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Modelling And Forecasting Of Annual Electricity Bill For A University Campus

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Abstract*— In this paper, the modelling and forecasting of annual electricity bill for a University campus is presented. The case study site is a University campus in Nsukara Akwa Ibom State, Nigeria. The data on the total yearly electricity consumption and the amount billed for the case study site were gathered from 2015 to 2022. Holt Winter's model was used for the purpose of projecting electricity bills or estimating electrical energy consumption beyond the study timeline of 2022. The model performance metrics used include mean absolute scaled error (MASE), symmetric mean absolute percentage error (SMAPE), mean absolute error (MAE) and root mean squared error (RMSE). The model prediction results show that the actual average cost per electrical energy consumed increase from 51.2 Naira per kW-h in 2018 to 60.96 Naira per kW-h in 2022 which amounts to 18.3 % increase over the period of four years. Within the same period, the annual cost of electrical energy consumption increased from 10,348,494.99 Naira in 2018 to 26,758,678.40 Naira in 2022 which amounts to 158.6 % increase. Also, forecast results show that the annual cost of electrical energy consumption has increased from 26,758,678.40 Naira in 2022 to 59,169,010.73 Naira in 2030 which amounts to 121.1 % increase in annual energy cost over the 8 years period. Finally, the forecast results showed that there will be between 85.6 % and 156.6 % increase in annual energy cost from 2022 to 2030. The results obtained in this study is essential for power system planning in the case study University campus.

Keywords*— Electricity Bill Modelling, Power System Planning Load Forecasting, Holt Winter's Model, Symmetric Mean Absolute Percentage Error (SMAPE), Mean Absolute Error (MAE)

1. INTRODUCTION

Effective energy supply is essential for the tertiary academic institutions, both for learning and research activities [1,2,3]. However, in Nigeria many tertiary institution are facing serious power outages [4,5]. As such, the power system of most tertiary institutions in Nigeria consists of different small units of power generating systems for some targeted department in the institutions [6,7,8]. In all these appropriate power system planning is required for proper design of the power supply for the institution [9,10].

Moreover, the Federal government is planning to argument the power supply to these institution with solar power system. Also, some institutions are also engaging in their own power generation strategy [11,12]. All these efforts require power system planning. The bedrock of effective power system planning is the determination of present energy demand as well as future energy demand [13]. Such model will account for the future expansions in the infrastructure and the attendant power demand increase. This is particularly essential for many academic institutions where there are many new academic programmes that are being introduced on a continuous bases. Accordingly, this work focus on the development of model for characterizing the energy demand of a case study University campus as well as forecasting the future energy demand based on the expansion plans of the institutions. The outcome of the study is expected to contribute to the power planning resources for the institution.

2. METHODOLOGY

2.1 THE TOTAL YEARLY ELECTRICITY CONSUMPTION DATA FOR THE CASE STUDY SITE

The case study site is a University campus in Nsukara Akwa Ibom State, Nigeria. Data / information relating to power generation, supply and distribution within the University were collected from Power Holding Company of Nigeria (PHCN), Port Harcourt and from the case study University. The data on the total yearly electricity consumption (kW-h) for the case study site were gathered from 2015 to 2022 and documented, and presented in Table 1. Also, some portion of the data on the amount billed (Naira) for some months are presented in Table 2.

Table 1 The data on electricity consumption (kW-h) for the case study site

Month	**Electrical Energy Consumed (kW-h)**				
Year	**2018**	**2019**	**2020**	**2021**	**2022**
Jan	N/A	15440	53820	11770	26100
Feb	N/A	27350	36840	13575	47780
Mar	N/A	30180	102070	0	59570
Apr	N/A	23600	66990	0	38180
May	51440	26620	24330	39395	37940
Jun	52990	9670	25180	56810	13450
Jul	24590	0	28850	29340	27470
Aug	9960	0	28620	26170	22250
Sep	11770	0	25580	32490	26790
Oct	3300	0	29460	29490	26140
Nov	19210	1860	23290	29130	31240
Dec	27590	39270	18990	35670	82060
Total	***200850***	***173990***	***464020***	***303840***	***438970***

Table 2 The data on the amount billed (Naira) for some months

Year	**Month**	**Amount Billed (Naira)**	**Electricity Consumption (kW-h)**
2018	May	2,650,368.84	51440
	Dec	1,421,533.37	27590
2019	Jan	795,522.84	15440
	Dec	2,023,327.85	39270
2020	Jan	2,772,994.77	53820
	Dec	1,027,857.49	18990
2021	Jan	637,065.96	11770
	Dec	2,077,545.65	35670
2022	Jan	1,520,155.35	26100
	Dec	5,224,944.84	82060

2.2 DETERMINATION OF ANNUAL COST OF ELECTRICAL ENERGY CONSUMPTION BILLED BETWEEN 2018 AND 2022

First, from the data gathered, total electrical energy consumed per year, E_{tc} from 2018 to 2022 was computed using Equation 1. Second, average cost per electrical energy consumed (Naira per kW-h), C_{EC} was estimated using Equation 2. Third, annual amount billed, AC_{EC} in Naira was estimated by the product of total yearly electricity consumed (kW-h) and average cost per electricity consumed (N per kW-h) as given in Equation 3.

$$E_{tc} = \sum_{t=1}^{t=12} (\text{electrical energy consumed in kW} - \text{h}) \quad (1)$$

$$C_{EC} = \frac{\text{Amount billed in months A and B (Naira)}}{\text{Electricity consumed in month A and B (kW−h)}} \quad (2)$$

$$AC_{EC} = (E_{tc})(C_{EC}) \quad (3)$$

Based on the data on electricity consumption (kW-h) for the case study site, as presented in Table 2, sample calculation are conducted for 2018 average cost per electricity consumption using data for the month of May and

December. In this case, the average is over two months. However, in practice, the average is over the number of months with available valid data records.

Cost per electricity consumption (N per kW-h) = $\frac{2,650,368.84\ (\text{Naira})}{51440\ (\text{kW-h})}$ = N51.52 per kW-h

Cost per electricity consumption (N per kW-h) = $\frac{1,421,533.37\ (\text{Naira})}{27590\ (\text{kW-h})}$ = N51.52 per kW-h

Average cost per electricity consumption = N51.52 per kW-h

2.3 ANNUAL ELECTRICITY BILL FORECAST BEYOND 2022 USING HOLT WINTER'S ALGORITHM

For the purpose of projecting electricity bills or estimating electrical energy consumption beyond the study timeline, exponential triple smoothing (ETS), an advanced algorithm also known as Holt Winter's algorithm was used (Aishwarya, 2020). It has the level, trend and seasonality components. However, the seasonal element may be in the additive or in the multiplicative form.

(i) ADDITIVE SEASONALITY

The model for the level (L_t) is given in Equation 4 as (Aishwarya, 2020):

$$L_t = \alpha (Y_t - S_{t-m}) + (1-\alpha) [L_{t-1} + T_{t-1}] \qquad (4)$$

where, Y_t is the historical data, α is level smoothing parameter known as alpha ($0 \leq \alpha \leq 1$), $Y_t - S_{t-m}$ is seasonality adjusted observation and T_{t-1} represents trend component computed for the previous time step. The trend model is given in Equation 5 as:

$$T_t = \beta (L_t - L_{t-1}) + (1-\beta) T_{t-1} \qquad (5)$$

where, β is beta, is a trend smoothing factor with range: $0 \leq \beta \leq 1$, t is trend at any period; Tt represents trend component computed for the previous time step. The forecasting model is represented in Equation 6 as (Aishwarya, 2020):

$$\hat{Y}_t = L_t + T_t \qquad (6)$$

When considering seasonality, the model for the additive seasonal component is given in Equation 7 as:

$$S_t = \gamma(Y_t - L_t) + (1-\gamma) S_{t-m} \qquad (7)$$

Here, gamma (γ) represents seasonal smoothing variation factor with range: $0 \leq \gamma \leq 1$.

(ii) MULTIPLICATIVE SEASONALITY

The level component is given in Equation 8 as (Aishwarya, 2020):

$$L_t = \alpha (Y_t / S_{t-m}) + (1-\alpha) [L_{t-1} + T_{t-1}] \qquad (8)$$

The trend model is given in Equation 5 (Aishwarya, 2020). Hence, the seasonal value at any time step (t) and the seasonal value at the t-m step is represented in Equation 9 as:

$$S_t = \gamma(Y_t / L_t) + (1-\gamma) S_{t-m} \qquad (9)$$

Then, the final forecasting model is given in Equation 10 as:

$$\hat{Y}_t = (L_t + T_t) (S_t) \qquad (10)$$

$$\hat{Y}_t = (\{\alpha (\frac{Y_t}{S_{t-m}}) + (1-\alpha) [L_{t-1} + T_{t-1}]\} + \{\beta (L_t - L_{t-1}) + (1-\beta) T_{t-1}\}) (\gamma (Y_t / L_t) + (1-\gamma) S_{t-m}) \quad (11)$$

I. 2.4 THE PROCEDURE FOR FORECASTING AND IMPLEMENTING THE HOLT WINTER'S ALGORITHM IN MICROSOFT EXCEL

The procedure for forecasting and implementing the Holt Winter's Algorithm in Microsoft Excel is presented as follows:

Step 1: The Microsoft Excel 2016 was launched. The columns for period and the corresponding values for either annual electricity billed or energy consumption were generated and highlighted.

Step 2: ***Data* Tab** was clicked on the Menu Bar and ***Forecast*** selected.

Step 3: ***Forecast Sheet*** was clicked and ***Create Forecast Worksheet Dialog Box*** appeared.

Step 4: ***Options*** button was tapped. Under ***Forecast Start and***

Forecast End, periods to begin and end the forecast were selected (say 2022 and 2030, respectively).

Step 5: ***Confidence Interval*** (by default 95%) was clicked. Under ***Seasonality***, **"Detect Automatically"** was radioed and ***Include Forecast Statistics*** was clicked. Data on existing periods automatically appeared in ***Timeline Range*** and ***Values Range*** cells.

Step 6: ***Interpolation*** and ***Average*** were selected under ***Fill Missings Point Using*** and

Aggregate Duplicates Using cells, respectively.

Step 7: Finally, ***Create*** button was clicked. The plot, forecasted values, smoothing and statistical parameters were generated.

II. 2.5 FORECASTING MODEL ACCURACY MEASURES

The model performance parameters used are; mean absolute scaled error (MASE), symmetric mean absolute percentage error (SMAPE), mean absolute error (MAE) and root mean squared error (RMSE).These parameters are computed in the Microsoft Excel used in the model implementation. During the model implementation, the values of MASE, SMAPE, MAE and RMSE were optimized (minimized) using the Microsoft Excel inbuilt Simplex Linear Programming. During the optimization process, the corresponding values of alpha (α), beta (β) and gamma (γ) as smoothing parameters /constants (decision variables) in the Holt Winter's were displayed. The range of values of the smoothing parameters is zero to 1.

3. RESULT AND DISCUSSION

3.1 Results of average cost per electrical energy consumed (C_{EC}) and the annual cost of electrical energy consumption Billed between 2018 and 2022

The results of the average cost per electrical energy consumed (C_{EC}) and the annual cost of electrical energy consumption (AC_{EC}) billed from 2018 to 2022 are presented in Table 3. The results in Table 3 show that the actual average cost per electrical energy consumed increase from 51.2 Naira per kW-h in 2018 to 60.96 Naira per kW-h in 2022 which amounts to 18.3 % increase in unit cost of energy over the period of four years. Within the same period, the annual cost of electrical energy consumption has increased from 10,348,494.99 Naira in 2018 to 26,758,678.40 Naira in 2022 which amounts to 158.6 % increase in annual energy cost. The high annual energy cost is a combination of the increase in the unit cost of energy over the period and the increase in annual energy consumption from 200850 kW-h in 2018 to 438970 kW-h per kW-h in 2022 which amounts to 118.6 % increase in annual energy consumption.

Table 3 The average cost per electrical energy consumed (C_{EC}) and the annual cost of electrical energy consumption billed (AC_{EC}) from 2018 to 2022

Year	Total Yearly Electricity Consumption (kW-h)	Average Cost per Electricity Consumption. C_{EC} (Naira per kW-h)	Annual Amount Billed. AC_{EC} (Naira)
2018	200850	51.52	10,348,494.99
2019	173990	51.52	8,964,573.78
2020	464020	52.82	24,511,798.53
2021	303840	56.18	17,071,212.41
2022	438970	60.96	26,758,678.40

3.2 Result of the Forecast of Annual Electricity Bill Beyond 2022

The results of the projection of yearly electrical bill beyond 2022, specifically from 2023 to 2030 are shown in Table 4, as well as in Figure 1. The Holt Winter's model that is used to do the forecast is given in Equation 11 and the values of the smoothing parameters or decision variables α is 0.501, β is 0.001 and γ 0.001. The model prediction performances are MASE = 0.267, SMAPE = 0.157%, MAE = 2, 272,801.18 Naira and RMSE = 2,900,750.47 Naira.

Also, the results in Table 4 show that the annual cost of electrical energy consumption has increased from 26,758,678.40 Naira in 2022 to 59,169,010.73 Naira in 2030 which amounts to 121.1 % increase in annual energy cost over the 8 years period. The lower confidence of the forecast results show 85.6 % increase in annual energy cost over the 8 years period whereas the upper confidence of the forecast results show 156.6 % increase in annual energy cost over the same period. Essentially, it is expected that there will be between 85.6 % and 156.6 % increase in annual energy cost from 2022 to 2030.

Table 4 Annual forecasted electricity bill between 2023 and 2030.

Timeline	Values (N)	Forecast (N)	Lower Confidence Bound (N)	Upper Confidence Bound (N)
2018	10,348,494.99	11,450,431.66		
2019	8,964,573.78	7,887,765.63		
2020	24,511,798.53	25,686,877.00		
2021	17,071,212.41	17,011,100.00		
2022	26,758,678.40	26,758,678.40	26,758,678.40	26,758,678.40
2023		23,590,748.33	17,905,381.88	29,276,114.78
2024		35,939,371.38	29,577,845.17	42,300,897.59
2025		31,333,961.45	24,356,879.37	38,311,043.53
2026		43,682,584.49	36,140,016.43	51,225,152.56
2027		39,077,174.57	31,004,610.85	47,149,738.28
2028		51,425,797.61	42,855,952.99	59,995,642.24
2029		46,820,387.69	37,776,951.36	55,863,824.01
2030		59,169,010.73	49,675,579.09	68,662,442.38

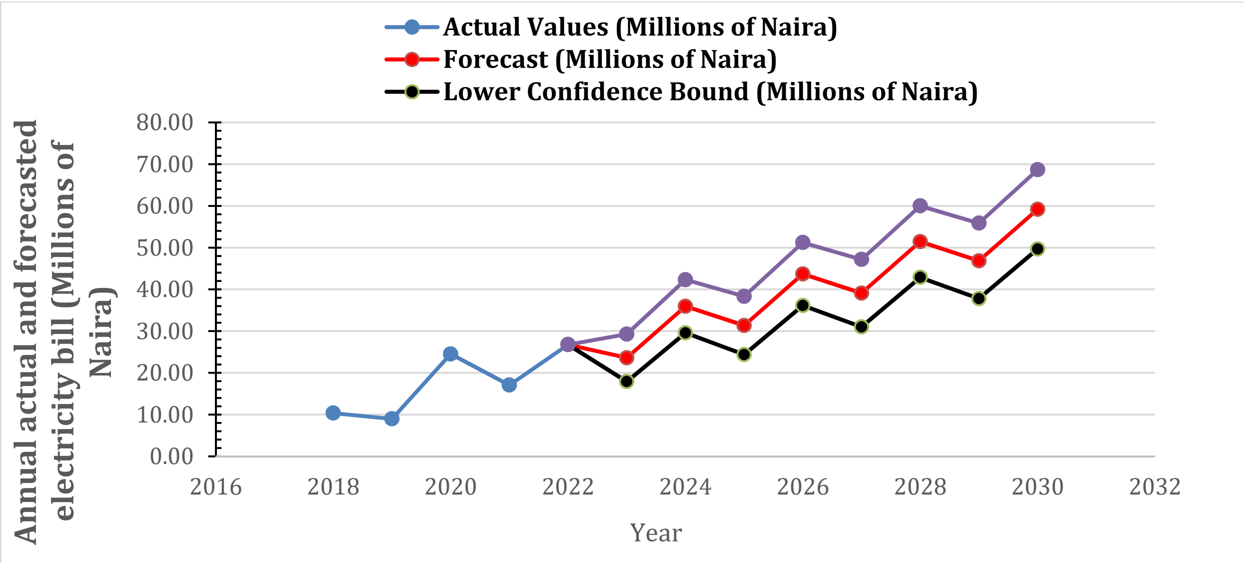

Figure 1: Annual actual and forecasted electricity bill (in Millions of Naira) from 2018 to 2030.

4. CONCLUSION

The analytical model for the prediction and forecasting of the annual electric energy cost for a university campus is presented. Specifically, the Holt Winter's model is used to model the annual energy cost. The energy consumption and billing data for a case study campus is used and the Holt Winter's model was implemented in Microsoft Excel. The model decision parameters were obtained from the Excel implementation and hence, the model was then used to forecast the energy consumption for an eight year period. The forecast results included the upper and the lower confidence values for each of the years of the energy cost forcast.

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