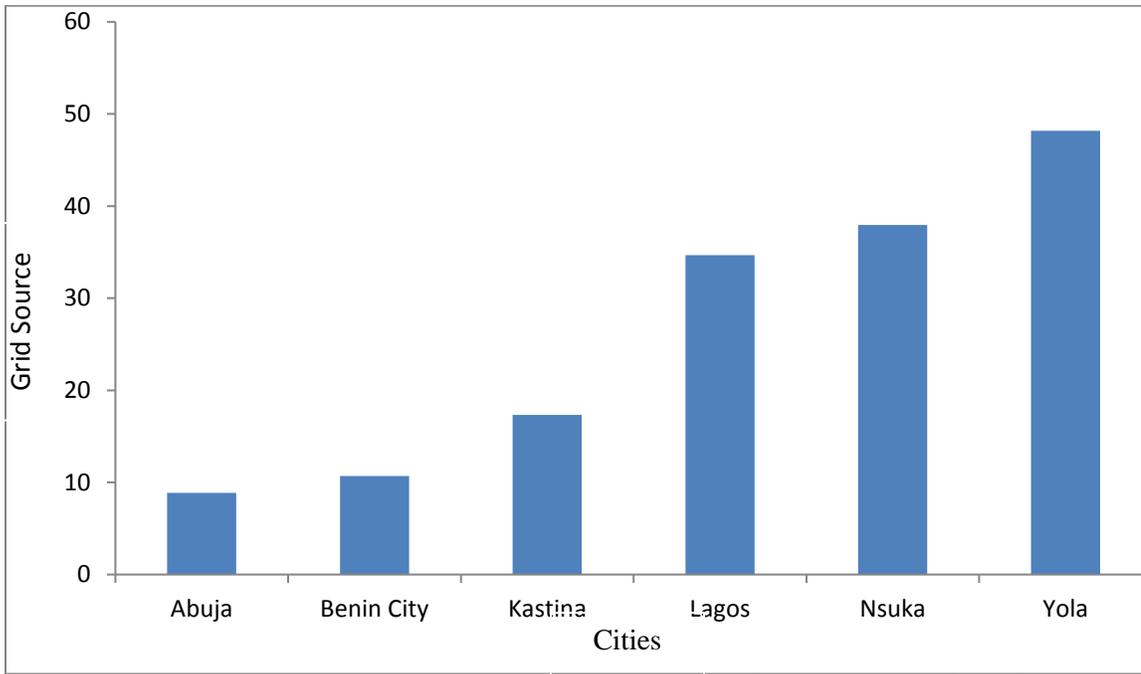


Figure 3: Energy Contribution of Grid Source

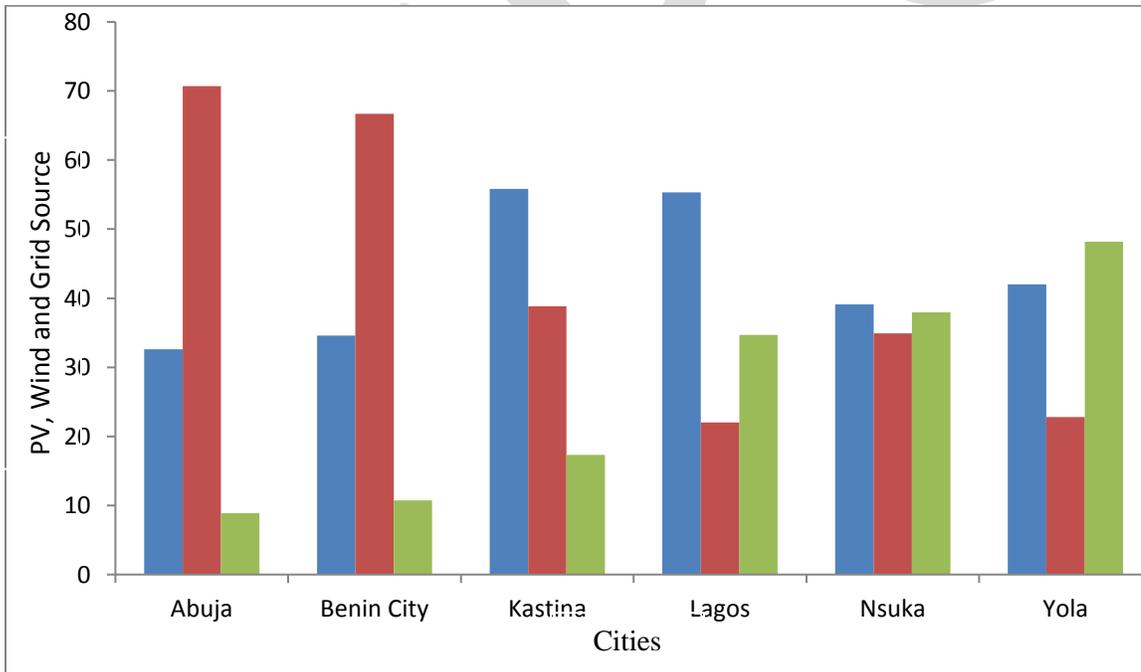


Figure 4: Energy Contribution of PV, Wind and Grid Sources

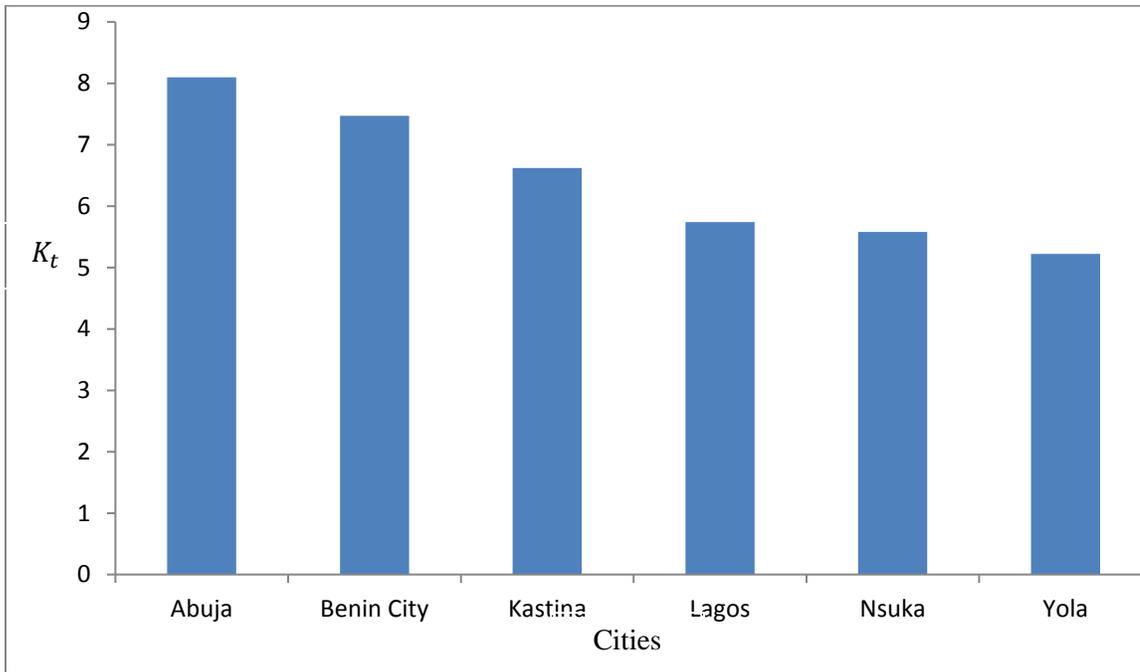


Figure 5:Energythroughput  $K_t$  of the cities

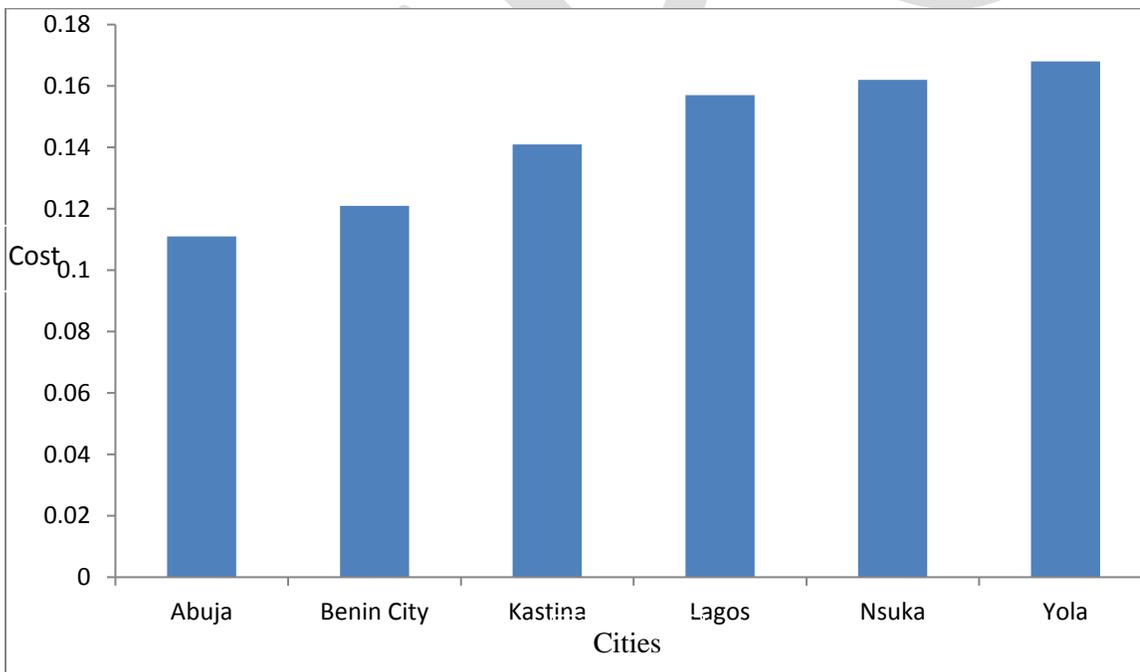


Figure 6: Cost of the cities

#### 4.0 Conclusion

A key performance index approach for assessment of global solar radiation in Nigeria has been presented. The system key performances indices show that the renewable energy contribution increases with increasing latitude. The percentage of the grid electricity purchased decreases from the Southern to the Northern parts of Nigeria as a result of the dependence of renewable resources on climatic conditions.

Kaduna recorded the highest PV energy contribution of 55.84 while Abuja had the least PV energy contribution of 32.63 due to percentage variation of the renewable energy contribution in the Northern part of the country which are compensated for through grid of electricity purchase. Abuja recorded the highest percentage wind energy contribution of 70.69% while Yola had the least percentage wind energy contribution of 22.81% due to the long operating hours of the wind turbine generator.

The energy throughput of Abuja, Benin City, Kastina, Lagos, Nsuka and Yola are 8.10kWh/N, 7.47kWh/N, 6.62kWh/N, 5.74kWh/N, 5.58kWh/N and 5.2kWh/N respectively. Yola recorded an economic cost of 0.168 #/kWh which appeared to be the highest in this range because the grid system tends to provide a higher economic performance of about 73% and a technical cost of about 62% at a power supply probability of about 43%.. Abuja with an economic cost of 0.111 #/kWh is ranked least in this range.

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