

Modelling and Forecasting of Residential Electricity Consumption in Nigeria Using Multiple and Quadratic Regression Models

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Abstract: In this paper statistical analysis of the residential electricity demand in Nigeria is presented. Particularly, multiple regression model with one period lagged and quadratic regression model without interactions were used to estimate residential electricity consumption and to forecast long-term residential demand for electricity based on annual data over the period 2006–2014. For the regression models' explanatory variable, population which is a socio-economic variable is used along with temperature which is a climatic variable. The results showed that the quadratic regression model without interactions was more accurate due to the fact that it has the highest coefficient of determinant of 93.87 and the least value of Root Mean Square Error (RMSE) of 52.77 as compared to the multiple regression model with one period lagged of the dependent variable with coefficient of determinant of 93.50 and RMSE of 53.16. The quadratic regression model was then selected and used to forecast the residential electricity demand in Nigeria for the years 2015 to 2029.

Keywords: Quadratic Regression Model, Regression Model Without Interactions, Multiple Linear Regression Model, Forecasting, Residential Electricity Demand

1. Introduction

Electricity is one of the most important commodities for the development of any nation [1-3]. Yet, electricity shortage still remains one of the main challenges facing the Nigeria nation [4-8]. This problem has been attributed to the inability of the electricity supply to meet the consumer demand [9-11]. The phenomenal increase in the population, economic activities as well as lack of maintenance of the existing power stations has also contributed to this problem [12-17]. More especially, with privatization at the power generation sector, more independent power generation stations are being installed. It is required that adequate plan for meeting the energy demand for different sectors and in this case, the residential sector should be considered. Available studies have focused on the integrated power demand for Nigeria. However, such model is not suitable for planning in many cases since there are different tariffs for different power consumer sectors.

Moreover, available studies have worked on power demand models data up to 2005. Models and analysis based on more recent data is essential, especially the one that identifies and focuses on the diverse consumer categories. In the research, the problem is on residential, electricity demand, modelling and forecasting for Nigeria.

2. Methodology

Residential electricity consumption in Nigeria is modelled using multiple regression model with one period lagged [18-27] and quadratic regression model [28-31]. Performance evaluation of the two models were also performed using Root Mean Square Error (RMSE), coefficient of determination (R^2) and F test. Data on residential electricity consumption (MW/h), between 2006-2014 were obtained from Central Bank of Nigeria Statistical Bulletin [32] while data on temperature ($^{\circ}\text{C}$) and population were obtained from the

Bulletin of the National Bureau of Statistics [33]. The data span between 2006 and 2014.

2.1. Model 1: Multiple Regression with One Period Lagged Dependent Variable

The multiple regression model with one period lagged dependent variable expresses electricity consumption (E_t) as a linear function of Population (P) and Temperature (T_t) as follows:

$$E_t = f(P_t, T_t, E_{t-1}) \quad (1)$$

$$E_t = \alpha_0 + \alpha_1 P_t + \alpha_2 T_t + \alpha_3 E_{t-1} + \varepsilon_t \quad (2)$$

Where α_0 is the intercept, α_1 , α_2 and α_3 are the contributions of Population (P) and Temperature (T) respectively.

Econometric Views (EViews) statistical package is used to perform the regression from which the values of the intercept α_0 and the regression coefficients α_1 , α_2 and α_3 are obtained for the multiple regression model.

2.2. Model 2: Quadratic Regression Model Without Interaction

$$E_t = \alpha_0 + \alpha_1 P_t + \alpha_2 T_t + \alpha_3 P_t^2 + \alpha_4 T_t^2 + \varepsilon_t \quad (3)$$

Making ε_t the subject gives;

$$\varepsilon_t = E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t + \alpha_3 P_t^2 + \alpha_4 T_t^2 \quad (4)$$

Sum of the square of the error, S is given as;

$$S = \sum_{t=1}^n \varepsilon_t^2 \quad (5)$$

Minimizing S gives;

$$S = \sum_{t=1}^n \left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t + \alpha_3 P_t^2 + \alpha_4 T_t^2 \right)^2 \quad (6)$$

Again, Econometric Views (EViews) statistical package is used to perform the regression from which the values of the intercept α_0 and the regression coefficients α_1 , α_2 , α_3 and α_4 are obtained for the quadratic regression model with interaction.

2.3. Validation and Diagnostic Criteria

2.3.1. F-Test

To check the goodness of fit of the models, F test is use and it is given as:

$$F = \frac{MSR}{MSE} \quad (7)$$

$$MSR = \frac{SSR}{P-1} \quad (8)$$

Where P is the number of parameters

$$MSE = \frac{SSE}{n-P} \quad (9)$$

Where n is the number of observation

The sum of square Total, SST is given as;

$$SST = E_t^1 E_t - \left(\frac{1}{n} \right) E_t^1 J E_t \quad (10)$$

Sum of square regression, SSR, can be calculated for each model as follows:

$$SSR (\text{Model 1}) = \alpha_d^1 U_d - \left(\frac{1}{n} \right) E_t^1 J E_t \quad (11)$$

$$SSR (\text{Model 2}) = \alpha_e^1 U_e - \left(\frac{1}{n} \right) E_t^1 J E_t \quad (12)$$

Where, J is the matrix,

$$\text{Sum of square Error (SSE)} = SST - SSR \quad (13)$$

2.3.2. Coefficient of Determination

The coefficient of determination shows the percentage of the variation in the dependent variable explained by the independent variables. It is given as

$$r^2 = \frac{SSR}{SST} \quad (14)$$

2.3.3. Root Mean Square Error (RMSE)

The square of the sum of square of differences between the predicted and observed value divided by the number of observation: It can be expressed mathematically as:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (E_t - \hat{E}_t)^2} \quad (15)$$

3. Result and Discussion

Table 1 shows the model parameters and performance measures for multiple regression with one period lagged of the dependent variable. From the results in Table 1, the multiple regression with one period lagged of the dependent variable is given as;

$$E_t = 489.67 + 16.02 P_t - 40.12 T_t + 0.314 E_{t-1} \quad (16)$$

The coefficient of determination r^2 of 0.935 shows that 93.5% of the variation in residential electricity consumption was accounted for by the multiple regression with one period lagged of the dependent variable. The contribution of

population ($\alpha_1 = 16.02$) is positive meaning that as population increases, residential electricity consumption also increases.

Table 2 and figure 1 show the actual and the predicted

residential electricity consumption in Nigeria for the years 2007 to 2014.

Table 1. Estimates of the model parameters and performance measures for the multiple regression with one period lagged of the dependent variable.

Model parameters	Coefficients	SST	SSE	SSR	r ² (%)	RMSE
Constant (α_0)	489.67	348190.99	22608.72	325582.27	93.5	53.16
$P_{t(\alpha1)}$	16.02					
$T_{t(\alpha2)}$	40.12					
$E_{t-1(\alpha3)}$	0.314					

SSR = Sum of Square Regression, SST = Sum of Square Total, SSE = Sum of Square Error, RMSE = Root Mean Square Error.

Table 2. Values of actual and predicted electricity consumption using the multiple regression with one period lagged of the dependent variable.

Year	Actual(MW/h)	Predicted(MW/h)
2007	1151.94	1146.09
2008	1165.72	1132.86
2009	1104.54	1226.58
2010	1365.50	1319.85
2011	1401.01	1361.86
2012	1437.43	1393.54
2013	1474.81	1493.77
2014	1513.15	1539.56

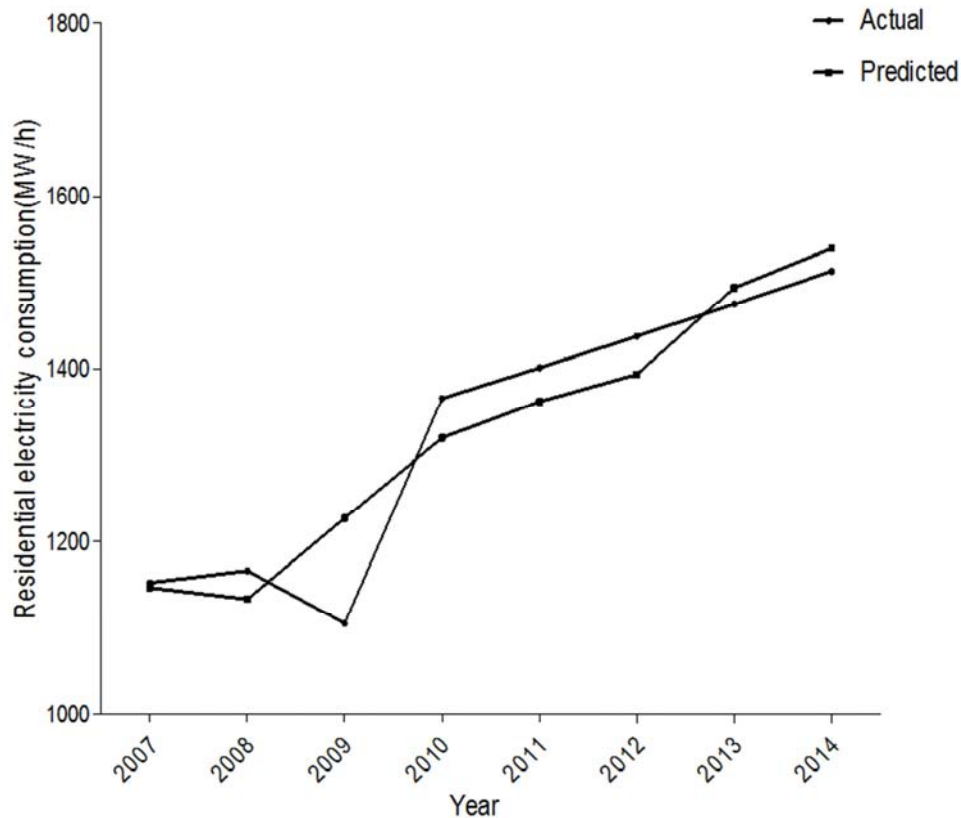


Figure 1. Graph of the Actual and Predicted Residential Electricity Consumption for the multiple regression with one period lagged of the dependent variable.

Table 3 shows the model parameters and performance measures for the quadratic regression with interaction. From the results in Table 3, the quadratic regression with interaction is given as;

$$E_t = 152014.90 + 386.57P_t - 10855.92T_t + 0.40P_t^2 + 177.38T_t^2 - 7.05P_t T_t \quad (17)$$

The r-square value of 0.9389 indicates that 93.89% of the variation in residential electricity consumption was explained by the quadratic regression with interaction. The model also reveals

that the linear term of population ($\alpha_1 = 386.57$) and the quadratic term for temperature ($\alpha_2 = 177.38$) have positive contribution to residential electricity consumption. This result indicates that as

these variables increases in value, residential electricity consumption also increases. Summary results of the actual and

predicted residential electricity consumption in Nigeria for the years 2007 to 2014 are as shown in Table 4 and figure 2.

Table 3. Estimates of the model parameters and performance measures for the quadratic regression with interaction.

Model parameters	Coefficients	SST	SSE	SSR	r ² (%)	RMSE
Constant(α_0)	152014.90	348190.99	27444.52	320746.47	0.9389	52.77
$P_{t(\alpha_1)}$	386.57					
$T_{t(\alpha_2)}$	-10855.92					
$P^2(\alpha_3)$	-0.40					
$T^2(\alpha_4)$	177.38					
$P.T(\alpha_5)$	-7.05					

SSR = Sum of Square Regression, SST = Sum of Square Total, SSE = Sum of Square Error, RMSE =Root Mean Square Error.

Table 4. Values of actual and predicted electricity consumption using the quadratic regression with interaction (QRI).

Year	Actual(MW/h)	Predicted(MW/h)
2006	894.11	948.39
2007	1151.94	1045.49
2008	1165.72	1214.45
2009	1104.54	1179.20
2010	1365.50	1317.55
2011	1401.01	1400.75
2012	1437.43	1459.71
2013	1474.81	1480.52
2014	1513.15	1515.73

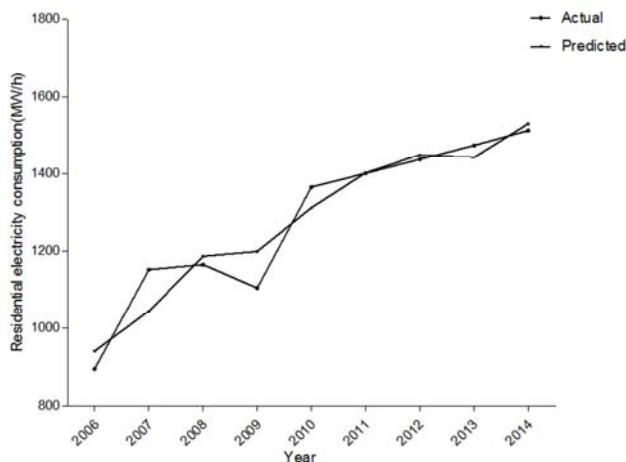


Figure 2. Graph of the actual and predicted residential electricity consumption for the quadratic regression with interaction (QRI).

Table 5. Comparison of the Performance of the two Models.

Models	r ² (%)	RMSE
The multiple regression with one period lagged of the dependent variable.	93.50	53.16
The quadratic regression with interaction (QRI)	93.87	52.77

Table 5 shows performance evaluation of the two competing models. The result shows that the two models were highly competitive as the r- square obtained for each model were very high. The quadratic regression with interaction gave the highest value of coefficient of determination (r^2) and the least Root Mean Square Error (RMSE) compared with multiple regression with one period lagged of the dependent variable. Hence, quadratic regression with interaction is recommended for forecasting residential electricity consumption in Nigeria.

The population for 2015 and 2019 were projected using the formula;

$$P_t = P_{t-1}(1+r)^n \quad (18)$$

Where n = number of years, P_{t-1} = previous year population, P_t = the population of the year to be estimated and r is the population growth rate of Nigeria which is given to 3.2% according to 2006 population census. Also, the temperature was predicted using simple linear regression where a simple regression model of temperature versus time was fitted as follows;

$$T = a_0 + a_1t \quad (19)$$

The model parameters a_0 and a_1 were estimated using Microsoft excel programme. $a_0 = 34.602$, $a_1 = 0.0613$

$$T = 34.602 + 0.0613t + \varepsilon_t \quad (20)$$

t = time, $t = 10, \dots, 24$

Table 6 and figure 3 show the forecasted residential electricity consumption in Nigeria from 2015-2029 using the quadratic regression with interaction. From the results in Table 5, the Residential Electricity Consumption in Nigeria will reach 6521.09 MW/h in the year 2029.

Table 6. The Forecast values for Residential Electricity Consumption (2015-2029).

S/N	Year	Population (Million)	Temp.(°C)	Predicted (MW/h)
1	2015	186.84	33.99	2937.90
2	2016	192.82	33.93	3116.81
3	2017	198.99	33.87	3305.97
4	2018	205.36	33.81	3504.57
5	2019	211.93	33.74	3714.71
6	2020	218.71	33.68	3934.14
7	2021	225.71	33.62	4166.97
8	2022	232.94	33.56	4410.53
9	2023	240.39	33.5	4667.68
10	2024	248.08	33.44	4937.62
11	2025	256.02	33.38	5222.63
12	2026	264.21	33.31	5522.81
13	2027	272.67	33.25	5838.59
14	2028	281.39	33.19	6171.24
15	2029	290.4	33.13	6521.09

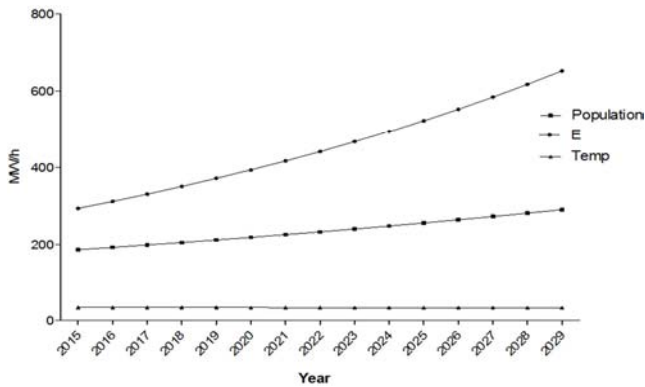


Figure 3. Graph of Forecasted Residential Electricity Consumption (2015-2029).

4. Conclusion

The paper statistical analysis of the residential electricity demand in Nigeria is presented, employing annual data over the period 2006–2014. Particularly, multiple regression model with one period lagged and quadratic regression model without interactions were used to estimate residential electricity consumption and to forecast long-term residential demand for electricity. The results showed that the quadratic regression model without interactions was more accurate due to the fact that it has the highest coefficient of determinant and the least value of Root Mean Square Error as compared to the multiple regression model with one period lagged of the dependent variable. The quadratic regression model was then selected and used to forecast the residential electricity demand in Nigeria for the years 2015 to 2029.

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