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A survey of power supply and lighting patterns in North Central Nigeria—The energy saving potentials through efficient lighting systems

I. Ahemen[a,*], A.N. Amah[a], P.O. Agada[b]

[a] Department of Physics, University of Agriculture Makurdi, P.M.B. 2373, Benue State, Nigeria
[b] Department of Mathematics, Statistics and Computer Science, University of Agriculture Makurdi, P.M.B. 2373 Benue State, Nigeria

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ABSTRACT

While power crises persist in Africa with many heads of governments placing priority on power generation, the need for energy conservation through efficient lighting can be a short-term solution. This paper compiles the power supply and consumption pattern from lighting of six cities and towns in North Central Nigeria. A total of 1637 residential households were surveyed. Each compound had 2 to 4 houses. Most of the households surveyed had a combination of modern and local buildings such as huts. The work revealed that the predominant form of electricity consumption is in lighting. Electricity supply is found to last for an average of 5 days a week and 9.8 h a day. The major electric lighting source is the 60 W and 100 W incandescent bulbs, but a significant population uses both incandescent and energy efficient lamps (e.g. compact fluorescent lamps, CFLs) for their lighting needs. In the absence of public power supply, kerosene and low power generators are used as alternative sources for lighting. The number of kerosene lamps in a residential compound was found to be 3 or more. About 70 per cent of power generated in Nigeria can be saved if efficient lighting sources such as CFLs and solid state lighting are urgently adapted. Also, an estimated 796.4 billion naira (US$4.98 billion) will be saved annually from fuel to power electric generators if they are replaced by solar- based lighting.

1. Introduction

Global residential energy demand is about 23 per cent and Africa has the largest share of residential energy end use with 54 per cent [1]. Similarly, the residential sector account for the largest share of energy use in Nigeria (65 per cent) [2]. This large energy consumption has triggered research interest in the residential sector with the aim of findings ways to effectively utilize residential utilities for potential energy savings. Some of these research have been carried in Thailand [3], Australia [4], United State of America [5], England [6] and Nigeria [7–9]. In all these studies, it was realized that besides heating, lighting is one of the major sources of energy consumed in the residential sector. Also, apart from counties were the use of incandescent lamps has been banned, incandescent lamps are still a major source of household lighting especially in developing countries.

Though, electric lighting represents the most efficient form of artificial lighting source, in Nigeria like most sub-Saharan African countries, electric lighting is hampered by inadequate electricity generation and supply. Over 51.5 per cent of the over 160 million people in Nigeria lack access to electricity [10,11]. Nigeria's electricity demand is in the range of 20,000 MW to 25,000 MW [12]. However, the current nominal electricity generation capacity is less than 6000 MW [13] with the actual electricity generated fluctuating between 2950 MW to below 4000 MW [14]. This enormous shortfall in electricity production is further exacerbated by high losses due to inefficient distribution system [15], hence the frequent power outages experienced by consumers. Beside infrastructure deficits, the spate of gas pipe line vandalism by militants has worsened the power situation in Nigeria [16]. Frequent power outages affects everyone: students cannot read at their desired times because of the fear for power failure; households and business owners are forced to look for alternative power supply to meet their lighting needs, hence the prevalence of small generators popularly called "I better pass my neighbour" in Nigeria's small to medium income households. For high income households, diesel generators are used for lighting and other domestic appli-

* Corresponding author.
E-mail addresses: ahemior@gmail.com, ahemen.iokyaa@uam.edu.ng (I. Ahemen).

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ances such as air conditioners, refrigerators, electric iron, etc. Beside huge income loss, generators are a source of stress (or fatigue) and health hazard as a result of the noise generated and the greenhouse gas emissions [17]. It has been reported that Nigeria spends an estimated sum of 796.4 billion naira, (US$4.28 billion equivalent) annually on fuel to power electric generators [18]. This huge expenditure on small power generators has a toll on the gross domestic product (GDP) growth of a nation whose per capita income is among the poorest globally [19]. Nigeria's KWh per capita electric power consumption of 148.9 KWh is the lowest among her peers such as Bangladesh (254.6 KWh), Brazil (2438.0 KWh), Indonesia (679.7 KWh) and South Africa (4315.1 KWh) [20].

As noted earlier in this work, electricity consumption in Nigeria has been reported to be dominated by the residential sector [18,21], of which lighting is a major contributor. Unfortunately, inefficient lighting sources such as the incandescent bulbs are generally common and are the most widely used in households [7]. Every household is adorned with incandescent bulbs. These lamps waste 95 per cent of their input energy as heat and barely convert 5 per cent of the energy to light. Besides the use of inefficient electric lighting bulbs, efficient utilization of available power by the end users is also lacking; it is not uncommon for electric lamps to be left on (glowing) when their light are not needed, e.g. during day light hours in homes, offices and commercial centers. With a population of more than 10 million people having access to electricity in Nigeria, there is a potential of saving large amount of electricity generated for other productive uses if efficient lighting technologies are adopted [22,23].

The Nigerian government's efforts towards solving the energy crises in the country has always been in the direction of building more power plants and the unbundling of agencies (National Electric Power Authority, NEPA in 2005 and the Power Holding Corporation of Nigeria, PHCN in 2013) [24] responsible for power generation, transmission and distribution. Despite this efforts and the huge amount of money invested into the power sector, electricity generation has remained below 4000 MW on the average. If the solution to electric power problem in the short term is not diversified to include electricity end users efficiency such as utilization of efficient lighting technologies, the quest for adequate and stable power supply would continue to elude the nation. Apart from the fact that efficient utilization of electricity means more power available to other productive and extended uses, it is also capable of substantially reducing materials waste and greenhouse gas emissions. The main objective of this work is to determine the energy consumption pattern of households in Nigeria and the energy saving potential associated with adapting new lighting technologies. Therefore, this paper presents the result of a survey carried out in North Central Nigeria on household electric lighting energy consumption. The contribution of this work comes about as the result of Nigeria's first attempt to evaluate energy savings opportunities from lighting by community households. In addition, this work would provide a framework for government to develop sustainable policies and programs on the efficient electricity utilization in the country, particularly in the area of efficient lighting systems. It will also inspire lighting retrofit scientist in developing countries to step-up efforts towards finding more efficient and cost effective lighting sources.

2. Methodology

The choice of residential building for this survey is because as stated in the introduction, residential energy consumption constitute about 65 per cent of the energy use in Nigeria [25]. Moreover, Lighting from households is one of the largest energy used in the residential sector. A large proportion of energy is wasted through the use of inefficient lighting sources and human behaviour. The 2006 national population and housing census report of the National Population Commission (NPC) is the latest document on population and housing in Nigeria. Therefore, this report was adapted for use in this work to decide on the number of residential households to conduct the survey. Other socio-economic information were obtained from the National Bureau of Statistics (NBS) report of 2010.

The study was conducted in two states in North central Nigeria and the map showing the surveyed areas is presented in Fig. 1. The choice of North Central Nigeria, and in particular, Benue and Nasarawa states is because to our knowledge this work has never been carried out in these places. In North Central Nigeria, there are reports on residential energy survey in Kaduna state [8], Plateau states [26] and Niger state [27,28]. States in Nigeria are divided into local Government areas (LGAs) and LGAs into council wards; six local government areas in Benue state and one in Nasarawa state were considered based on the 2006 housing census. These places make up the study strata were each local government area is a stratum and each ward is adopted as a sub-stratum consisting of households. A total of 1637 households were selected across wards, representing 10 per cent of the population (in the selected research areas) enumerated, based on the 2006 national population and housing census. The survey method includes the use of household questionnaires, interview with key informants (especially heads of households now known as respondent or their representatives), physical observations of different kinds of lighting fixtures and review of existing documents from relevant agencies.

2.1. Questionnaire

Questionnaires were administered orally to randomly selected households in the various wards that make up the local governments by enumerators who filled out the questionnaires during the interview. This questionnaire guided oral interview approach was employed because some of the households were illiterates. A sample of the questionnaire developed for this work is presented in Appendix A.The enumerators carried with them samples of electric light bulbs to the respondents. In households where access was granted the enumerators conducted energy audit by counting the bulbs by themselves and determined their numbers, types and properties. However, very few households allowed access to their homes especially bed rooms. Therefore, data obtained from this audit were only used for complementary purposes.

The questionnaire was divided into three sections; sections A, B and C. Section A involves some basic information regarding the household such as name, number of buildings in the house and house type. Section B duels exclusively on electric lighting generated from the grid system. Section C duelled primarily on lighting from alternative sources such as rechargeable lamps, kerosene lamps and generators among others. In both section B and C, questions include; sources of electricity for the home, characteristics of the various sources, duration of usage and activities in which the supplied electricity was used in the home. The data collected were subjected to simple statistical analysis using statistical package for social science (SPSS). It was used to implement selected descriptive statistics on the study data. The statistics include the mean, frequency and percentages and the results were presented in tables and charts.

Table 1 compares the lumen output of CFLs, LEDs and incandescent lamps. Using the information in Table 1 and Table 2, the total energy consumption by each lighting source was estimated using the modified top-down approach reported by Gifford et al., [5]:

$$E_i = P_r txnN \quad (1)$$

where,

E_i = Average energy consumption for a given lamp type

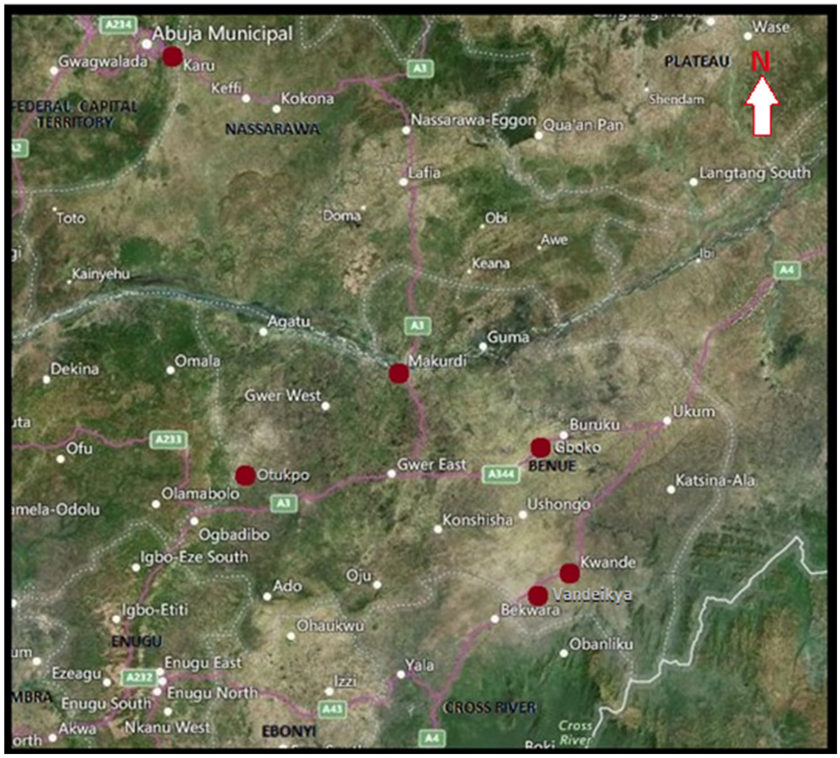

Fig. 1. Google map showing the surveyed areas for this study.

Table 1
Power rating of various bulbs according to their lumen [29].

Lumen (lm)	Incandescent (W)	CFL (W)	LED (W)
>5000	–	80–100	–
2600	150	32–35	25–28
1600	100	23–26	16–20
1100	75	18–22	13
800	60	13–15	8–12.5
450	40	9–11	6–9

Table 2
The number of incandescent bulbs per household, days with electricity per week and hours with electricity per day.

Area	Ave. No. of Incandescent lamps per household	Ave. No. of days with electricity per week	Ave. no. of hours with electricity per day
Gboko	3.8	2	4
Karu	3.5	7	12
Kwande	18.0	4	8
Makurdi	2.5	4	14
Otukpo	2.5	7	10
Vandeikya	7.8	6	11
Total Average	6.4	5	9.8

P_r = watts of bulb
t = duration for which the bulbs were left glowing in hours
x = Percentage of population that uses the type of lighting
n = the population sampled
N = number of days with electricity in a year

As an example, using Eq. (1) and information in Table 1 and Table 2, consider that a 60 W incandescent bulb is replaced by a higher lumen output light such as an 18 W CFL. The energy consumed (E_1) by the 60 W bulb per year for lighting is 978 kWh, while the 18 W CFL will consume 294 kWh energy (E_2) within the same period. The energy saving potential ϕ is calculated using Eq. (2):

$$\phi = \left(1 - \frac{E_2}{E_1}\right) \times 100\% \quad (2)$$

$$\phi = \left(1 - \frac{294}{978}\right) \times 100\% = 69.9\%$$

Therefore, replacing a 60 W incandescent bulb with an energy efficient CFL will save 69.9 per cent of electrical energy from lighting alone. A similar method was employed to estimate the potential energy savings from lighting in the surveyed areas, North Central Nigeria and the entire country using the data generated from this research and others obtained from National Bureau of Statistics (NBS) [23].

3. Results and discussion

The number of hours electricity is supplied to households in the surveyed areas is shown in Table 2. The result shows that electricity supply range from 4 to 12 h with an average of 9.8 h per day. This value is slightly higher than the number of lighting hours reported by CERDC in 2009 [30] which may perhaps be due to a slight improvement in power generation and distribution by successive governments. However, no household received uninterrupted power supply for a whole day. Investigations also revealed that electricity supply is often rationed and that there is no guarantee that there would be constant power supply during the rationed period. The worst affected town is Gboko were electricity supply last for only between one and four hours per day.

On the number of days electricity is supplied to the selected study areas, it is clear from Table 2 that Otukpo and Karu receive electricity supply daily while Gboko, Kwande and Makurdi receive an average electricity supply of two – four days per week. The electricity supplied in these towns/cities is mostly rationed due to the use of old transformers or overloading of existing transformers [31].

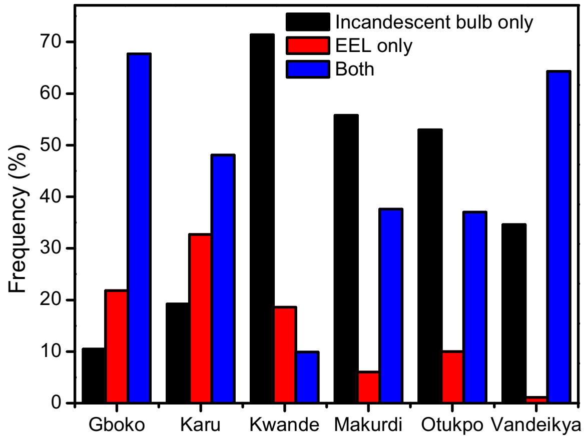

Fig. 2. Types of electric lamps and frequency of use.

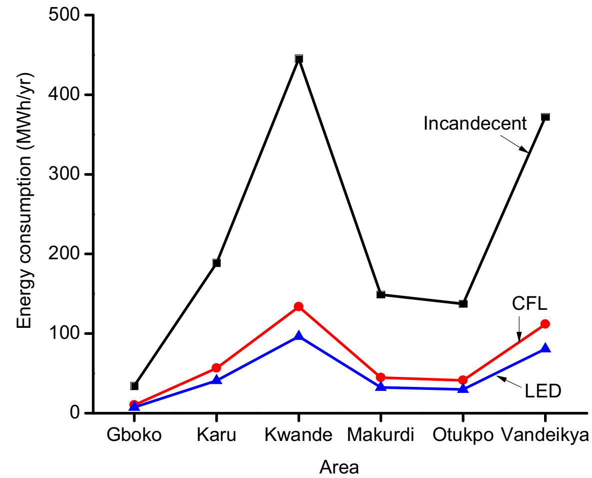

Fig. 3. Power consumption in the studied areas.

It is common to have a large cluster of residence that is fed from a single transformer of low power rating. Gboko is again the town that is the worst affected.

Despite the power challenges government has not found it expedient to bring up policies that would curb power wastages through the use of energy efficient technologies. Fig. 2 displays a breakdown of lighting types and frequency of usage by study areas, showing incandescent bulbs as the most commonly used lighting source (i.e. by 40.8% of respondents). A good proportion of respondents (44.7%) also use both energy efficient lamps (EELs) such as compact fluorescent lamps (CFLs), and incandescent lamps (Fig. 2). This result is consistent with the report by CREDC [30]. There is no definite pattern from Fig. 1 that suggests whether or not awareness of the energy efficiency of lighting sources was responsible for the choice respondents made. For example, a large proportion of respondents (55.8%) in Makurdi, the capital city of Benue state use only incandescent bulbs for their lighting needs. This study also revealed that the incandescent lamps in use are rated at 60 W, 100 W and 200 W. Of these, 60 and 100 W are the most commonly used, and the choice between these two is a matter of availability (their costs are about the same, i.e. ₦40.00 or $0.2), and a function of the household's mains current level, which in most cases varies depending on how close the household is to the transformer or what size of the transmission wire was used. Those who live in traditional hut structures are not allowed to connect to the national grid system. Therefore, in order to have access to the public power supply, they obtain electricity from their neighbours using the 1.5 mm copper wire which are often buried under ground. These wires leak current to the ground thereby creating low shielding to adjacent households.

There is significant increase in the use of energy efficient lighting technologies among households in Otukpo (10%), Kwande (17.6%), Gboko (20.8 per cent) and Karu (31.7%) towns unlike Vandeiky (1.1%) and Makurdi (6.0%) towns. The primary reason has been the high lumen output otherwise known as "brightness" of these EELs when compared to incandescent bulbs especially in the face of low power supply voltage from the national grid. Unfortunately, the power ratings of the common EELs in use are high (40 and 80 W), though; 18 W and 24 W CFLs are also available. The use of higher power rated EELs is aimed at achieving higher "brightness" under low power/voltage situations. One other factors that have discouraged the rapid deployment of EELs is the lifespan and high cost per lamp [20,32,33]. Although it is expected that EELs should have 4 times the average lifespan of incandescent bulbs, it is common to find that most CFLs supplied to the Nigerian market are substandard and so burnout easily [13,14]. Energy efficient lamps/bulbs are also far more expensive than incandescent bulbs [34], e.g. a 60 W or 100 W incandescent bulb cost about ₦40 ($0.2) while a standard

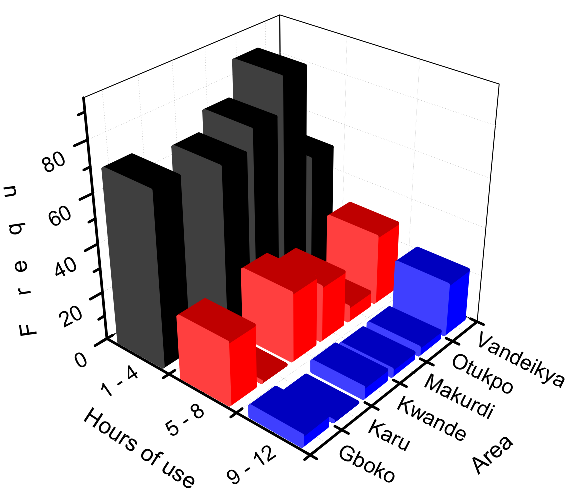

Fig. 4. Hours Kerosene lamps are used.

CFL cost between ₦500 ($2.5) to ₦1500 ($7.6) for 40 W and 80 W, respectively. However, it is worth mentioning that some substandard CFLs could be purchased for as little as ₦150 ($0.76) and ₦200 ($1.02) [35]. The conversion from Naira to dollar was considered at the prevailing exchange rate of ₦197 to $1. Beside the high initial cost of CFLs, the inability of households to measure or determine the true saving benefits of CFLs in electricity bills due to lack of meters or because of non-functional meters has retarded CFL deployment [36].

Fig. 3 shows energy consumption in the studied areas for incandescent, CFL and LED light sources in a year. The result shows Kwande and Vandeikya as consuming the highest amount of electricity, most probably because of the higher number of lighting points being used in their household (see Table 2). Gboko has the lowest energy consumption due to poor power supply to this area.

Persistent power outages, brownout and few hours of electricity supply per day means that significant proportions of indoor night time lighting for many households is backed-up by other lighting sources such as kerosene lamps and smaller gasoline generators. Fig. 4 shows that some households in all the study areas except Karu have between 2 and 4 kerosene lamps which are used for an average of 4 h for lighting at nights without public power supply.

Fig. 5 shows the number of hours household in the studied areas use generators when there is blackout from the public power supply. It is clear from Fig. 5 that a higher percentage of respondents

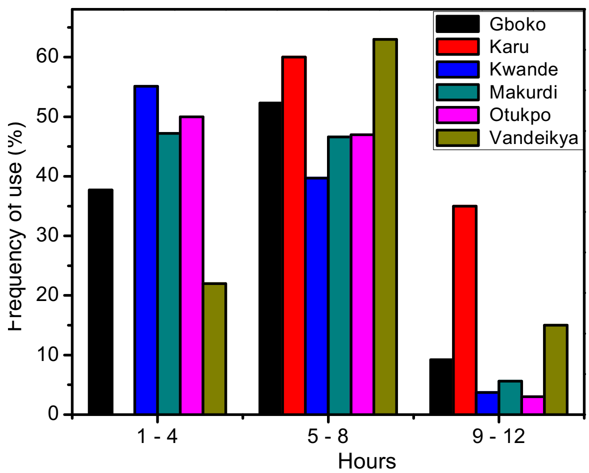

Fig. 5. Hours generators are used per day.

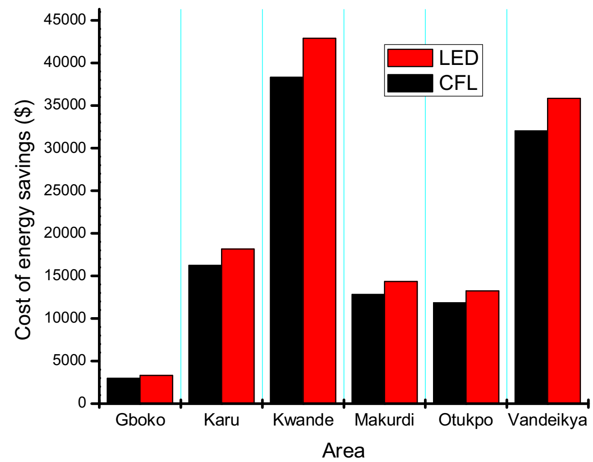

Fig. 7. Cost savings from EELs.

Fig. 6. Common household generator.

used generators between 4 and 8 h a day The most common generator used, popularly known as "I better pass my neighbour" (Fig. 6), is rated at 950 VA. Fewer lighting lamps are used with this kind of generator, because these lamps are often the inefficient incandescent bulbs. The generators under these loading conditions can provide electricity for four hours, consuming 2 L of gasoline fuel.

3.1. Energy saving potentials

Electric energy consumed by lighting fixtures in Nigeria can be drastically reduced to meet other pressing needs if technologies such as incandescent bulbs were replaced with energy efficient lamps. The results of estimated energy savings are presented in Table 3. The result shows that even with higher illumination, about 70 per cent and 78 per cent of electrical energy supplied from public power supply can be saved annually if incandescent bulbs are replaced with EELs such as CFLs and LEDs, respectively. This result is consistent with earlier reports of 60 to 67 per cent saving potential by switching from incandescent to CFLs [37,38]. The huge quantity of electricity that can be potentially saved could be consumed by other services (end uses), increase the hours of reliable electricity supply, or increase access to electricity such as those communities that are yet to be connected to the national grid system. Also, EELs can reduce energy bills, thereby freeing up money that can be spent elsewhere in the economy. The expected cost of energy savings by replacing incandescent lamps with efficient lighting sources are presented in Fig. 7 and Table 3. The cost was calculated using the average of the current unit cost of electricity tariff for residential sector, that is, ₦ 24.24 ($0.12) [39]. About $15,00 to $45.00 can be saved annually by these communities alone by embracing EELs. At a larger scale, about 126 million to 956 million US dollars can be saved annually from lighting alone if each household embraces EELs in North Central Nigeria and the entire country, respectively. These monies can then be channelled to improving power supply to other parts of the country without access to the national grid system.

Now that the energy saving potential has been shown, the question remains: what approach can we use to drive the EELs into Nigerian households? There are basically two approaches; technological approach and behavioural approach. For the technological approach government must develop policies that will encourage the use of EELs such as banning the importation and use of incandescent bulbs, increase surveillance on substandard

Table 3
Estimated energy saving potential from efficient lighting technologies in Nigeria.

Area	Total No. of House-holds	Electric Lighting Energy Consumption, GWh/yr			Energy Savings, per cent		Cost of energy saved (Million Dollar) per yr	
		Incandescent Bulbs	CFL	LED	CFL	LED	CFL	LED
This work	1637	1.50	0.48	0.35	70.0	78.1	0.122	0.138
North Central	1,546,838	1,510.82	453.2	327.3	70.0	78.3	126,9	142.0
Nigeria	10,422,427	10,179.70	3,053.9	2,205.6	70.0	78.3	855.1	956.9

EELs, and by substantially subsidizing the cost of EELs. Behavioural approaches include improving efficiency and energy wastage awareness through educational campaigns.

4. Conclusions

Efficient energy utilization through the use of efficient lighting technologies to replace incandescent lamps promises to be the short term solution to the prevailing energy crisis in Nigeria. A saving of over 70 per cent of the electrical energy consumed by lighting appliances can be achieved by replacing incandescent bulbs with energy efficient lamps (EELs). However, this can only be possible through changes in consumer behaviours toward EELs and government policies that encourages the use of these efficient technologies. The energy saved as a result of using EELs can be used for other purposes that may enhance the overall economic growth of the country. About 70 per cent of power generated in Nigeria can be saved if efficient lighting sources such as CFLs and solid state lighting are urgently adapted. Also, an estimated 796.4 billion naira (US$4.98 billion) will be saved annually from fuel to power electric generators if they are replaced by solar- based lighting.

5. Study limitations and recommendations

The study is limited by the use of 1637 number of households out of the 1,107,087 households enumerated and by the fact that only two states in North central Nigeria were listed for the study. This is due to the limited finances of the researchers at the time of this research. This challenge calls for the proximity factor in the selection of the two states considered in the study.

Short term solution to the acute power shortage is deployment of energy saving lamps in households, this can be achieved by increasing the import duty of incandescent lamps while at the same time granting incentives to importers of EELs. In order to curtail influx of substandard lamps, government agencies saddled with the responsibilities of maintaining standards of goods should be given the necessary tools to punish offenders by imposing severe fine to defaulters.

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Appendix A.

APPENDIX 1

FEDERAL UNIVERSITY OF AGRICUTURE, MAKURDI
DEPARTMENT OF PHYSICS

QUESTIONAIRE ON LIGHTING ENERGY CONSUMPTION PATTERN IN MAKURDI METROPOLIS OF BENUE STATE, NIGERIA

BY

Name of enumerating officer:

Objective: To assess the rate, types and duration of lighting energy consumption in Makurdi Metropolis Benue State.

Section A. (Please tick √/write in boxes or spaces provided)

1. Name………………………………………………………………………………

2. Please indicate your position in the family…………………………,,,,,,,,,,,,,,,,,,,,,

3. Locality/District/Ward………………………………………………………………

4. Number of houses in the compound…………………………………………………

5. Types of house (s): Flat ☐ Hut ☐ single room ☐

others specify………………..

Section B: Grid Lighting

7. Source(s) of lighting: grid electricity ☐ kerosene lamp ☐ Battery lamp ☐

Rechargeable lamp ☐ others specify…………………………………………………

If your answer in question 7 is grid electricity then answer the following;

8. How many days in a week do you have electricity……………………………………

9. How long does the electricity supply last…………………………………………………

10. Illumination level (please tick); Bright ☐ Dim ☐

11. What types of lighting bulbs do you use? Incandescence ☐ Fluorescence ☐

Energy saving bulb (CFL) ☐

12. Power rating (Watts) and number of incandescent bulb and: 40W ☐ 60W ☐

100 W ☐ 200 W ☐

13. Power rating (Watts) and number of incandescent bulb and: 18 W ☐ 25W ☐

80W ☐ 60W ☐ 80W ☐ 200W ☐ others specify……………………

14. NEPA bill for at least 1 month (Please specify date):

a. Unit consumed:…………………………………… '……..

b. Cost per unit:……………………………………………………

Section C: Alternative lighting

14. If alternative source of lighting

a. Specify:…………………………………………………………

b. Quantity (No of units)………………………………………

c. How long do you put it in use (in hours): ……………………

d. Type of fuel: ……………………………………………………

e. Power specification (Watts): …………………………………

15. If Generator

a. What is the power rating (Watts) and model: ………………

b. Operating hours per day (in Hours):…………………………

c. Amount of fuel consumed (in litre):…………………………

d. Type(s) of fuel: …………………………………………………

e. How many lighting points do you use with generator……..

f. What type of lighting bulbs…………………………………

g. What are the power ratings…………………………………..

h. Others specify…………………………………………………

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