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Analysis of Domestic Energy Usage for Electrical Appliances in a Nigerian Metropolitan Area.

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ABSTRACT

A research was conducted on energy usage in Owerri metropolitan area. Energy consumption survey was done using questionnaires. Classification was made into low, medium and high income earners in order to determine domestic energy consumption in appliances. To analyse the various sources of energy available for domestic use in appliances and know which is more economical, a model equation was used and R^2 value of 0.9516 for domestic appliances were obtained, which is an indication of goodness of fit of the model. It also predicts that there was a strong interaction between the source of power and level of income of the populace. It also predicts that in domestic appliances the low income earners spent least using diesel while the high income earners spent most using petrol.

Key words: Analysis, Appliances, Consumption, Domestic, Energy, Electricity, Metropolitan and Usage.

1. BACKGROUND INFORMATION

Energy is one of the basic requirements of human societies. It is vital for human life and technology advancement. In general energy can contribute to widening opportunities and it empowers people to exercise choices. The demand for energy today is far greater than ever in our highly technological world. It is a well known fact that the high rate of industrial growth of any country is a function of the amount of energy available in that country and the extent to which this energy is utilized. (Nigeria Energy Study, 2005)

2. PROBLEM STATEMENT

While the world works towards the use of cleaner energy our priority should be to use the energy we generate more efficiently. The major challenge has been that energy policy in Nigeria has undermined the importance and gain of energy efficiency to the environment and economic growth.

Efficiency is not only cheaper than all other options; it also leads to growth in jobs and personal income (Nnaji et al.2012). Predicting energy usage with model equation in order to know which source is more economical is hereby looked into.

3. OBJECTIVES OF THE RESEARCH

The aim of the research is to study the pattern of energy usage domestically and industrially in Owerri metropolitan area, an urban city in south eastern Nigeria.

The objectives of the study are:

1 To identify the major energy sources in use
2 To determine the level of consumption of the energy sources
3 To identify lapses in energy use.
4 To identify renewable energy potentials in the region and Nigeria in general.
5 To identify which source of energy is more economical and environmental friendly.

4. MATERIALS AND METHODS

4.1 Study area.

Household energy consumption survey was carried out in Owerri , Nigeria. Owerri lies within latitudes 5^0 .29'N and 5.485^0N, and longitude 7^0.02'E and 7.035^0E. It is the capital of Imo state in Nigeria, set in the heart of the Igboland. It consists of three local government areas including Owerri municipal, Owerri North and Owerri West. It had an estimated population of about 400,000 as at 2006 census and is approximately 40 square miles ($100km^2$) in area. Owerri is bordered by the Otamiri River to the east and the Nworie River to the south (www.ngex.com).

4.2 Materials

A household energy survey was conducted to elicit information on the pattern of energy consumption for domestic cooking, domestic lightening and domestic appliances during the period of October 2015 to March 2016. The household questionnaire comprised two main parts: first part consisted of questions addressing the socio-economic characteristics of the respondents and households sampled. This then enabled me to classify them into low income, medium and high income earners, while second part consisted of questions which addressed the pattern of energy used for cooking, appliances and lighting.

4.3 Method of data collection

I made use of questionnaires to obtain responses from households in the metropolis; the questionnaire is exact, simple and objective, covering issues relating to the subject matter. The questionnaire was administered by hand. A total of 120 questionnaire forms were administered in a random sampling method with 108 valid responses representing 90% response rate. In classifying the respondents, 31 household fell under low income earners, 58 under medium income while 19 fell under the high income earners, making a total of 108 respondents. Apart from the above primary source, data were obtained from secondary sources as well; these include the statistical bulletin of Central Bank of Nigeria (CBN), the website of Power Holding Company of Nigeria (PHCN) and relevant literature.

4.4 Method of data analysis

Quantitative data collected in the field were collated and tables showing frequencies of observation were compiled using the statistical package for social science (SPSS) computer program (see tables 4.1, 4.2a, 4.3a, 4.4a, 4.5, 4.5a, 4.6a, 4.7a, 4.8, 4.9a 4.10a and 4.11a).

Fisher's least significant difference (LSD) was used in the analyses:

$$LSD = t_{\alpha/2}\sqrt{MSE\left(\frac{1}{ni}+\frac{1}{nj}\right)} \qquad 4.1$$

Where;
MSE = Mean Squares due to Error
$t_{\alpha/2}$ is based on a t distribution with n_T – k degree of freedom
n_i and n_j are observations.
α - level of significance

Finally, Matlab software package was used to find which of the energy sources is more economical across different classes of income earners. Data were fitted into a model equation (equation 3.2) from Matlab package and used to predict the level of use of the energy sources.

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_1X_2 + a_4X_1^2 + a_5X_2^2 \qquad 4.2$$

$a_0 + a_1X_1 + a_2X_2$ = Linear part of the equation.
$a_3X_1X_2$ = the interaction part.
$a_4X_1^2 + a_5X_2^2$ = the quadratic part.

4.4.1 Model Specification

$$Y = f(x_1 + x_2 + x_1x_2 + x_1^2 + x_2^2) \qquad 4.3$$

Where;
Y = Domestic Energy usage
x_1 = Income level
x_2 = Source of power
x_1x_2 = Interaction of income level and power source.

Matrix form of the equation is:

$$a_0n + a_1\sum x_1 + a_2\sum x_2 + a_3\sum x_1x_2 + a_4\sum x_1^2 + a_5\sum x_2^2 = \sum y \qquad 1$$

$$a_0\sum x_1 + a_1\sum x_1^2 + a_2\sum x_1x_2 + a_3\sum x_1^2x^2 + a_4\sum x^3 + a_5\sum x_1x_2^2 = \sum yx_1 \qquad 2$$

$$a_0\sum x_2 + a_1\sum x_1x_2 + a_2\sum x_2^2 + a_3\sum x_1x_2^2 + a_4\sum x_1^2x_2 + a_5\sum x_2^3 = \sum yx_2 \qquad 3$$

$$a_0\sum y + a_1\sum x_1y + a_2\sum x_2y + a_3\sum x_1x_2y + a_4\sum x_1^2y + a_5\sum x_2^2y = \sum y^2 \qquad 4$$

$$a_0\sum x_1^2 + a_1\sum x_1^3 + a_2\sum x_1^2x_2 + a_3\sum x_1^3x_2 + a_4\sum x_1^4 + a_5\sum x_1^2x_2^2 = \sum yx_1^2 \qquad 5$$

$$a_0\sum x_2^2 + a_1\sum x_1x_2^2 + a_2\sum x_2^3 + a_3\sum x_1x_2^3 + a_4\sum x_1^2x_2^2 + a_5\sum x_2^4 = \sum yx_2^2 \qquad 6$$

$$\begin{pmatrix} n_1 & \sum x_1 & \sum x_2 & \sum x_1x_2 & \sum x_1^2 & \sum x_2^2 \\ \sum x_1 & \sum x_1^2 & \sum x_1x_2 & \sum x_1^2x^2 & \sum x^3 & \sum x_1x_2^2 \\ \sum x_2 & \sum x_1x_2 & \sum x_2^2 & \sum x_1x_2^2 & \sum x_1^2x_2 & \sum x_2^3 \\ \sum y & \sum x_1y & \sum x_2y & \sum x_1x_2y & \sum x_1^2y & \sum x_2^2y \\ \sum x_1^2 & \sum x_1^3 & \sum x_1^2x_2 & \sum x_1^3x_2 & \sum x_1^4 & \sum x_1^2x_2^2 \\ \sum x_2^2 & \sum x_1x_2^2 & \sum x_2^3 & \sum x_1x_2^3 & \sum x_1^2x_2^2 & \sum x_2^4 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{pmatrix} = \begin{pmatrix} \sum y \\ \sum yx_1 \\ \sum yx_2 \\ \sum y^2 \\ \sum yx_1^2 \\ \sum yx_2^2 \end{pmatrix}$$

$E \times a_i = C \qquad a_i = C/E \quad = CE^{-1} \qquad 4.4$

4.5 Definition of terms used.

4.5.1 T- stat

This is a ratio of the departure of an estimated parameter from its notional value and its standard error.
Let $\beta^{\wedge}$ be an estimator of parameter β in some statistical model. Then a t- stat for this parameter is a quantity of the form.

$$t_\beta = \frac{\beta^{\wedge} - \beta_o}{s.e\ (\beta^{\wedge})} \qquad 4.5$$

Where β_0 is a non random known constant.
s.e = The standard error of the estimator $\beta^{\wedge}$. By default statistical package report t-stat with β_o = o (this t–stat values are used to test the significance of corresponding regressors). However, when t- stat is needed to test the hypothesis of the form Ho: $\beta=\beta_o$, Then a non zero β_o may be used.

4.5.2 P value:

This is the probability that an effect at least as extreme as the current observation has occurred by chance.
If P-value is less than or equal to 0.05 it means that there is no more than a 5% probability of observing a result as extreme as that observed solely due to chance and considered statistically significant.

4.5.3 F- statistics

This is a value resulting from a standard statistical test used in ANOVA and regression analysis to determine if the variances between the means of two populations are significantly different. For practical purposes, it is important to know that this value determines the p – value, but the F – statistics number will not actually be used in the interpretation here.

4.5.4 Standard Error (s.e)

Standard error is the deviation of the sampling distribution of a statistics. It is a statistical term that measures the accuracy with which a sample represents a population. In statistics, samples mean deviates from the actual mean of a population; this deviation is the standard error. The smaller the standard error the more representative the sample will be of the overall population. The s.e is also inversely proportional to the sample size. The larger the sample size, the smaller the s.e because the statistics will approach the actual value.
p- value ≤ 0.05 (at 5% confidence)
Rule of thumb: t stat ≥2. The coefficient is significant.

4.5.5 Correlation coefficient R squared (R^2)

R^2 - indicates how well data points fit a statistical model - sometimes simply a line or curve. It is a statistic used in the context of statistical models whose main purpose is either the prediction of future outcomes or the testing of hypotheses, on the basis of other related information.

$$R^2 = \frac{1-SS_{res}}{SS_{tot}} \qquad 4.6$$

Where

SS_{tot} = Total sum of square
SS_{res} = Sum of square of residuals

R^2 is a measure of fit, Adj R^2 is instead a comparative measure of suitability of alternative nested sets of explanators. As such, care must be taken in interpreting and reporting this statistic. Adj R^2 is particularly useful in feature selection stage of model building.

4.5.6 Adjusted R squared (Adj.R^2)

The Adj.R^2 compares the explanatory power of regression models that contain different numbers of predictors. The Adjusted R^2 is a modified version of R^2 that has been adjusted for the number of predictors in the model. The Adj R^2 increases only if the new terms improve the model more than would be expected by chance. The Adj R^2 can be negative, but it's usually not. It is always lower than the R^2.

4.5.7 Decision Rule

H_o = Null Hypothesis.

Using test statistics: Reject H_o if $F_{CAL} > F_{TAB}$

Where the value of F_{TAB} is based on an F-distribution with k - 1 numerator degrees of freedom and n_T – 1denominator degrees of freedom.

5. DATA PRESENTATION / DISCUSSION.

The household questionnaire comprised two main parts: first part consisted of questions addressing the socio-economic characteristics of the respondents and households sampled. This then enabled me to classify them into low income, medium and high income earners, while second part consisted of questions which addressed the pattern of energy used for cooking, appliances and lightening.

A total of 120 questionnaire forms were administered in a random sampling method with 108 valid responses representing 90% response rate. In classifying the respondents, 31 household fell under low income earners, 58 under medium income while 19 fell under the high income earners making a total of 108 respondents

Quantitative data collected in the field were collated and tables showing frequencies of observation were compiled using the statistical package for social science (SPSS) computer program. Matlab software was also used in the analysis.
Apart from the above primary source, data were obtained from secondary source as well; these include the statistical bulletin of Central Bank of Nigeria (CBN), the website of Power Holding Company of Nigeria (PHCN) and relevant literature.

Fisher's least significant difference (LSD) was used in the analyses:

$$LSD = t_{\alpha/2}\sqrt{MSE\left(\frac{1}{ni} + \frac{1}{nj}\right)} \quad \text{.....4.1}$$

Finally matlab software package was used to find which of the energy sources is more economical across different classes of income earners. Data were fitted into a model equation (equation 3.2) from matlab package and used to predict the level of use of the energy sources.

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_1X_2 + a_4X_1^2 + a_5X_2^2 \quad \text{.....5.1}$$

5.1 Statistical analysis for domestic cooking (low income earners)

With SPSS software the following tables and figure were generated;

Table 5.1a: Amount (₦) spent per household on domestic appliances per month by low income earners.

Sample	Electricity	Petrol	Diesel
1	2500	2000	900
2	2300	2200	1100
3	1500	3000	1000
4	2400	2300	800
5	2000	2500	800
6	2000	2400	900
7	2500	2700	1200
8	1800	2200	950
9	2500	2000	1200
10	1700	2600	1000
11	2000	2500	900
12	1900	2250	1000
13	1800	2000	1100
14	2100	2250	950
15	1700	3000	800
16	2200	2400	1100
17	1500	2800	1000
18	2300	2400	1200
19	1500	2500	1200
20	1800	2500	1200
21	1550	2000	800
22	1650	3000	1200
23	1700	2100	850
24	1700	2100	900
25	1800	2300	1100
26	1900	2400	1200
27	2200	2500	900
28	2200	2500	1100
29	2400	2200	800
30	2300	2600	850
31	2500	2700	850
Total	61900	74900	30850
Mean	1996.77[b]	2416.13[a]	995.16[c]

SD	±333.40	±291.95	±147.40

All values are expressed as means ± SD
Means with uncommon superscripts a to d along columns differ significantly at $p < 0.05$ i.e. mean with different superscript are significantly different at 95% level of confidence.

Diesel with superscript c was more economical than other sources of energy for domestic appliances.

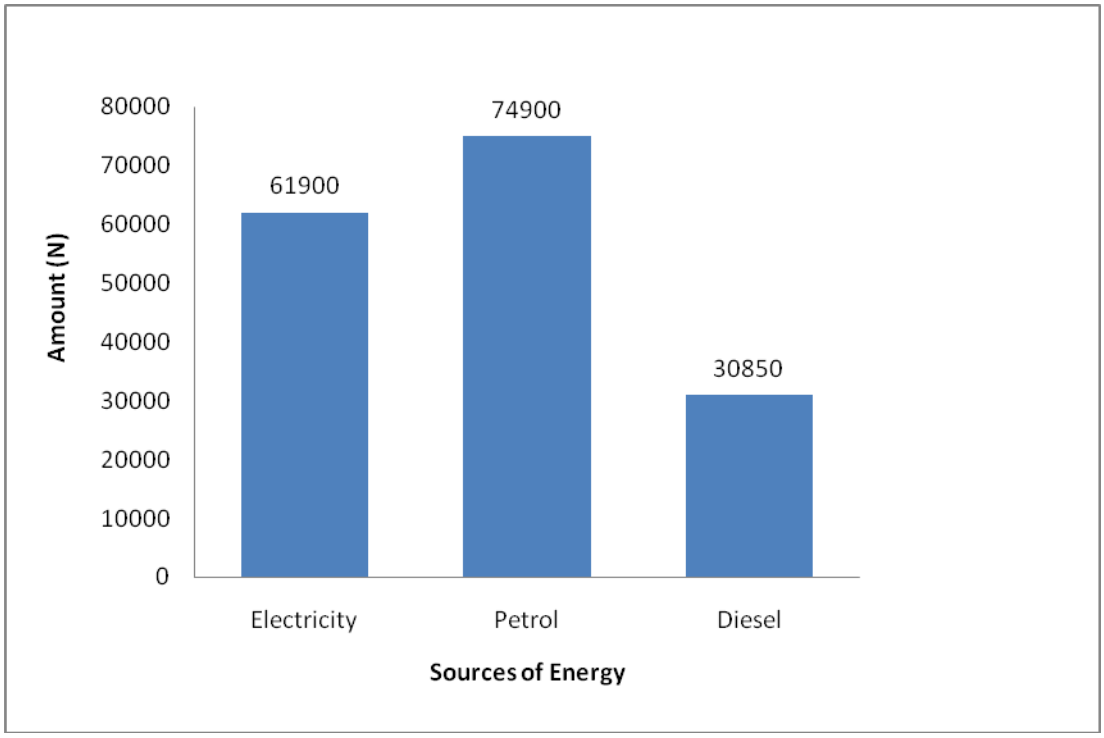

Fig 5.1: Total amount (₦) spent by households on different energy sources for domestic appliances per month (low income).

Table 5.1b: One - way ANOVA table for domestic appliances per month (low income)

Source of Variation	*SS*	*df*	*MS*	F_{CAL}	F_{TAB}
Between Groups	33048441	2	16524220	227.2798	3.097698
Within Groups	6543387	90	72704.3		
Total	39591828	92			

Decision: Using test Statistics: Reject H_o if $F_{CAL} > F_{TAB}$

Since $F_{CAL} > F_{TAB}$, we reject H_o and conclude that there is difference in the source of energy used per household on domestic appliances per month.

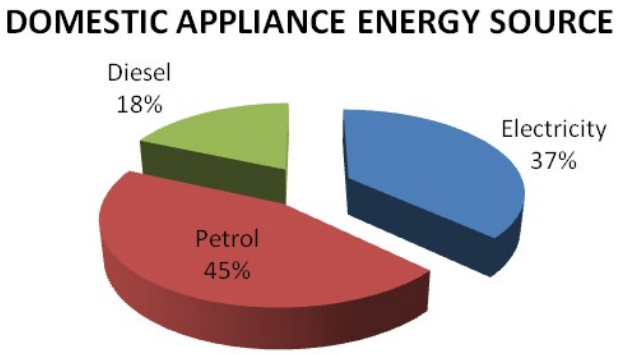

Fig. 5.2 Domestic Appliances Energy Sources in Percent (Low Income).

From fig. 5.2, 45% of domestic appliances energy source was petrol, followed by electricity with 37%, and diesel with 18%. The statistical summary in fig 4.6 has shown that petrol was the major source of domestic energy appliance for low income earners. Diesel with 18% was the least source of power for appliances. This was largely due to the fact that diesel generators are costlier and less common than petrol generators.

Table 5.2a: Amount (₦) spent per household on domestic appliances per month (By medium income earners).

Sample	Petrol	Diesel	Electricity (PHCN)
1	5200	3600	2800
2	4200	2550	1600
3	4500	3000	2000
4	5000	3400	2600
5	5000	3500	2700
6	4500	2800	1800
7	4200	2500	1500
8	5200	3600	2700
9	4500	2700	1700
10	4800	3200	2400
11	5500	3800	2800
12	4500	2700	1800
13	4800	2800	1800
14	6000	4000	3000
15	6000	4000	3000
16	4200	2500	1500
17	5500	3800	2800
18	4500	3000	2000
19	4400	2700	1500
20	4200	2400	1200
21	4100	2300	1100
22	4500	3000	1900
23	4100	2300	1100
24	5000	3500	2500

Sample	Petrol	Diesel	Electricity (PHCN)
25	5500	4000	2800
26	6000	3900	3000
27	4800	3500	2500
28	6000	4000	3000
29	4800	3200	2400
30	4300	2600	1600
31	5000	3400	2600
32	5500	3900	2800
33	4500	2800	1900
34	5200	3800	2800
35	5000	3000	2000
36	4100	2300	1200
37	4300	2500	1100
38	4200	2550	1500
39	4800	3500	2500
40	6000	4000	3000
42	4200	2400	1200
43	4200	2550	1500
44	6000	4000	3000
45	5300	3200	2500
46	5200	3400	2700
47	5000	3500	2600
48	4100	2300	1100
49	4800	3200	2400
50	4500	2700	1800
51	4100	2400	1200
52	4500	3200	2000
53	4300	2700	1800
54	5200	3600	2700
55	4200	2550	1500
56	4300	2700	1600
57	5500	3900	2800
58	4500	2800	1800
Total	278600	180300	122300
Mean	4803.45[a]	3108.62[b]	2108.62[c]
SD	±592.63	±566.55	±629.75

All values are expressed as means ±SD

Means with uncommon superscripts a to c along columns differ significantly at $p < 0.05$ i.e. mean with different superscript are significantly different at 95% level of confidence. Electricity (PHCN) with superscript c was likely to be more economical than other sources of energy for domestic appliances if available regularly.

Table 5.2b: One - way ANOVA table for domestic appliances per month (medium income)

Source of Variation	*SS*	*Df*	*MS*	F_{CAL}	F_{TAB}
Between Groups	215267701.1	2	107633850.6	302.12	3.048
Within Groups	60920689.66	171	356261.34		
Total	276188390.8	173			

Decision: Using test Statistics: Reject H_o if $F_{CAL} > F_{TAB}$
Since $F_{CAL} > F_{TAB}$, we reject H_o and conclude that there is difference in the source of energy used per household on domestic appliances per month.

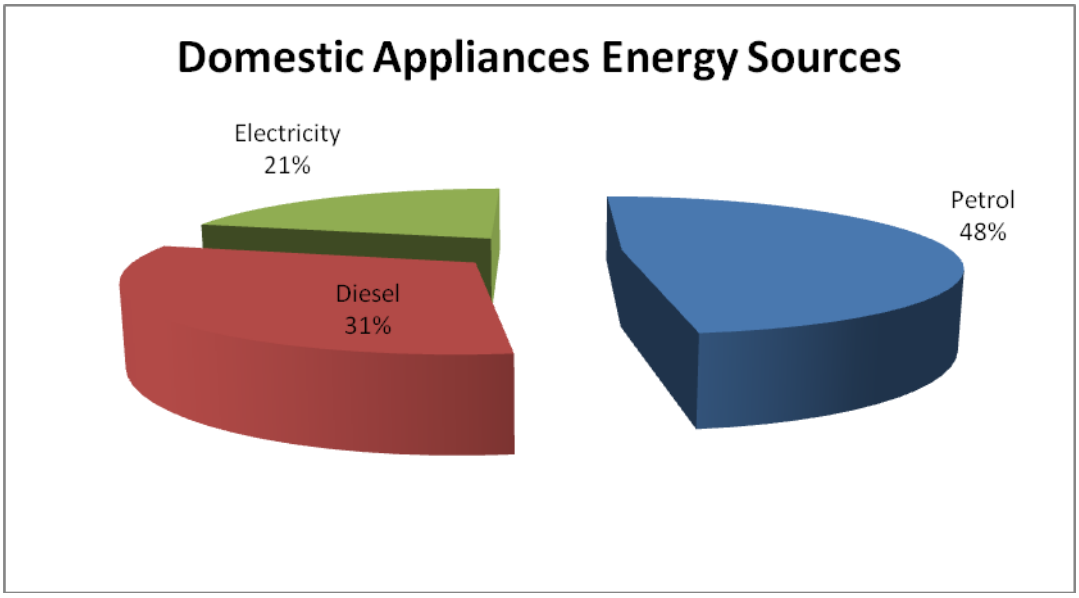

Fig. 5.3: Domestic appliances energy sources (monetary values) in percent (medium income).

Fig 5.3 summarises the cost of energy for domestic appliances by medium income earners sampled as 48% petrol, 31% diesel and 21% electricity (PHCN).

Table 5.3a: Amount (₦) spent per household on domestic appliances per month (by high income earners).

Sample	Petrol	Diesel	Electricity (PHCN)
1	6200	4000	2300
2	5500	3100	1100
3	6000	3200	1700
4	6000	3100	1500
5	7000	3500	2200
6	5800	3600	1500
7	9000	4000	3000
8	5500	3100	1200
9	8000	4000	3000
10	6000	3900	2000
11	7000	3800	2500
12	7200	3200	3000
13	7000	3200	3000
14	5800	3400	1400
15	6300	3100	2800
16	8000	3400	3000
17	6000	3500	2300
18	5600	3300	1300
19	5950	3700	1600
Total	123850	66100	40400
Mean	6518.42[a]	3478.95[b]	2126.32[c]
SD	±977.70	±334.30	±701.46

All values are expressed as means ±SD

Means with uncommon superscripts a to c along columns differ significantly at $p < 0.05$ i.e. means with different superscript are significantly different at 95% level of confidence.
Electricity with superscript c was more economical than other sources of energy for domestic appliances.

Table 5.3b: One -way ANOVA table for domestic appliances per month (high income)

Source of Variation	*SS*	*Df*	*MS*	F_{CAL}	F_{TAB}
Between Groups	192271140.4	2	96135570	184.91	3.17
Within Groups	28074473.68	54	519897.7		
Total	220345614	56			

Decision: Using test Statistics: Reject H_o if $F_{CAL} > F_{TAB}$
Since $F_{CAL} > F_{TAB}$, we reject H_o and conclude that there is significant difference in the source of energy used per household on domestic appliances per month.

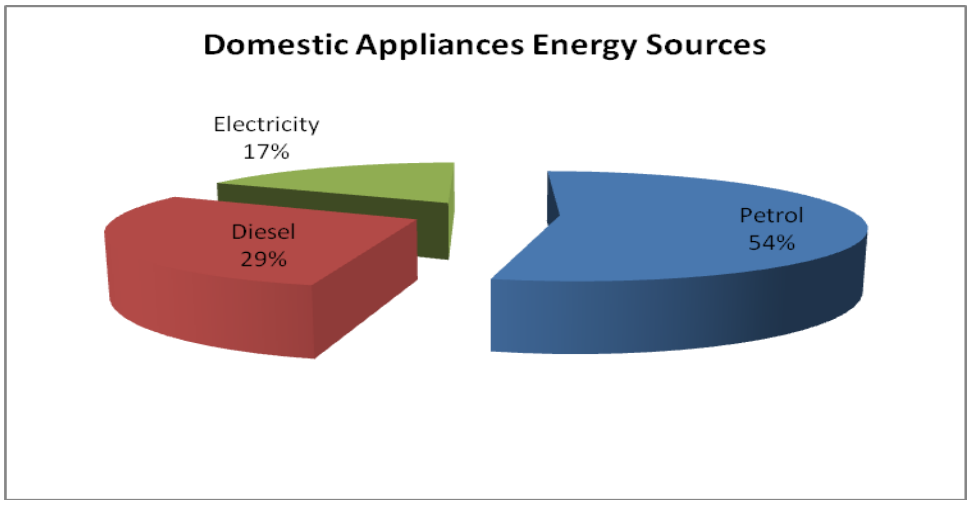

Fig. 5.4: Domestic appliances energy sources (monetary values) in percent (high income).

Fig 5.4 shows that the high income earners spent 54% on petrol, 29% on diesel and 17% on electricity (PHCN) as sources of energy for domestic appliances.

5.2 Analysis with matlab.

For domestic appliances; Xa_1 represent income level while Xa_2 represent source of power.

Low Income =1
Middle Income =2
High Income =3

} Xa_{1i} Income Level where i = 1, 2, 3

Let low income = Xa_{11}, Medium income = Xa_{12}, High income = Xa_{13}

Sources of power for appliances

Petrol =1
Diesel =2
Electricity =3

} Xa_{2j} Power source where j = 1, 2, 3

Petrol = Xa_{21}, Diesel = Xa_{22} and Electricity= Xa_{23}

Table 5.4: Codes with cost (mean) for domestic appliances

Xa_1	1 (xa_{11})	1 (xa_{11})	1 (xa_{11})	2 (xa_{12})	2 (xa_{12})	2 (xa_{12})	3 (xa_{13})	3 (xa_{13})	3 (xa_{13})
Xa_2	1 (xa_{21})	2 (xa_{22})	3 (xa_{23})	1 (xa_{21})	2 (xa_{22})	3 (xa_{23})	1 (xa_{21})	2 (xa_{22})	3 (xa_{23})
Cost	2416.13	995.16	1996.77	4803.45	3108.62	2108.62	6518.42	3478.95	2126.32

Costs (mean) are from tables 5.1a, 5.2a and 5.3a

Table 5.5: Model analytical values for domestic appliances

Variables	coefficients	Se	T stat	P val	F statistics
a_0	-964.9656	2467	-0.39114	0.72182	sse=$1.1029x10^6$
a_1	$4.4876x10^3$	1835.7	2.4446	0.092124	dfe=3
a_2	-13.7383	1835.7	-0.0074838	0.9945	dfv=5
a_3	-847.6225	303.16	-2.7959	0.068082	ssv $2.1661x10^7$
a_4	-418.2717	428.74	-0.97559	0.40122	f=11.784
a_5	90.2233	428.74	0.21044	0.84681	Pval=0.034644

R^2 = 0.9516
Adj. R^2 = 0.8708
MSE = $3.6763x10^5$

The coefficients of equation 4.2 and other parameters in table 5.5 were obtained by fitting the field data of table 5.4 into that equation.

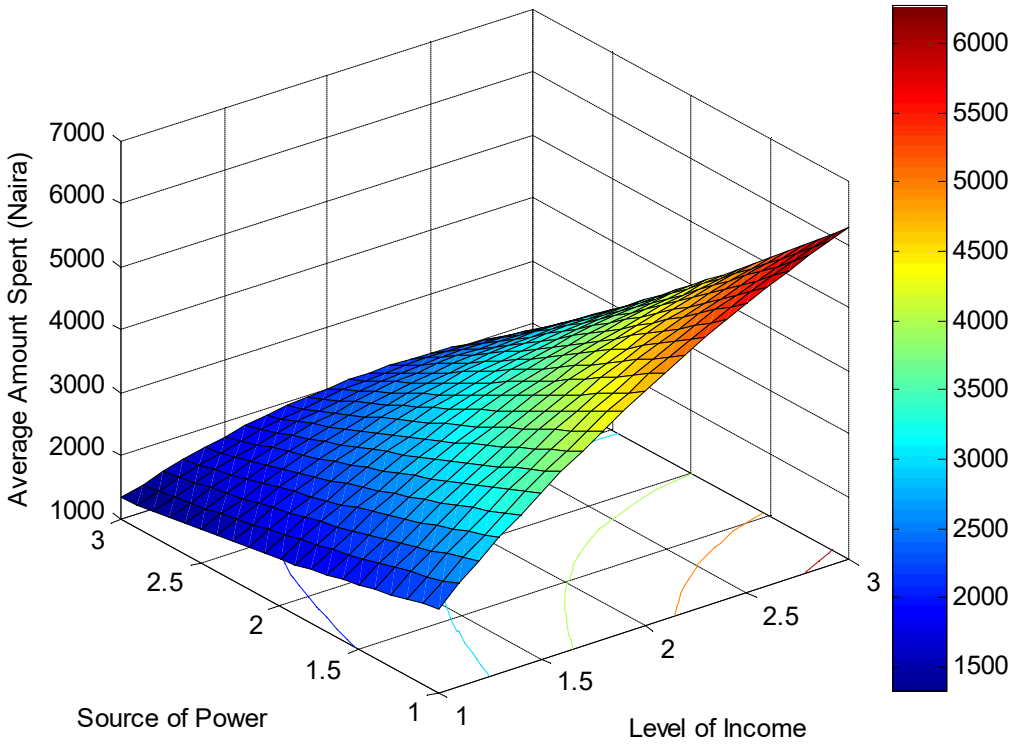

Fig. 5.5: Surface plot for domestic appliances

5.3 Model prediction for domestic appliances

The t-statistics table shows the significance at 90% confidence of the linear component of level of income, this linear relationship shows up in the surface plot too (Fig. 5.5). Source of power has less effect on amount spent on domestic appliances than it does on domestic cooking and lightening, though the effect is significant at 90% confidence level. Level of income has effect on amount spent on domestic appliances. The two variables (level of income and source of power) also affect the amount spent on domestic appliance interactively as revealed by the contour of the surface plot (Fig. 5.5). The low income earners (Xa_{11}) using diesel (Xa_{22}) spent the least amount on domestic appliances; the amount is N1332.30 based on the model (equation 4.2) and N995.16 based on table 5.1a. The high income earners (Xa_{13}) spent the most amount on domestic appliances using petrol (Xa_{21}), the amount is N6267.00 based on the model and N6518.42 based on table 5.3a.

6. CONCLUSIONS

The study on household energy usage for appliances in Owerri metropolitan area revealed the following;

1. The major source of energy for the household in the area is from petroleum products or fossil fuel (petrol, kerosine, gas and diesel).
2. Electrical and other forms of energy consumption were much lower.
3. Renewable energy technologies have not been effectively utilized.
4. There is a strong interaction between source of energy and level of income which invariably determines energy consumption rate.

7. CONTRIBUTIONS TO KNOWLEDGE

1. Models were developed for predicting energy usage in domestic appliances.
2. Energy sources for applinces that are preferred by the populace in Owerri metropolis were identified.
3. Predictive model's result was compared with that of experimental data results analysed with a statistical package (SPSS).

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