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Potential of solar and wind energy for large scale power generation in eastern region of Rwanda.

[1]Manirakiza Jean Felix*, [2] Ogbuefi C. Uche, and [3]Okoro P. Anthony
1,2 Department of Electrical Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria.
3, Bebeque Limited/ Department of Electrical Engineering, University of Nigeria, Nsukka.
**Corresponding Author: Manirakiza Jean Felix*

ABSTRACT : *Renewable energy sources such as solar, wind, hydroelectric energy and geothermal power are available in Rwanda. These sources of energy can contribute to economic development when they are fully exploited. Lack of awareness on potentials of energy sources in the region makes them under used. Assessment of wind energy potential and solar energy potential in Eastern region of Rwanda was carried out in this study. Wind energy potential and solar energy potential have been determined and compared. Hargreaves equation was used for determining solar energy potential while wind energy potential was determined using Weibull distribution model. The data used in this study was gotten from the Rwandan Meteorological Agency. The data contains air density, wind speed, solar radiation and minimum and maximum temperature of eastern region of Rwanda for the period between January 2016 and December 2017. Excel spreadsheet was used for data analysis. The results showed that in the considered region, wind energy potential is higher than solar energy potential with potentials of 1.5kWh/m^2 per day for wind and 0.28kWh/m^2 per day for solar respectively. These are as the result of weather condition of the region.*

KEYWORDS: Energy potential, wind energy, wind speed, solar radiation solar energy, power generation.

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I. INTRODUCTION

Nowadays, energy security, energy equity and environment sustainability have dominated most of the countries developmental agenda objectives worldwide. These objectives are highlighted and taken into consideration while evaluating energy sector. The European countries top priority is energy security while for African countries priorities are energy equity (Accessibility and Affordability) [1]. Rwanda's vision 2020 emphasizes the need for economic growth, private investment and economic transformation supported by reliable and affordable energy supply as a key factor for the development process. To achieve this transformation, the country will need to increase energy production and diversify into alternative energy sources. It is thus known that the current inadequate and expensive energy supply constitute a limiting factor to sustainable development [1]. Rwandan nations don't have small-scale solar, wind and geothermal devices in operation providing energy to urban and rural areas. Rwanda has adequate wind and solar energy potentials to support its energy demand however, most potential still remain untapped due to the lack of awareness about the potential of energy sources in the region [2, 3]. These types of energy sources are especially needed in remote locations due to excessive cost of transportation of electricity from large-scale power plants [1]. This study brought awareness about the available potential of energy to the people in the area. Using the information contained in this study, different techniques will be used for harnessing energy and use energy generated for daily activities.

Different studies have been carried out for the assessment of wind energy potential using various models [3-5]. Philip and Anyaka (2018) have conducted the similar study in Sokoto state (Nigeria) using Weibull probability distribution function (PDF) and observed that the annual mean power density for Sokoto state is 346.74W/m^2 [5].

Chiemeka and Chineke (2009), made use of minimum and maximum temperature data obtained from 1st - 30th November, 2007 using the maximum and minimum thermometers placed in the Stevenson screen at 1.5 m above ground level and observed that, the mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 kwh/m2/day [6]. The Hargreaves equation is preferred for evaluating solar energy potential because it uses temperature data that is available in many locations (rural and urban) [6]. The aim of this study is to determine the potential of wind energy and solar energy in eastern region of Rwanda and highlight the highest energy source by comparing their energy potentials. A two year data obtained between January 2016 and December 2017 from Rwanda meteorological agency was used and Excel spreadsheet was used for data analysis

II. MATERIALS AND METHODS

II.1 Materials

The data used in this study is a primary data received from Rwanda meteorological Agency. The data received are monthly maximum and minimum temperatures, wind speed, air density and solar radiation for the period between January 2016 and December 2017. Microsoft Excel was used for data analysis.

II.2 Methods

There are many PDFs suitable for wind potential estimation such as Weibull distribution, gamma distribution, and lognormal distribution. Weibull distribution was adopted for wind data assessment because it gives good correlation with experimental data when compared with other models [5].

In this study, Hargreaves equation was used to determine the global solar energy potential in Eastern Region of Rwanda based on available climatic parameters of measured maximum and minimum temperature, computed values of extraterrestrial solar radiation (EXRAD) and maximum day light duration (N). Hargreaves equation was chosen according to its robustly and reasonably accurate method for estimating Global Solar energy potential [7].

$$R_s = K_{rs}\left(\sqrt{T_{\max} - T_{\min}}\right) \times R_a \qquad (1)$$

With $\mathbf{R_a}$= Extraterrestrial radiation in $KWhm^{-2}day^{-1}$,

$\mathbf{T_{max}}$=Maximum temperature,

$\mathbf{T_{min}}$=Minimum temperature.

$\mathbf{K_{rs}}$ is an adjustment coefficient and has a value of 0.16 for interior regions [7].

II.3 Theory/Calculations

As the wind strikes the rotor blades, the kinetic energy is converted into mechanical energy as the rotor turns. The amount of kinetic energy is given by

$$E_{kinetic} = \frac{1}{2} m v^2 \qquad (2)$$

Where m =mass in [kg] and v = velocity in [m/s]

The mass of flowing air per unit time (mass flow rate) that strikes the rotor blades is given by:

Mass $m = \rho \times A \times v$ =air density $\times$ area of rotor blade $\times$ velocity (3)

Putting the value of mass flow rate into kinetic equation, we get the available power of wind

$$P_{wind} = \frac{1}{2}(\rho \times A) \times v^2 = \frac{1}{2}\left(\rho A v^3\right) \qquad (4)$$

Where P_{wind} =power of wind in [Watts], ρ=air density of air in [kg/m^3], v = wind speed in [m/s] and A=the area swept by rotor blades in [m^2].

From the above expression we can see that the power of wind is proportional to:

- the area of windmill being swept by the wind
- the cube of the wind speed
- the air density which varies with the altitude.

The wind power density is given by the following equation

$$P_D = \frac{P_{wind}}{A} = \frac{1}{2} \rho v^3 \qquad (5)$$

Where P_D is the wind power density.

By considering the **Betz' law,** as defined in [1] states that: "No wind turbine can convert more than 16/27(about 59.3%) of the kinetic energy of the wind into mechanical energy at the rotor." According to Betz' law, the power coefficient $C_P = 16/27$

$$P_{Beltz} = 16/27 \times P_D \qquad (6)$$

The annual energy output is given as follow:

$$E = (16/27) \times (8760/1000) \times P_D \qquad (7)$$

$$= (16/27) \times (8760\ /1000\ ) \times (1/2) \times \left(\rho\, v^3\right) \qquad (8)$$

With E = annual energy output in [kWh/m^2]

Table I: Annual wind power density between January 2016 and December 2017

Month	Air Density in kg/m^3	Wind speed in m/s	Wind Power density (W/m^2)
January	1.08	0.78	0.25
February	1.03	1.14	0.77
March	0.95	1.10	0.63
April	1.06	1.03	0.58
May	1.06	0.96	0.47
June	1.09	0.72	0.20
July	1.09	0.47	0.06
August	0.97	0.59	0.10
September	0.98	0.73	0.19
October	1.02	0.83	0.29
November	1.02	0.87	0.34
December	1.06	0.74	0.21
Annual	**1.03**	**0.83**	**0.29**

Table II: Extraterrestrial solar radiation, annual temperatures and solar energy potential between January 2016 and December 2017

Month	Extraterrestrial Solar Radiation in kWh/day	Maximum Temperature(^{0}C)	Minimum Temperature(^{0}C)	Solar Energy Potential in kWh/day
January	2.99	18.4	18.2	**0.21**
February	2.56	17.9	17.7	**0.18**
March	2.78	17.7	17.4	**0.24**
April	2.69	17.2	17	**0.19**
May	2.78	18.7	18.4	**0.24**
June	2.89	19.4	19.1	**0.25**
July	3.82	20.5	20.1	**0.39**
August	4.22	21.6	21.1	**0.48**
September	3.76	20.9	20.5	**0.38**
October	3.72	19.9	19.5	**0.38**
November	3.31	20.2	19.8	**0.33**
December	3.17	19.2	19.1	**0.16**
Average	**3.22**	**19.3**	**19.0**	**0.29**

III. RESULTS AND DISCUSSIONS

The minimum and maximum values of monthly mean wind speeds are found to be 0.47 and 1.14 m/s respectively for Eastern region of Rwanda as shown in table 1 above. Figures 1 and 2 illustrate graphically the wind speed variation as well as the power density function for eastern region of Rwanda. The monthly mean power density varies from 0.06 W/m^2 in July to 0.77 W/m^2 in February. However, the annual mean power density for this region stands at 0.29W/m^2

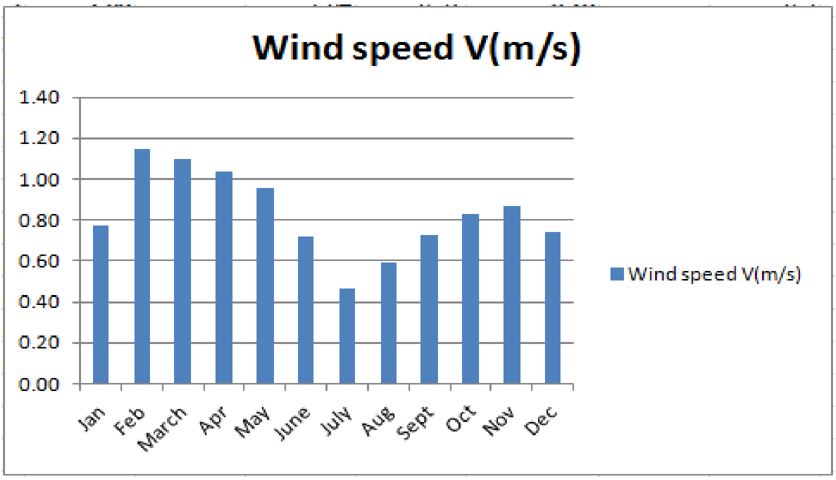

Figure 1: Monthly mean wind speed for eastern region of Rwanda between January 2016 and December 2017

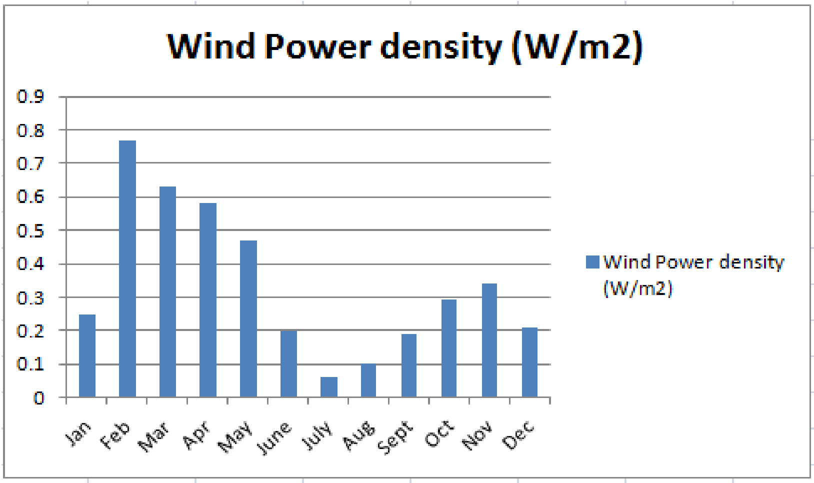

Figure 2: Monthly mean power density for eastern region of Rwanda between January 2016 and December 2017

From Figure 2, it is observed that the highest wind density is obtained between February and May while the lowest wind density is obtained between July and September.
The wind power density is determined using equation 5 as follows

$$P_D = P_{wind} / A = (1/2) \times \rho v^3$$
$$= (1/2) \times 1.03 \times 0.83^3$$
$$= 0.29 W / m^2$$

Considering the Beltz's law, the generated wind power will be determined as

$$P_{Beltz} = (16/27) \times P_D$$
$$= (16/27) \times 0.29$$
$$= 0.17 W / m^2$$

The annual mean energy output is determined using equation 7 as follow

$$E = (16/27) \times (8760/1000) \times P_D$$
$$= 0.17 \times (8760/1000)$$
$$= 1.5 kWh / m^2$$

This result shows that the annual wind energy potential is determined as 1.5kWh/m^2 in Eastern region of Rwanda.

The values of monthly extraterrestrial solar radiation (EXRAD) on a horizontal surface that is computed over the year of 2016 and 2007 in Eastern region of Rwanda are shown in Figure 3.

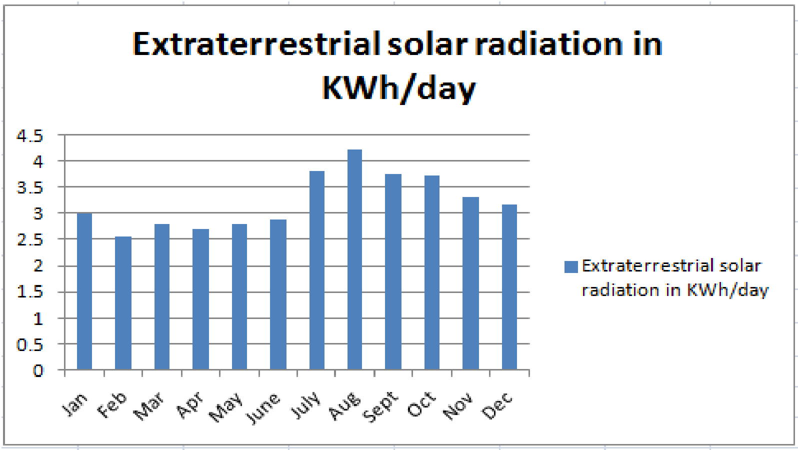

Figure 3: Monthly mean Extraterrestrial Solar Radiation in Eastern region of Rwanda between January 2016 and December 2017.

The values that were obtained ranged from 2.56 kWh/day in February to 4.22 kWh/day in August. The mean extraterrestrial Solar Radiation for the period in eastern region of Rwanda was found as 3.22 kWh/day.

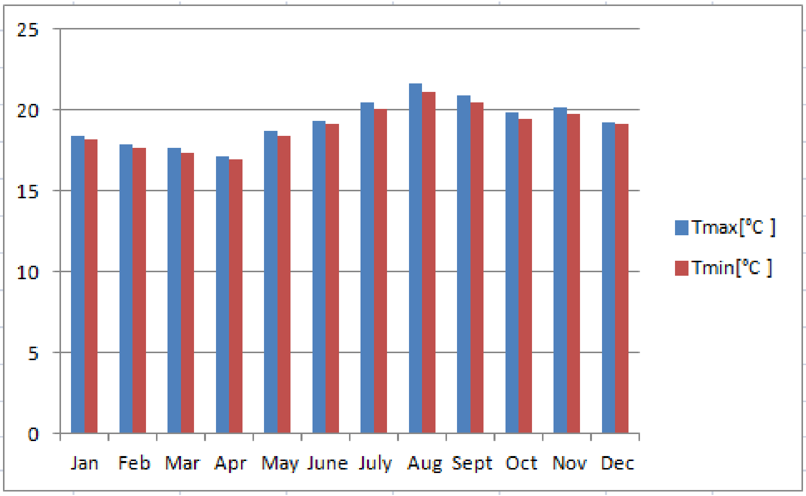

Figure 4: Measured maximum and minimum temperatures between January 2016 and December 2017.

The maximum temperature was highest in August at a temperature of 21.6°C while it is lowest in April at a temperature of 17.2°C. The highest minimum temperature was recorded in August at a temperature of 21.1°C and the lowest minimum temperature of 17°C in April.

Figure 5 shows the global solar energy potential in Eastern region of Rwanda between January 2016 and December 2017. The values were calculated making use of the Hargreaves equation.

Global solar energy potential (GLORAD) in Eastern region of Rwanda was highest in August (0.48 kWh/day) and lowest in December (0.16kWh/day).

The annual mean global solar energy potential is calculated using equation 8 as follow:

$$R_s = 0.16\left(\sqrt{19.3-19.0}\right)\times 3.22$$

$$= 0.28\text{kWh/}\,\text{m}^2\,\text{per day}$$

This result shows that the annual solar energy potential is obtained as 0.28KWh/m^2

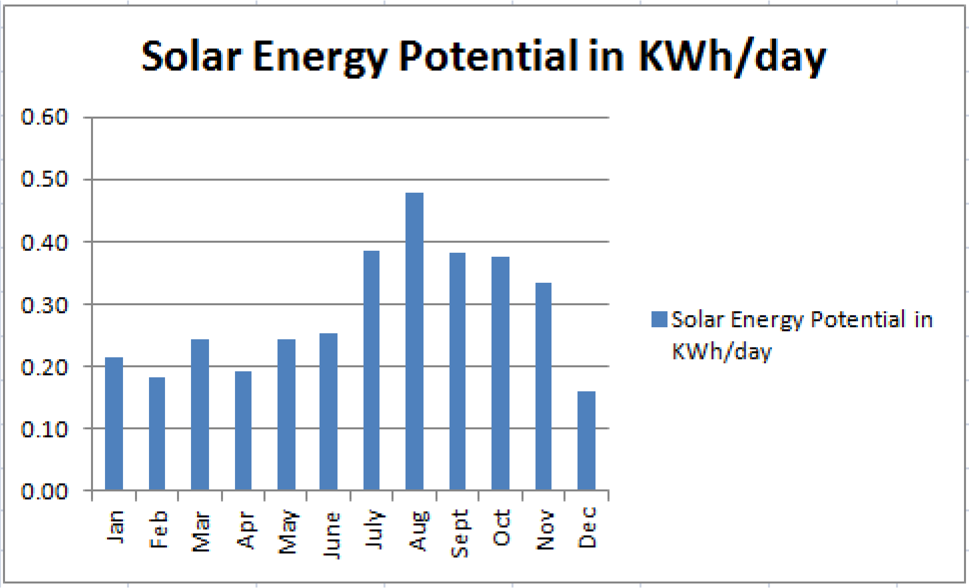

Figure 5: Monthly and mean global solar energy potential in Eastern region of Rwanda between January 2016 and December 2017.

From Figure 5, the highest solar energy potential is obtained between July and November while the lowest energy potential is obtained between December and June.

IV. CONCLUSION

This study showed that, wind energy potential is higher than solar energy potential in Eastern region of Rwanda. The results showed that wind energy potential is averaged at 1.5kWh/m^2 per day while solar energy potential is averaged at 0.28kWh/m^2 per day for a considered period between January 2016 and December 2017.

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