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Rural Electrification Peak Load Demand Forecast Model Based on End User Demographic Data

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Abstract

In this paper a rural electrification peak load demand forecast model was developed based on the readily available United Nation and World Bank data on the electric power consumption in KWh per capita, along with the population and land mass data of the rural community. Furthermore, in the situation where there is no available data on the land mass area, a web map applications can be used for computing the land mass area in Km^2 for the project coverage area. In this paper, the rural community used as the case study was Orji town in Owerri North local government area in Imo state, Nigeria. The forecast results showed that the part of Orji community that was considered in the study had landmass area of 2.4760387Km^2; a population of 2898 in 2015 and peak load demand of 81.14 KVA in the same year with 45% population having access to electricity. However, in 2025, the same part of Orji town will have a population of 3971.791 and peak load demand of 261.79 KVA with 75% population having access to electricity.

Keywords: Rural Electrification; Load factor; Load demand; Peak load Demand; Demography; Electric Demand Forecast; Electric Demand Per Capita

1. Introduction

As the years go by, increasing number of rural communities in Nigeria are having access to electricity through various rural electrification projects. Basically, rural electrification is the process of bringing electric power to rural communities [1,2]. At the rural community level, electricity is used for lightening and household purposes. In addition, electricity is also used for the purpose of farming operations, agriculture, and for other small and medium scale industry operations [3]. In order to effectively plan and operate the rural electric power utility system, the load demand of the rural community must be accurately estimated and also forecasted, especially on long-term bases. On the bases of the outcome of such forecast, electric utility company can manage their resources to satisfy the forecasted demand using a least-cost plan [4, 5, 6]

On the basis of forecasting periods, load forecasting can be categorized into short-term (i.e. from 1 hour to 1 week), medium term (i.e. from 1 week to 1 year), and long-term (i.e. for more than 1 year) time frames [7,8,9, 10]. Long-term demand forecasting provides power utility company with lead times enough to plan for long-term maintenance, construction scheduling for developing new generation facilities, purchasing of generating units, developing transmission and distribution systems [5,11,12,13,14]. According to experts, long-term load demand forecasting techniques can be classified into parametric methods and artificial intelligence based methods [5]. The parametric methods use mathematical model to relate the load demand to the factors that affect the load demand. The model parameters are usually estimated from historical data of load and those factors that affect the load [5,15,16,17,18].

Over the years, the three most commonly used parametric methods are; trend analysis, end-use modelling and econometric modelling. Trend analysis method tries to predict the future electricity demand based on past data. On the other hand, the end-use approach directly estimates energy consumption by using extensive information on end users, such as applications, the customer use, their age, sizes of houses, and so on [5]. The econometric approach is a combination of statistical techniques and economic theories in forecasting electricity demand. This approach estimates the relationship between energy consumption (dependent variables) and factors influencing consumption. The relationships are estimated by the least-square method or time series method [5].

In all the load demand forecasting methods for rural electrification, data is required for modeling the electricity consumption in the community. Consequently, electricity demand forecasting for rural communities where no previous load data is available is quite difficult. As such, in this paper, an alternative method is developed which can utilize United Nation and World Bank data on the electric power consumption per capita, along with the population and land mass data of the rural community to model and hence forecast the electricity demand for the community. The applicability of the method is demonstrated through a sample case study of the peak load demand forecast for a rural community in Orji located in Owerri local government area in Imo state, Nigeria. The advantage of the proposed method is that it utilizes readily available data and tools to estimate the electric load demand of any rural community.

2. Methodology

In this section, available historical end user demographic datasets are used to develop analytical models for estimating the peak electric load demand for a community considered in a rural electrification project. First, an analytical model is developed for estimating the electric energy consumption per capita (that is, electricity consumption per person) based on historic data of electric power consumption (kWh per capita) obtained from World Development Indicators and the World Bank [19]. Another analytical model is developed for estimating the population and hence the total energy demand of the rural community considered in the rural electrification project. Importantly, analytical models are also developed for estimating the variations in load factor and the percentage of the population with access to electricity. Finally, an algorithm is developed that shows how all the input data and analytical models are used to obtain the peak load demand estimates for the rural community and how the projected peak load demand are also determined for the years ahead.

2.1. Estimating the Electric Energy Consumption Per Capita

Table 2.1 shows 21-years electric energy consumption data for Nigeria obtained from World Development Indicators and the World Bank [19]. Let EDPPPY_X be the national electricity consumption per capita (that is, electricity consumption per person) per year in year x. EDPPPY_X is the data on actual electricity consumption per capita obtained from World Development Indicators [19] as shown in Table 2.1.

Next , an online nonlinear regression tool [20] is used to fit a nonlinear equation, to the 21-years electric energy consumption data obtained from World Development Indicators and the World Bank to obtain Eq 2.1 for $\mathrm{EDPPPY_X}$:

$$EDPPYF_x = \frac{x}{(-0.000322187x^2+0.654044394x^2+1.552391192)} \quad (2.1)$$

where x = 0, 1,2,... and x = 0 in year 2008; and $\mathrm{EDPPPYF_X}$ is the model estimated value of $\mathrm{EDPPPY_X}$, as shown in Table 2.1. Now, if n is the number of data items and y_i denote the actual values of the dependent variable, and $\hat{y}_i$ as the fitted or estimated value, then the prediction accuracy (PA in %) is calculated as follows:

$$\mathrm{PA} = \left\{1 - \frac{1}{n}\left(\sum_{i=1}^{i=n}\left|\frac{|y_i - \hat{y}_i|}{y_i}\right|\right)\right\} * 100\% \quad (2.2)$$

The Root Mean Square Error (RMSE) is calculated as follows:

$$\mathrm{RMSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n}(y_i - \hat{y}_i)^2\right]\right\}} \quad (2.3)$$

Accordingly, in table 2.1, the Root Means Square Error (RMSE) and Prediction Accuracy (PA) of the model (of Eq2.1) are 0.010557 and 99.9935% respectively.

Table 2.1. Electric power consumption (kWh per capita) for Nigeria. Source: Column 1 and Column 3 data are from World Development Indicators [19]

Year	Actual Electricity Consumption in KWh Per Capita	Predicted Electricity Consumption in KWh Per Capita
1992	89	89.47736707
1993	100.5	78.3699806
1994	95.1	80.40277599
1995	91.1	82.54383181
1996	85.5	84.80203307
1997	81.6	87.18726441
1998	76.6	89.71055473
1999	75.4	92.38424771
2000	74.1	95.22220373
2001	75.2	98.24004022
2002	104.1	101.4554192
2003	101.4	104.8883932
2004	123	108.5618237
2005	128.6	112.5018912
2006	111.1	116.73872
2007	138.1	121.3071494
2008	126.5	126.2476949
2009	119.9	131.6077521
2010	135.6	137.4431225
2011	149.3	143.8199633
2012	155.9	152.0963902
RSME:	***12.40934***	
Prediction Accuracy (%):		***90***

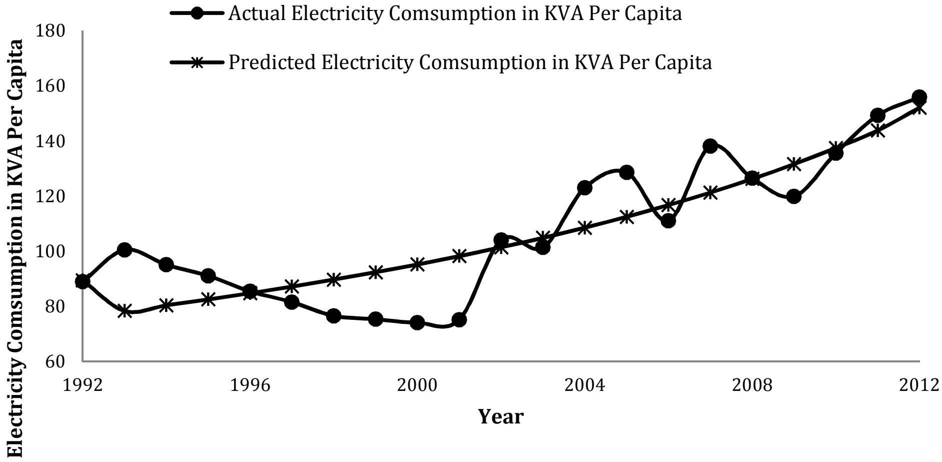

Fig. 2.1. Actual and Predicted Electricity Comsumption in KVA Per Capita.

2.2. Model for estimating the Yearly Population Projections for the Rural Electrification Project Coverage Area

The rural community considered in the study is Orji in Owerri North Local Government Area (LGA), in Imo State, Nigeria. Let $(\mathrm{POPL}_{LGA})_x$ be the population in year x for the local government area where the rural community being considered is located. Also, let AREA_{LGA} be the area of the LGA. Then the expression for projection of the population is given as [19];

$$\mathrm{POPLL}_{LGA(x)} = \mathrm{POPLL}_{LGA(0)} * \left(1 + \mathrm{r}_{plgr}\right)^n \qquad (2.4)$$

where

$\mathrm{POPLL}_{LGA(x)}$ is the projected population at year x,

$\mathrm{POPLL}_{LGA(0)}$ is the population at the base year for the projected population.

r_{plgr} is the population growth rate

n is the number of years from the base year of the projected population

Let $\mathrm{AREA}_{\mathrm{RC}}$ be the area (in km^2) of the rural community being considered in the rural electrification project. The area in km^2 for the project site can be obtained through any of the following techniques:

i. Use web-based map mashup application for marking the project coverage area on Google Map and computing the area enclosed by the marks.
ii. Use GPS tool to collect the boundary coordinates of the rural electrification project coverage area and then compute the area. Specifically, if the coordinates of the project area are collected in counterclockwise order and they are x_1,y_1 ; x_2,y_2 x_3,y_3; …. x_n, y_n , then the area of the project site, $\mathrm{AREA}_{\mathrm{RC}}$ is given as:

$$\mathrm{AREA}_{\mathrm{RC}} = \frac{1}{2}\left(x_1y_2 - x_2y_1 + x_2y_3 - x_3y_2 + \cdots x_{n-1}y_n - x_ny_{n-1} + x_ny_1 - x_1y_n\right) \qquad (2.5)$$

Let $\mathrm{POPLDEN}_{LGA(x)}$ be the population density in year x for the local government area where the rural community being considered in located. Hence,

$$\mathrm{POPLDEN}_{LGA(x)} = \frac{\mathrm{POPLL}_{LGA(x)}}{\mathrm{AREA}_{LGA}} \qquad (2.6)$$

Let $\mathrm{POPL}_{RC(x)}$be the population in year x for the rural community being considered in the rural electrification project. Then;

$$\text{POPL}_{RC(x)} = \text{AREA}_{RC} * \text{POPLL}_{LGA(x)} \quad (2.7)$$

$$\text{POPL}_{RC(x)} = \left(\frac{\text{AREA}_{RC}}{\text{AREA}_{LGA}}\right) * \text{POPLL}_{LGA(x)} \quad (2.8)$$

2.3. Yearly Energy Demand Projections for the Rural Electrification Project Coverage Area

Let EDRC_X be the electric energy demand in year x for the rural community being considered in the rural electrification project; where x = 0,1,2,3,4,5....
Let PAERC_X be the estimate of percentage of the population with access to electricity in the rural community; then;

$$\text{EDRC}_x = \text{POPL}_{RC(x)} * \text{PAERC}_x * \text{EDPPPY}_x \quad (2.9)$$

2.4. Yearly Load Factor Projections for the Rural Electrification Project Coverage Area

The load factor (LF) is usually low for the rural communities. However it grows over time. In most rural electrification, LF is assumed to tend towards 0.75. Let LF_X be the load factor at any given year x and let nf be the total number of years considered in the forecast from a base year 0 (x =0). Then, LF_0 is the load factor at the base year, x= 0. Also, $LF_{nf\,-1}$ is the load factor at the last year of the forecast, when x= nf -1. Then, simple proportion with respect to LFx, x and nf gives the following expressions,

$$\frac{LF_X - LF_0}{(x-0)} = \frac{LF_{nf-1} - LF_0}{(nf-0)} \quad (2.10a)$$

$$\frac{LF_X - LF_0}{x} = \frac{LF_{nf-1} - LF_0}{nf} \quad (2.10b)$$

$$nf(LF_X - LF_0) = (LF_{nf-1} - LF_0)x \quad (2.11)$$

$$nf(LF_X) = (LF_{nf-1} - LF_0)x + nf(LF_0) \quad (2.12)$$

$$LF_X = \left(\frac{(LF_{nf-1} - LF_0)}{nf}\right)x + LF_0 \quad (2.13)$$

For simplicity, it will be assumed that $\text{PAERC}_{X,}$ the percentage of the population with access to electric in the rural community increases over the years in line with the power factor. Thus,

$$\text{PAERC}_X = LF_X \quad (2.14)$$

Transmission and distribution losses: let ETD_X be the percentage transmission and distribution losses. In this paper, it is assumed that ETD_x = 10% of EDRC_x. Let electric energy demand at the bus bar be denoted as EDBB_x where;

$$\text{EDBB}_x = \left(\text{EDRC}_x + \text{EDRC}_x\left(\frac{ETD_x}{100}\right)\right) \quad (2.15)$$

2.5. Peak Load Demand Projections

Let EED_x, be the Peak Load Demand in KVA for the year x, then:

$$\text{Peak Load Demand (in KVA)} = \frac{\text{Number of units actually supplied in a year}}{(\text{Load factor})*(365*24)*\text{Power factor}} \quad (2.16)$$

Hence,

$$\text{EED}_x = \left(\text{EDRC}_x + \text{EDRC}_x\left(\frac{ETD_x}{100}\right)\right) * \left(\frac{1}{\text{Power factor}}\right) * \left(\frac{1}{LF_x}\right) * \left(\frac{1}{365*24}\right) \quad (2.17)$$

$$\text{EED}_x = (\text{EDBBx}) * \left(\frac{1}{\text{Power factor}}\right) * \left(\frac{1}{LF_x}\right) * \left(\frac{1}{365*24}\right) \quad (2.18)$$

2.5.1. The Algorithm for the Peak Load Demand Forecasting for Rural Electrification

Step 1: Generate the trend model for estimating the Electric Energy Demand per Person per Year

Step 1.1: Input the UN and World Bank data on Electric Energy Demand in KWh per Capita. Source, Source: World Development Indicators (2015). The World Bank Available at:

http://data.un.org/Data.aspx?d=WDI&f=Indicator_Code%3AEG.USE.ELEC.KH.PC

For the study, 21-year data on Electric power consumption (kWh per capita) for Nigeria from 1992 to 2012 is used.

Step 1.2: Use the Online Nonlinear Regression (ONLR) tool (available at: http://www.xuru.org/rt/NLR.asp) to generate the trend model for estimating the Electric Energy Demand in KWh per Capita. In this paper, the trend line model fitted on the graph of actual electricity consumption in KWh per capita versus year in Table 2.1 is given in Eq2.1 as;

$$EDPPYF_x = \frac{x}{(-0.000322187x^2 + 0.654044394x^2 + 1.552391192)}$$

Step 1.3: Determine the goodness of fit of the trend model for estimating the Electric Energy Demand in KWh per Capita. In this paper, the RMSE and Prediction accuracy are used.

Step 2: Compute AREA_{RC}→ the area (in km^2) of the rural community being considered in the rural electrification project.

2.1 Use GPS tool or online mapping tool to get the coordinates (longitude and latitude) of the project coverage area for the rural electrification project

2.2 Compute AREA_{RC}→the landmass area of the rural community in Km^2 by loading or pasting the Longitude and latitude of the project coverage area into the text box provided in the online program at the URL:

http://geographiclib.sourceforge.net/cgi-bin/Planimeter

Step 3 Compute the Yearly Population Projections For The Rural Electrification Project Coverage Area

3.1 Input $\text{POPLL}_{LGA(0)}$→ the population at the base year for the projected population. In this paper, the base year where x =0 is year 2008, So, $\text{POPLL}_{LGA(0)}$ is the population of the LGA in 2008 and the value is 4182949.

3.2 Input r_{plgr}→the population growth rate. In this paper, for the project coverage area, $\text{r}_{plgr} = 0.032$

3.3 Compute $\text{POPLL}_{LGA(x)}$→ the projected population at year x, using Eq2.4

$$POPLL_{LGA(x)} = POPLL_{LGA(0)} * (1 + r_{plgr})^n$$

3.4 Input AREA_{LGA} → the area of the LGA where the area for the rural electrification project is located. In this paper, the LGA is Owerri North with land area of 199.996 km^2 and 2006 population of 176,334.

3.5 Compute $\text{POPL}_{RC(x)}$→ the population in year x for the rural community being considered in the rural electrification project, using Eq2.8

$$\text{POPL}_{RC(x)} = \left(\frac{\text{AREA}_{RC}}{\text{AREA}_{LGA}}\right) * \text{POPLL}_{LGA(x)}$$

Step 4 Compute the Peak Load Demand Projections

4.1 For x = 0 to 10 where 10 is the number of year of the Peak Load Demand forecast from the present year, 2015.

4.2 Year = 2015 + x

4.3 Compute $EDPPYF_x$→Electric Energy Demand Per Person Per Year for the year x

$$EDPPYF_x = \frac{x}{(-0.000322187x^2 + 0.654044394x^2 + 1.552391192)}$$

4.4 Input LF_0→ the load factor at the base year , x = 0. In this paper, LF_0 = 0.45

4.5 Input LF_{nf-1}→ the load factor at the last year of the forecast. In this paper,

$$\text{LF}_{\text{nf}-1} = 0.75$$

4.6 Compute nf→ the total number of years considered in the forecast from a base year . In this paper, nf = 10

4.7 Compute LFx→ the load factor at any given year x using Eq2.13 ;

$$\text{LF}_\text{X} = \left(\frac{(\text{LF}_{\text{nf}-1} - \text{LF}_0)}{\text{nf}}\right)\text{x} + \text{LF}_0$$

4.8 Compute PAERC_X, → the percentage of the population with access to electric in the rural community increases over the years in line with the power factor. Thus, in this paper,

$$\text{PAERC}_\text{X} = LF_X$$

4.9 Compute EDRC_X→ the electric energy demand in year x for the rural community being considered in the rural electrification project; using Eq2.9

$$\text{EDRC}_x = \text{POPL}_{RC(x)} * \text{PAERC}_x * \text{EDPPPY}_x$$

4.10 Compute ETD_X→ the percentage transmission and distribution losses. In this paper, $ETD_x = 10$

4.11 Compute EDBB_x→ the electric energy demand at the bus bar , using Eq2.15

$$\text{EDBB}_\text{x} = \left(\text{EDRC}_x + \text{EDRC}_x\left(\frac{ETD_x}{100}\right)\right)$$

4.12 Compute or Define Power factor. In this paper, Power factor = 0.8

4.13 Compute EEDx→ the Peak Load Demand in KVA for the year using Eq2.18

$$\text{EED}_x = (\text{EDBBx}) * \left(\frac{1}{\text{Power factor}}\right) * \left(\frac{1}{LF_x}\right) * \left(\frac{1}{365*24}\right)$$

4.14 Next x

3. Results and Discussions

The rural community considered in the case study is Orji which if in Owerri North local government area in Imo state, Nigeria. The 23 coordinates used to define the rural electrification coverage area is shown in Fig 3.1 along with the Google map plot of the coordinates. The landmass area of the rural electrification coverage area in Orji as defined by the coordinates in Fig 3.1 is computed as $2476038.7m^2$ by the online Planimeter software, as shown in Fig 3.2. According to the census data of 2006, the Area of Owerri North LGA $=199.996$ Km^2. Also, from Fig 3.2, the area of the rural community considered for the electrification project in Orji is $2.4760387Km^2$. Hence, by simple proportion based on the two areas, the estimated population of the LGA and the rural community in Orji are given in Fig 3.3 and Table 3.1.

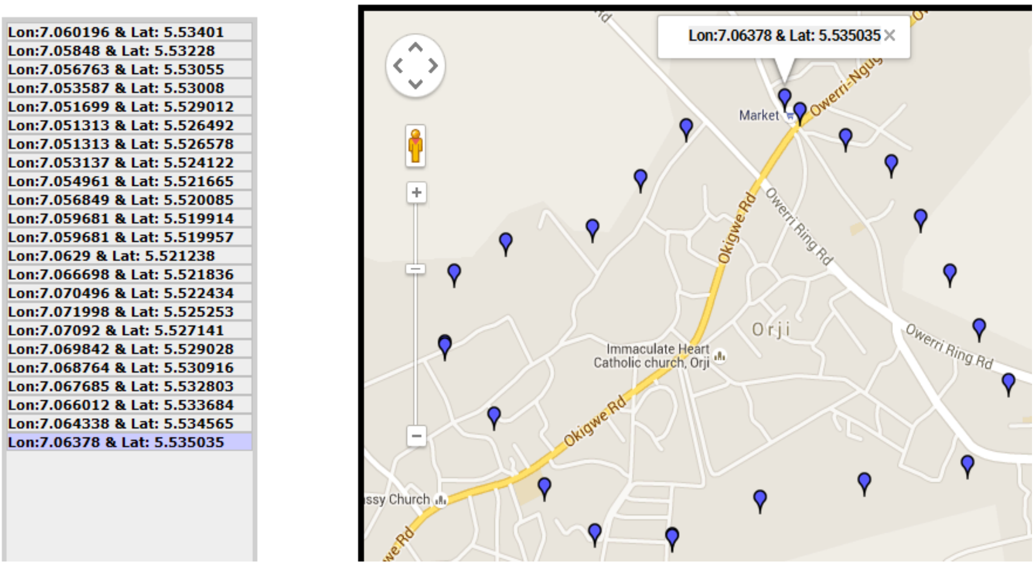

Fig. 3.1. The coordinates used to define the rural electrification coverage area in Orji along with the Google map plot of the coordinates.

Online geodesic polygon calculations using the Planimeter utility

Closed/open: ◉ Polygon ○ Polyline
Edge type: ◉ Geodesic ○ Rhumb line

Enter the vertices as latitude longitude pairs, one per line:

```
7.06378 5.535035
7.064338 5.534565
7.066012 5.533684
7.067685 5.532803
7.068764 5.530916
7.069842 5.529028
7.07092 5.527141
7.071998 5.525253
7.070496 5.522434
7.066698 5.521836
7.0629 5.521238
7.059681 5.519957
7.059681 5.519914
7.056849 5.520085
7.054961 5.521665
7.053137 5.524122
7.051313 5.526578
7.051313 5.526492
7.051699 5.529012
7.053587 5.53008
7.056763 5.53055
7.05848 5.53228
7.060196 5.53401
```

☐ Convert vertices to decimal degrees

Select action:
Submit Reset

Results:

```
STATUS               = OK
number of vertices   = 23
Perimeter (m)        = 6150.183306
area (m^2)           = 2476038.7
```

Fig. 3.2. The landmass area of the rural electrification coverage area in Orji computed as 2476038.7m2 by the online Planimeter software.

Source: Online Planimeter available at
http://geographiclib.sourceforge.net/cgi-bin/Planimeter

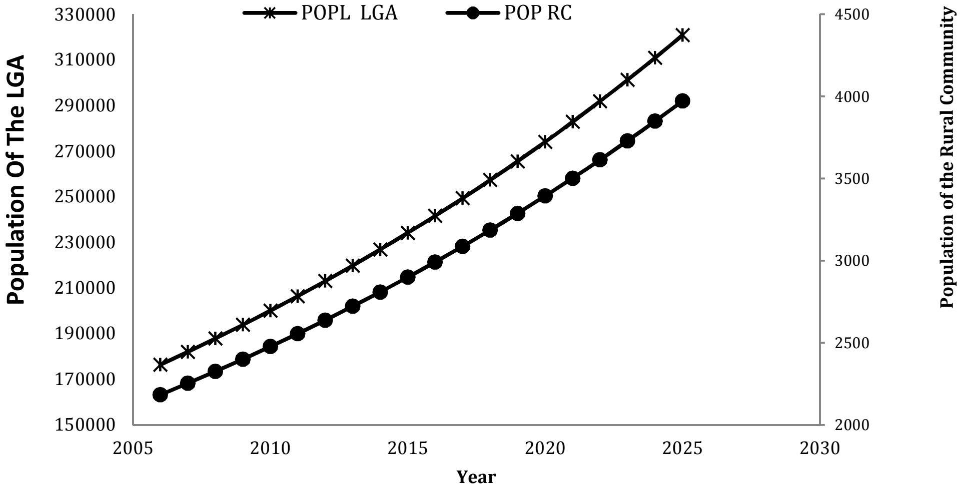

Fig 3.3. Estimated Population of the LGA and the Rural Community For the Electrification Project. Note: Population estimation is based on 2006 census data for the LGA

Table 3.1. The estimated population of the Owerri North LGA and the rural community in Orji

S/N	Year	POPL LGA (Population Of The LGA)	POP RC (Population Of The Rural Community)	S/N	Year	POPL LGA (Population Of The LGA)	POP RC (Population Of The Rural Community)
1	2006	176334	2183	11	2016	241620	2991
2	2007	181977	2253	12	2017	249352	3087
3	2008	187800	2325	13	2018	257331	3186
4	2009	193810	2399	14	2019	265566	3288
5	2010	200011	2476	15	2020	274064	3393
6	2011	206412	2555	16	2021	282834	3502
7	2012	213017	2637	17	2022	291885	3614
8	2013	219834	2722	18	2023	301225	3729
9	2014	226868	2809	19	2024	310864	3849
10	2015	234128	2899	20	2025	320812	3972

The plot of the load factor is shown in Fig. 3.4. According to Fig. 3.4 , the load factor increases from 0.45 in 2015 to 0.75 in 2025. Similar variation is assumed for the percentage of the population with access to electricity.

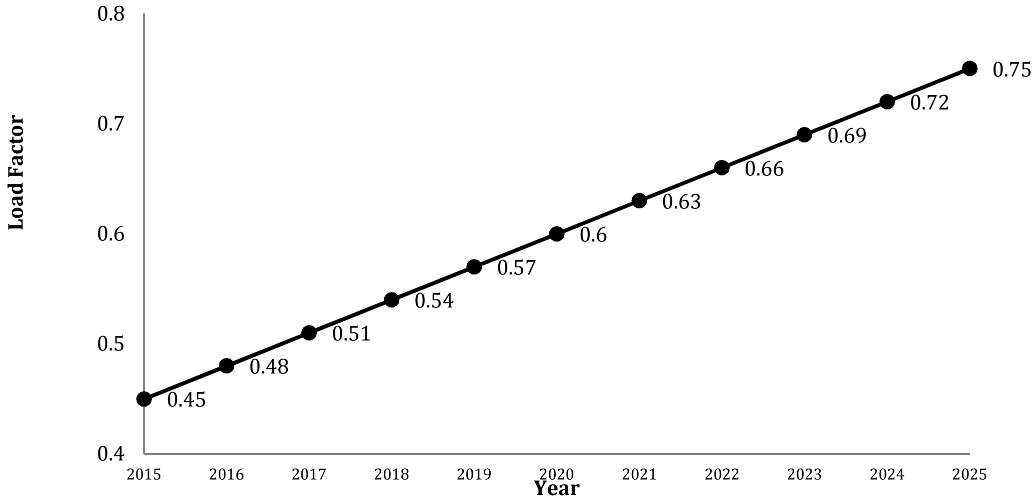

Fig. 3.4. Load Factor versus Year.

Table 3.2 The forecasted Peak Load Demand in KVA and Electric Energy Consumption in KWh Per Capita.

Year	Predicted Electric Energy Consumption in KWh Per Capita	Peak Load Demand in KVA
2015	178.3	**81**
2016	189.2	**89**
2017	201.5	**98**
2018	215.5	**108**
2019	231.7	**120**
2020	250.4	**133**
2021	272.4	**150**
2022	298.6	**169**
2023	330.4	**193**
2024	369.8	**223**
2025	419.9	**262**

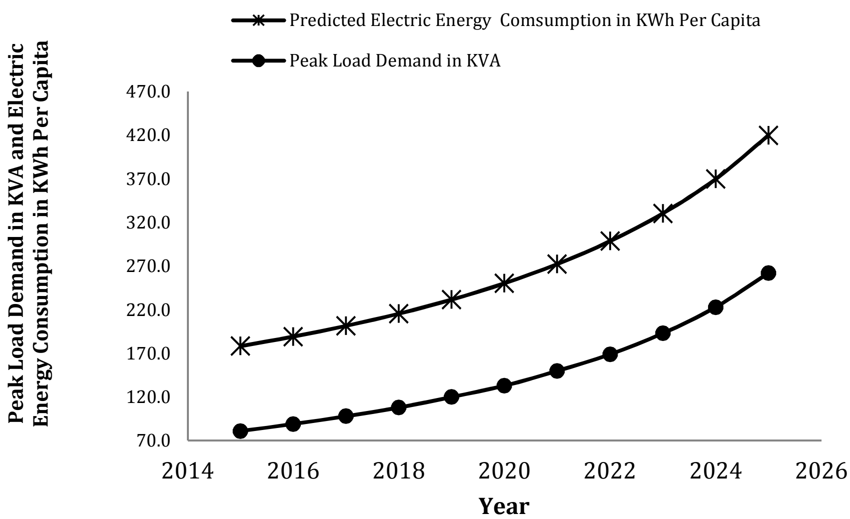

Fig 3.5. Peak Load Demand in KVA and Electric Energy Consumption in KWh Per Capita versus Year

The forecasted Peak Load Demand in KVA and Electric Energy Consumption in KWh Per Capita are shown in Table 3.2 and Fig 3.5. According to the results, the Peak Load Demand is 81 KVA in 2015 and 262 KVA in 2025. Fig 3.5 also shows that the peak load demand varies in the same manner as the Electric Energy Consumption in KWh Per Capita.

4. Conclusion

Rural electrification peak load demand forecast model was developed based on the readily available data on the electric power consumption in KWh per capita, along with the population and land mass data of the rural community. Furthermore, a web map applications is used for computing the land mass area in m^2 for the project coverage area. In this paper, Orji town in Owerri North local government area in Imo state, Nigeria was used as the case study. The forecast results showed that the peak load demand varies in the same manner as the Electric Energy Consumption in KWh Per Capita. In all, the peak load demand forecasting method developed here relies on readily available data that are in most cases available and accessible online. This makes it very useful for rural electrification planning in those communities that are yet to have data on electricity consumption.

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