CHARACTERIZATION OF THE ANNUAL RESIDENTIAL ENERGY DEMAND IN NIGERIA USING THE MULTIPLE LINEAR REGRESSION MODEL

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Abstract— In this paper, characterization of the annual residential energy demand in Nigeria using the multiple linear regression model is presented. The study is based on a 46-years (1970-2015) data on the annual residential energy demand in Nigeria along with the data on temperature and population as the explanatory variables. The MLR model has R-square value of 0.7715 (77.15%), sum of squared error (SSE) of 885970 and the root mean square error (RMSE) of 138.781. The quadratic regression model with interaction has R-square value of 0.7289 (72.89%), sum of squared error (SSE) of 1051200 and the root mean square error (RMSE) of 151.1664.The Multiple Linear Regression (MLR) Model has better prediction accuracy than the quadratic regression model with interaction. Consequently, the MLR model was used to forecast the annual residential energy demand in Nigeria for the years , 2018 to 2030. The forecast results show that in 2030, the annual residential energy demand will be about 14463 MW/h. The results presented in this study slightly contradicted a related study published in 2017 which was based on a 9-years data. Specifically, the previous study with small sample of data had better prediction performance in terms of R-squared value and the quadratic regression model with interaction terms performed better than the MLR model. However, when the models are subjected to the long term (46-years) data, their prediction performance dropped and the MLR model had a better prediction performance. In all, the model based on the long term data is believed to give a more realistic estimation of the annual residential energy demand in Nigeria.

Keywords—component; **Energy Demand, Multiple Linear Regression Model , Quadratic Regression Model With Interaction, Explanatory Variables, Prediction Performance, Residential Energy Demand**

1. INTRODUCTION

Generally, Nigerian electricity power supply has not been sufficient to meet the demand of the teeming population of the country [1,2,3,4,5]. Notably, the residential electric energy consumers are among the most affected. As such, most households in Nigeria are relaying on other forms of energy supply as alternative to the electric energy from the national grid [6,7,8,9,10]. In any case, in recent years, the Federal government of Nigeria has been making effort to address the issues of inadequate power supply to all the sectors. In this wise, it becomes necessary to provide requisite estimate of the energy demand for the various categories of electric energy consumers [11,12,13,14,15].

In this paper, the focus is on the residential energy consumers and the approach is to characterize the annual residential energy demand in Nigeria using regression model. Available related study by [12] was based on a 9-years (2006 -2014) data which was insufficient for effective characterization of the annual electric energy demand of the nation. In their study [12] concluded that from the study based on the short term data , the quadratic regression model with interaction had better prediction than the multiple linear regression model. As such, the study adopted the quadratic regression model with interaction for the forecast of the annual residential energy demand in Nigeria. However, in this paper, the two regression models employed in the previous study were subjected to the long term (46 years) data ranging from 1970 to 2014 and the prediction performance was slightly contrary to the published findings. Consequently, in this paper, an updated study on the characterization of the annual electric energy demand in Nigeria based on the quadratic regression model with interaction had better prediction than the multiple linear regression model is presented. The detailed model development process is presented and the results obtained from the MATHLAB program-based computations and graph plots of the actual and model predicted annual residential energy demand are also presented. The prediction performance of the two models are also assessed and the more efficient model is used to forecast the annual residential energy demand in Nigeria,

2. METHODOLOGY

2.1 Development of Model 1: Multiple Linear Regression Model

The Multiple Linear Regression (MLR) expresses residential electricity demand (E_t) as a linear function of Population (P_t) and temperature (T_t) as follows:

$$E_t = \alpha_0 + \alpha_1 P_t + \alpha_2 T_t + \varepsilon_t \quad (1)$$

where: α_0 is the intercept, α_1 and $\alpha_2$are the contributions of population (P) and temperature (T) respectively. Making ε_t the subject, gives,

$$\varepsilon_t = E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t \quad (2)$$

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

To estimate the parameters α_0, α_1 and α_2 in Equation (1), the sum of square error (S) is minimized as follows:

$$S = \sum_{t=0}^{n}(\varepsilon_t^2) \quad (4)$$

$$S = \sum_{t=0}^{n}(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t)^2 \quad (5)$$

Taking the partial derivative of Equation (5) with respect to α_0, α_1 and α_2 gives:

$$\frac{\partial S}{\partial \alpha_0} = -2\sum_{t=0}^{n}(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t) = -2\sum_{t=0}^{n}(E_t) - 2(n\alpha_0) - 2\sum_{t=0}^{n}(-\alpha_1 P_t) - 2\sum_{t=0}^{n}(\alpha_2 T_t) \quad (6)$$

$$\frac{\partial S}{\partial \alpha_1} = -2\sum_{t=0}^{n}(P_t)(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t) \quad (7)$$

$$\frac{\partial S}{\partial \alpha_1} = \left[\left(E_t P_t - \alpha_0 \sum_{t=0}^{n}(P_t) - \alpha_1 \sum_{t=0}^{n}(P_t^2) - \alpha_2 \sum_{t=0}^{n}(T_t P_t)\right)\right] \quad (8)$$

$$\frac{\partial S}{\partial \alpha_2} = -2\sum_{t=0}^{n}(T_t)(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t) \quad (9)$$

$$\frac{\partial S}{\partial \alpha_2} = -2\left[E_t T_t - \alpha_0 \sum_{t=0}^{n}(T_t) - \alpha_1 \sum_{t=0}^{n}(T_t P_t) - \alpha_2 \sum_{t=0}^{n}(T_t^2)\right] \quad (10)$$

Next, the derivatives are set to zero as follows;

$$\frac{\partial S}{\partial \alpha_0} = \frac{\partial S}{\partial \alpha_1} = \frac{\partial S}{\partial \alpha_2} = 0 \quad (11)$$

Re-arranging the equations gives the following,

$$\left.\begin{aligned} \sum E_t &= n\alpha_0 + \alpha_1 \sum P_t + \alpha_2 \sum T_t \\ \sum E_t P_t &= \alpha_0 \sum P_t + \alpha_1 \sum P_t^2 + \alpha_2 \sum T_t P_t \\ \sum E_t T_t &= \alpha_0 \sum T_t + \alpha_1 \sum T_t P_t + \alpha_2 \sum T_t^2 \end{aligned}\right\} \quad (12)$$

The parameters of the sets of Equations (12) can be obtained by solving three systems of equations with three unknowns; α_0, α_1 and α_2. The systems of Equations (12) can be written in matrix form as follows;

$$\begin{pmatrix} n & \sum P_t & \sum T_t \\ \sum P_t & \sum P_t^2 & \sum T_t P_t \\ \sum T_t & \sum T_t P_t & \sum T_t^2 \end{pmatrix} \begin{pmatrix} \alpha_0 \\ \alpha_1 \\ \alpha_2 \end{pmatrix} = \begin{pmatrix} \sum E_t \\ \sum E_t P_t \\ \sum E_t T_t \end{pmatrix} \quad (13)$$

$$R_a = \begin{pmatrix} n & \sum P_t & \sum T_t \\ \sum P_t & \sum P_t^2 & \sum T_t P_t \\ \sum T_t & \sum T_t P_t & \sum T_t^2 \end{pmatrix} \quad (14)$$

$$U_a = \begin{pmatrix} \sum E_t \\ \sum E_t P_t \\ \sum E_t T_t \end{pmatrix} \quad (15)$$

$$a_a = \begin{pmatrix} \alpha_0 \\ \alpha_1 \\ \alpha_2 \end{pmatrix} \quad (16)$$

Equation (13) can be written as:

$$R_a(a_a) = U_a \quad (17)$$

Equation (17) can be expressed as;

$$a_a = R_a^{-1}(U_a) \quad (18)$$

Solution of Equation (18) gives the values of the model parameters; α_0, α_1 and α_2. In this paper, the least square method to solve multiple regression models is employed. Based on the case study dataset consisting of data on P_t, T_t and E_t the other components of Equation (14) and Equation (15) are obtained, and then Equation (18) is solved and the result gives the values of α_0, α_1 and α_2 as follows;

$$\alpha_0 = -781.6431$$

$$\alpha_1 = 20.3915$$

$$\alpha_2 = 1.3871$$

Therefore, E_t, the residential electricity demand in Nigeria can be modeled according to the multiple linear regression model given as;

$$E_t = -781.6431 + 20.3915 P_t + 1.3871 T_t \quad (19)$$

2.2 Development of Model 2: Quadratic Regression Model with Interaction Terms

The quadratic regression model with interaction terms in this study expresses residential electricity demand, E_t as a function of population, P_t and temperature, T_t, as follows;

$$E_t = \alpha_0 + \alpha_1 P_t + \alpha_2 T_t + \alpha_3 P_t^2 + \alpha_4 T_t^2 + \alpha_5 P_t T_t + \varepsilon_t \quad (20)$$

Where $\varepsilon_t$is the error term, α_0 is the intercept, α_1, α_2, α_3, α_4 and α_5 are the contributions of the explanatory variables or the contributions of the various combinations of the explanatory variables. When in Equation 20, ε_t is made the subject, it gives;

$$\varepsilon_t = E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t \quad (21)$$

$$\varepsilon_t^2 = \left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right)^2 \quad (22)$$

The sum of square error, S is given as;

$$S = \sum_{t=0}^{n}(\varepsilon_t^2) = \sum_{t=0}^{n}\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right)^2 \quad (23)$$

Taking the partial derivative of Equation (4) with respect to $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4$ and α_5 gives:

$$\frac{\partial S}{\partial \alpha_0} = -2\sum_{t=0}^{n}\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right) \quad (24)$$

Expanding Equation (24) given;

$$\frac{\partial S}{\partial \alpha_0} = -2\left[\sum_{t=0}^{n}(E_t) - n\alpha_0 - \sum_{t=0}^{n}(\alpha_1 P_t) - \sum_{t=0}^{n}(\alpha_2 T_t) - \sum_{t=0}^{n}(\alpha_3 P_t^2) - \sum_{t=0}^{n}(\alpha_5 P_t T_t)\right] \quad (25)$$

$$\frac{\partial S}{\partial \alpha_0} = -2\left[\sum E_t - n\alpha_0 - \sum \alpha_1 P_t - \sum \alpha_2 T_t - \sum \alpha_3 P_t^2 - \sum \alpha_4 T_t^2 - \sum \alpha_5 P_t T_t\right] \quad (26)$$

Similarly,

$$\frac{\partial S}{\partial \alpha_1} = -2\sum_{t=0}^{n}(P_t)\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right) \quad (27)$$

$$\frac{\partial S}{\partial \alpha_1} = -2\left(\sum E_t P_t - \alpha_0 \sum P_t - \alpha_1 \sum P_t^2 - \alpha_2 \sum T_t P_t - \alpha_3 \sum P_t^3 - \alpha_4 \sum T_t^2 P_t - \alpha_5 \sum P_t^2 T_t\right) \quad (28)$$

$$\frac{\partial S}{\partial \alpha_2} = -2\sum_{t=0}^{n}(T_t)\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right) \quad (29)$$

$$\frac{\partial S}{\partial \alpha_2} = -2\left(\sum E_t T_t - \alpha_0 \sum T_t - \alpha_1 \sum T_t P_t - \alpha_2 \sum T_t^2 - \alpha_3 \sum P_t^2 T_t - \alpha_4 \sum T_t^3 - \alpha_5 \sum P_t T_t^2\right) \quad (30)$$

$$\frac{\partial S}{\partial \alpha_3} = -2\sum_{t=0}^{n}(P_t^2)\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right) \quad (31)$$

$$\frac{\partial S}{\partial \alpha_3} = -2\left(\sum E_t P_t^2 - \alpha_0 \sum P_t^2 - \alpha_1 \sum P_t^3 - \alpha_2 \sum T_t P_t^2 - \alpha_3 \sum P_t^4 - \alpha_4 \sum T_t^2 P_t{}^2{}_t - \alpha_5 \sum P_t^3 T_t\right) \quad (32)$$

$$\frac{\partial S}{\partial \alpha_4} = -2\sum_{t=0}^{n}(T_t^2)\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right) \quad (33)$$

$$\frac{\partial S}{\partial \alpha_4} = -2\left(\sum E_t T_t^2 - \alpha_0 \sum T_t^2 - \alpha_1 \sum P_t T_t^2 - \alpha_2 \sum T_t^3 - \alpha_3 \sum P_t^2 T_t^2 - \alpha_4 \sum T_t^4 - \alpha_5 \sum P_t T_t^3\right) \quad (34)$$

$$\frac{\partial S}{\partial \alpha_5} = -2 \sum_{t=0}^{n} (P_t T_t)\left(E_t - \alpha_0 - \alpha_1 P_t - \alpha_2 T_t - \alpha_3 P_t^2 - \alpha_4 T_t^2 - \alpha_5 P_t T_t\right) \quad (35)$$

$$\frac{\partial S}{\partial \alpha_5} = -2\left(\sum E_t P_t T_t - \alpha_0 \sum P_t T_t - \alpha_1 \sum P_t^2 T_t - \alpha_2 \sum P_t T_t^2 - \alpha_3 \sum P_t^3 T_t^2 - \alpha_4 \sum P_t T_t^3 - \alpha_5 \sum P_t^2 T_t^2\right) \quad (36)$$

The derivatives are set to zero as follows;

$$\frac{\partial S}{\partial \alpha_0} = \frac{\partial S}{\partial \alpha_1} = \frac{\partial S}{\partial \alpha_2} = \frac{\partial S}{\partial \alpha_{13}} = \frac{\partial S}{\partial \alpha_4} = \frac{\partial S}{\partial \alpha_5} = 0 \quad (37)$$

Re-arranging the equations gives the following set of six simultaneous equations;

$$\sum E_t = n\alpha_0 - \alpha_1 \sum P_t - \alpha_2 \sum T_t - \alpha_3 \sum P_t^2 - \alpha_4 \sum T_t^2 - \alpha_5 \sum P_t T_t \quad (38)$$

$$\sum E_t P_t = \alpha_0 \sum P_t + \alpha_1 \sum P_t^2 + \alpha_2 \sum T_t P_t + \alpha_3 \sum P_t^3 + \alpha_4 \sum T_t^2 P_t + \alpha_5 \sum P_t^2 T_t \quad (39)$$

$$\sum E_t T_t = \alpha_0 \sum T_t + \alpha_1 \sum T_t P_t + \alpha_2 \sum T_t^2 + \alpha_3 \sum P_t^2 T_t + \alpha_4 \sum T_t^3 + \alpha_5 \sum P_t T_t^2 \quad (40)$$

$$\sum E_t P_t^2 = \alpha_0 \sum P_t^2 + \alpha_1 \sum P_t^3 + \alpha_2 \sum T_t P_t^2 + \alpha_3 \sum P_t^4 + \alpha_4 \sum T_t^2 P_t^2 + \alpha_5 \sum P_t^3 T_t \quad (41)$$

$$\sum E_t T_t^2 = \alpha_0 \sum T_t^2 + \alpha_1 \sum P_t T_t^2 + \alpha_2 \sum T_t^3 + \alpha_3 \sum P_t^2 T_t^2 + \alpha_4 \sum T_t^4 + \alpha_5 \sum P_t T_t^3 \quad (42)$$

$$\sum E_t P_t T_t = \alpha_0 \sum P_t T_t + \alpha_1 \sum P_t^2 T_t + \alpha_2 \sum P_t T_t^2 + \alpha_3 \sum P_t^3 T_t^2 + \alpha_4 \sum P_t T_t^3 + \alpha_5 \sum P_t^2 T_t^2 \quad (43)$$

The set of six equations can be solved using matrix approach , where R_b, U_b and a_b are defined as follows;

$$R_b = \begin{pmatrix} n & \sum P_t & \sum T_t & \sum P_t^2 & \sum T_t^2 & \sum P_t T_t \\ \sum P_t & \sum P_t^2 & \sum T_t P_t & \sum P_t^3 & \sum P_t T_t^2 & \sum P_t^2 T_t \\ \sum T_t & \sum T_t P_t & \sum T_t^2 & \sum P_t^2 T_t & \sum T_t^3 & \sum P_t T_t^2 \\ \sum P_t^2 & \sum P_t^3 & \sum P_t^2 T_t & \sum P_t^4 & \sum T_t^2 P_t^2 & \sum P_t^3 T_t \\ \sum T_t^2 & \sum P_t T_t^2 & \sum T_t^3 & \sum T_t^2 P_t^2 & \sum T_t^4 & \sum P_t T_t^3 \\ \sum P_t T_t & \sum P_t^2 T_t & \sum P_t T_t^2 & \sum P_t^3 T_t & \sum P_t T_t^3 & \sum P_t^2 T_t^2 \end{pmatrix} \quad (44)$$

$$U_b = \begin{pmatrix} \sum E_t \\ \sum E_t P_t \\ \sum E_t T_t \\ \sum E_t P_t^2 \\ \sum E_t T_t^2 \\ \sum E_t P_t T_t \end{pmatrix} \quad (45)$$

$$a_b = \begin{pmatrix} \alpha_0 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{pmatrix} \quad (46)$$

The matrix form of the six simultaneous equation can be expressed in terms of R_b, U_b and a_b as follows;

$$R_b(a_b) = U_b \quad (47)$$

Hence, the regression coefficients a_b can be obtained as;

$$a_b = R_b^{-1}(U_b) \quad (48)$$

Based on the case study dataset consisting of data on P_t, T_t and E_t thevalues of the regression coefficients $\alpha_0, \alpha_1, \alpha_3, \alpha_4$ and α_5 are obtained after solving Equation (48) and the values are;

$$\alpha_0 = 431.645$$
$$\alpha_1 = 54.542$$
$$\alpha_2 = 10.412$$
$$\alpha_3 = -3.187$$
$$\alpha_4 = 1.815$$
$$\alpha_5 = 0.451$$

Eventually, E_t, the residential electricity demand in Nigeria can be modeled according to the quadratic regression model with interaction terms given as;

$$E_t = 431.645 + 54.542P_t + 10.412T_t - 3.187P_t^2 + 1.815T_t^2 + 0.451P_t T_t \quad (49)$$

3. Results and Discussion

The plot of the actual annual residential energy consumption in Nigeria and the multiple linear regression (MLR) model predicted values, as well as the temperature and population as the explanatory variables are presented in Figure 1.The MLR model has R-square value of 0.7715 (77.15%), sum of squared error (SSE)of 885970 and the root mean square error (RMSE)of 138.781.

The plot of the actual annual residential energy consumption in Nigeria and the quadratic regression model with interaction predicted values, as well as the temperature and population as the explanatory variables are presented in Figure 2.The quadratic regression model with interaction has R-square value of 0.7289 (72.89%), sum of squared error (SSE)of 1051200 and the root mean square error (RMSE)of 151.1664.

The Multiple Linear Regression (MLR) Model has better prediction accuracy than the quadratic regression model with interaction. Consequently, the MLR model was used to forecast the annual residential energy demand in Nigeria for the years , 2018 to 2030, as shown in Table 1 and Figure 3. The forecast results show that in 2030, the annual residential energy demand will be about 14463 MW/h.

The prediction results slightly contradicted previous related study conducted by [12] in which case the quadratic regression model with interaction had better prediction than the MLR model. That study was based on a 9-years (2006 -2014) data and it gave a very high R-squared value of 0.873 for the MLR model and 0.9387 for the quadratic regression model with interaction. However, in this study, the 46-years (1970 -2015) data was used. As such, the study in this paper gives a more realistic characterization of the annual residential energy demand in Nigeria.

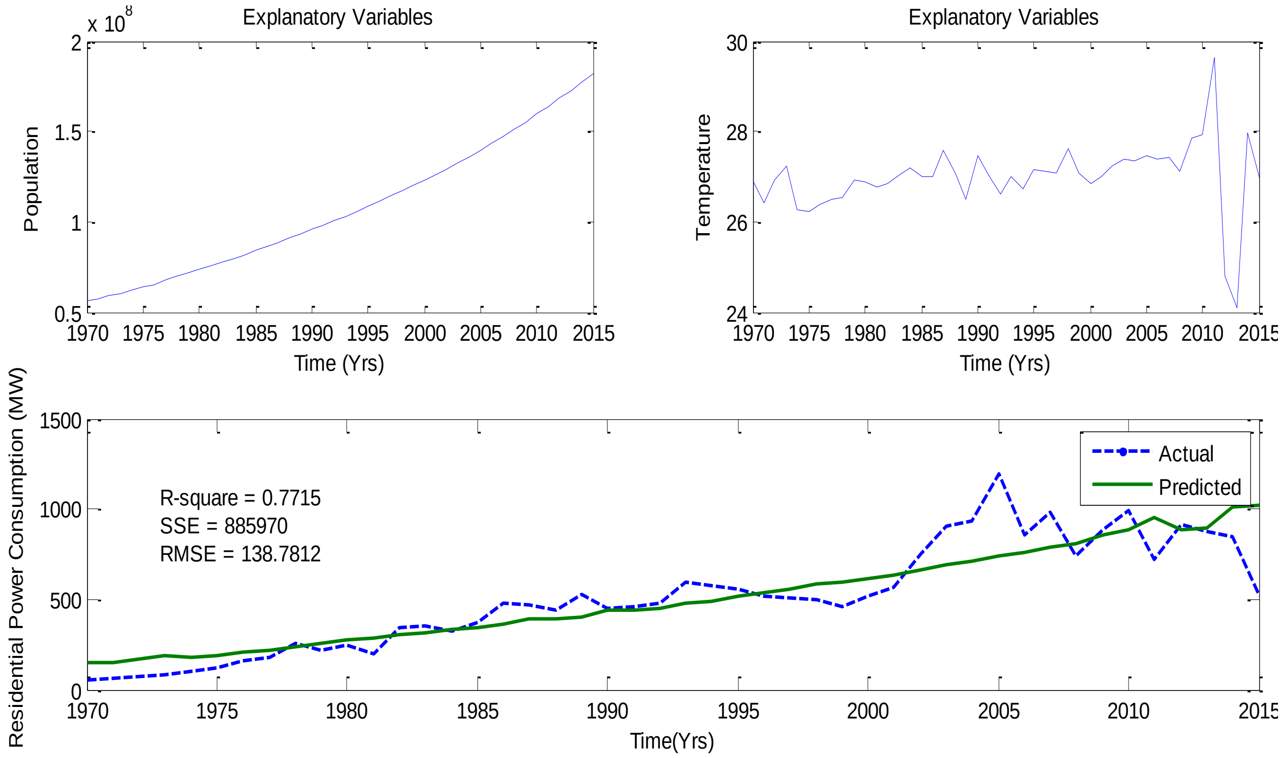

Figure 1:The plot of the actual annual residential energy consumption in Nigeria and the multiple linear regression (MLR)model predicted values, as well as the explanatory variables (temperature and population)

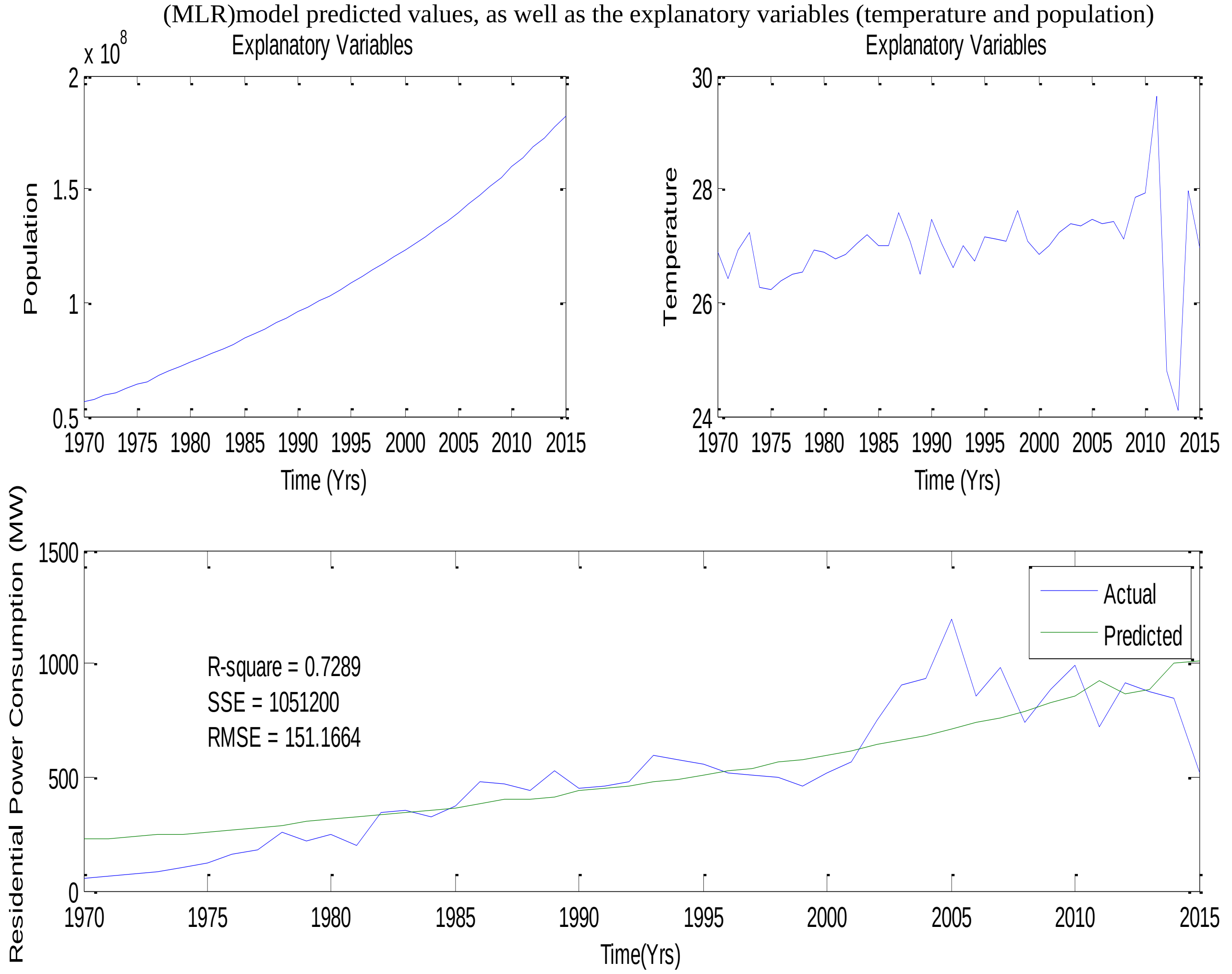

Figure 2: The plot of the actual annual residential energy consumption in Nigeria and the quadratic regression model with interaction predicted values, as well as the explanatory variables (temperature and population)

Table 1: The 13 Years (2018 -2030) Multiple Linear Regression Model Forecast of the Annual Residential Energy Demand (MW/h)

Years	Multiple Linear Regression Model Forecast of the Annual Residential Energy Demand (MW/h)
2018	11778.2
2019	11978.8
2020	12217.7
2021	12468.5
2022	12659.6
2023	12898.4
2024	13149.2
2025	13340.3
2026	13591.1
2027	13782.2
2028	14033
2029	14271.9
2030	14463.0

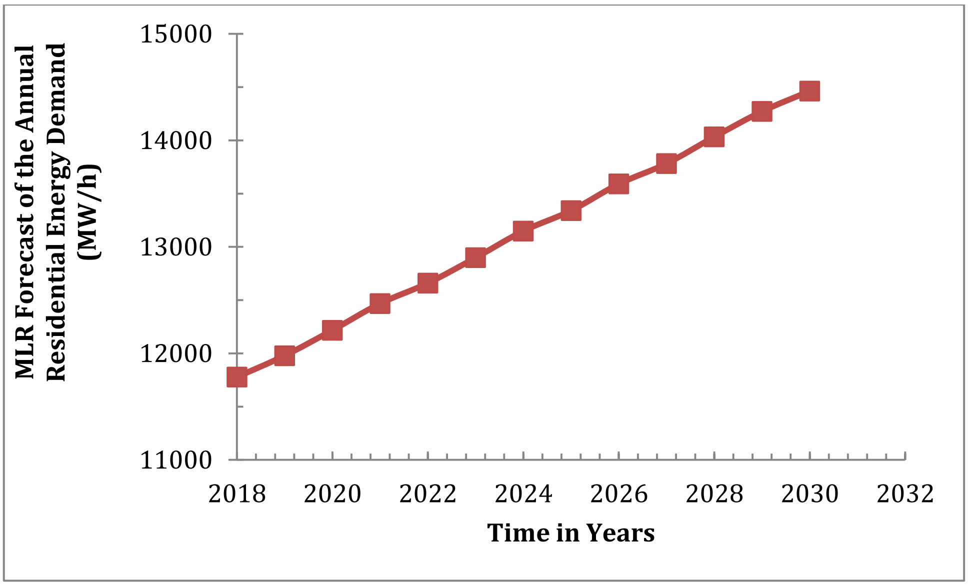

Figure 3: The 13 Years (2018 -2030) Multiple Linear Regression Model Forecast of the Annual Residential Energy Demand (MW/h)

4. CONCLUSION

The annual residential energy demand in Nigeria is modeled using the multiple linear regression (MLR) model and the quadratic regression model with interaction terms. The study is based on a 46-years data of the annual residential energy demand along with the requisite data on the explanatory variables. The results slightly contradicted a related study published in 2017 which was based on a 9-years data. Specifically, the previous study with small sample of data had better prediction performance in terms of R-squared value and the quadratic regression model with interaction terms performed better than the MLR model. However, when the models are subjected to the long term (46-years) data, their prediction performance dropped and the MLR model had a better prediction performance. In all, the model based on the long term data is believed to give a more realistic estimation of the annual residential energy demand in Nigeria.

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