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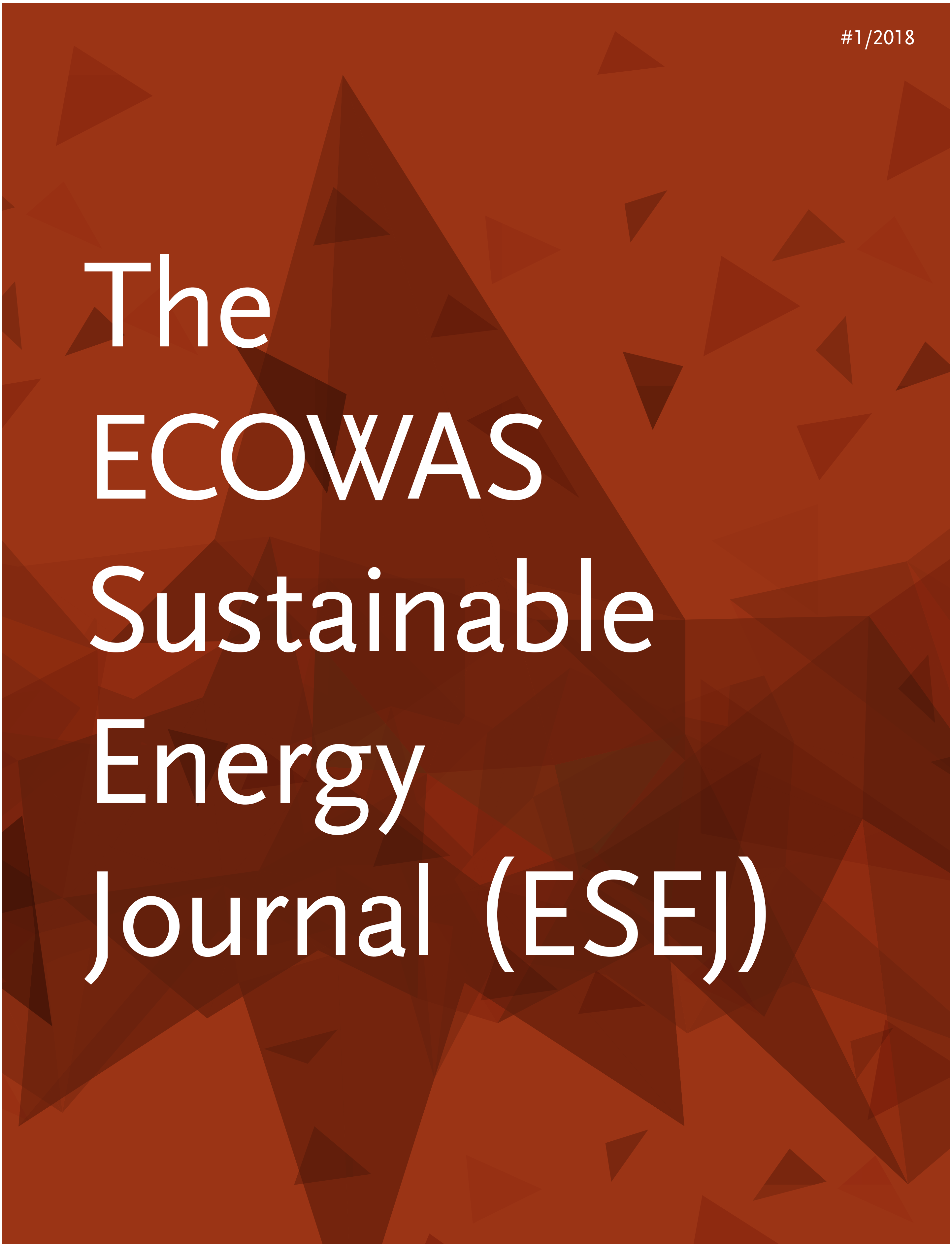
TOWARDS SUSTAINABLE ENERGY



#1/2018

The ECOWAS Sustainable Energy Journal (ESEJ)

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The ECOWAS Sustainable Energy Journal (ESEJ) is a peer reviewed journal published annually by the Economic Community of West African States (ECOWAS) Centre for Renewable Energy and Energy Efficiency (ECREEE), Achada Santo Antonio, C.P 288, Praia, Cape Verde.

ESEJ is aligned with the objective of ECREEE which is to promote renewable energy and energy efficiency markets in West Africa by addressing technical, financial, policy and regulatory barriers. Moreover, with the ongoing energy landscape transformation in the region the importance of having relevant, evidence-based knowledge to aid in decision-making cannot be overemphasized.

By increasing the knowledge level of decision makers, science has played a key role in shaping the energy landscape, influencing decisions to cater for the needs of the present and, even, future generations. For the ECOWAS region, with issues of data availability and scarcity of country-specific research studies, the need to stimulate and cultivate the development of scientific, yet policy relevant, research projects have never been more pressing, especially in light of the region's sustainable development ambitions. Through its link with the ECOWAS Youth Leadership Development in Energy, ESEJ particularly aims to gives a voice to West African youth, by providing a platform through which they may contribute to informing decisions in the energy sector in the region.

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About ECREEE

ECREEE was established by Regulation C/REG.23/11/08 of the 61st Session of the Economic Community of West African States (ECOWAS) Council of Ministers in Ouagadougou, Burkina Faso, in November 2008. ECREEE is a specialized ECOWAS Agency, which acts as an independent body but within the legal, administrative and financial framework of existing rules and regulations of ECOWAS. The Centre exists to promote the establishment of regional renewable energy and energy efficiency markets by supporting various activities to mitigate existing barriers on different levels and sectors. These activities include policy development, capacity building, awareness raising, knowledge management and advocacy as well as investment promotion and business development.

Article Manuscripts

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The ECOWAS Sustainable Energy Journal (ESEJ)

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The ECOWAS Sustainable Energy Journal (ESEJ)

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Introduction from the Editor in Chief, Mahama Kappiah, Executive Director of ECREEE

Dear Reader,

I am excited to present to you the first edition of the ECOWAS Sustainable Energy Journal (ESEJ).

As an organization established with the mandate to identify and mitigate barriers to the creation and effective functioning of renewable energy and energy efficiency markets in the West African region, knowing these bottlenecks, what they are and why they persist, is essentially our business.

Over the years, ECREEE has developed, and continues to implement, initiatives that address existing technology, financial, legal, policy, institutional and capacity related barriers as it concerns the sustainable energy sector. We have achieved these by working closely with the public and private sector. Through ESEJ, we wish to deepen our collaboration by hearing directly from you where you still see barriers as well as what your recommendations are for addressing these barriers. We see ESEJ as being a platform by which our solutions are fine-tuned and tailored to the needs of our stakeholders, determined through empirical methods.

ESEJ encompasses the qualities ECREEE promotes, such as evidence-based decision-making and presentation of practical, implementable and measurable solutions. In addition to these is inclusion, for youth and women. This edition is particularly special because the research articles were developed through the ‘ECOWAS initiative on Youth Leadership in Development in Energy’. The initiative provided grants to research teams comprised of male and female MSc and PhD students in the region. They also received supervision and mentorship from faculty members in top West African universities to support them in researching on topical issues in the energy sector and, thus, enable them contribute to informing energy related decisions in their respective countries and the region as a whole.

I am confident that you will enjoy this edition and I look forward to presenting subsequent editions to you.

Yours sincerely,

Mahama Kappiah

Determinants of Household Energy Expenditures: A Gender Analysis from Nigeria[1]

EFOBI UCHENNA[a] AND AKINYEMI OPEYEMI[b]

Abstract

This paper explores the determinants of energy expenditure at the household level across the different thresholds of energy expenditures, while taking the gender dimension into consideration. A nationwide survey dataset (2012/2013 period) that contains information about households across the different regions of Nigeria was used to achieve our objective. The estimations were performed using both the parametric and the non-parametric regression approach to draw a robust conclusion. We find a concave shaped (non-linear) relationship between income and energy expenditures across households. We also find other important determinants of the household energy expenditures including the presence of both heads of the household, average age of the household members, the household type, location, assets, to mention a few. The results underline the importance of designing differentiated policy measures to address policies that affect energy prices. This is because the determinants of household energy expenditures vary by household characteristics, depending on the amount of energy expenditure across such households.

KEYWORDS: GENDER, HOUSEHOLD ENERGY, NIGERIA

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This research project was funded by the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency – ECREEE Research Grant. The guidance from the ECREEE team and the useful comments from our mentor, Professor Adeola Adenikinju (Centre for Petroleum, Energy Economics and Law, University of Ibadan), are highly appreciated. The authors take responsibility for every other views that are expressed in this document.

1. Introduction

Modelling household demand for electricity has been an important topic since the 1970s due to the interest in energy conservation and impact of increasing electricity prices on welfare. Since then, the power sector in Nigeria has experienced several reforms to improve service delivery. As a result, the average price paid for residential electricity has increased over the years, and the impact on different income groups has remained a concern. Most especially, this relationship concerns a policy relevant issue on poverty and welfare, since there are likely to be differential impacts on different households, depending on their income group. Therefore, the relationship between electricity use and income remains a major interest for scholars, policy analysts, and policy makers.

Household expenditure on energy has been growing steadily in act with the societies' increasing economic affluence. The impact on the household sector raises important concerns because they account for a significant share of total energy use and economic welfare in modern economies. As such, the residential energy demand is expected to continue to grow in the foreseeable future (Jamasb and Meier, 2010). This growth requires that some important socio-economic dimensions of households that need to be better understood needs to be considered. It is in this light that this research aims to understand some of these dimensions in the light of the income and the structure of the household, with particular focus on gender issues related to the household head and composition. However, linking energy spending and income of the household cannot be explained by a simple linear description. In most cases, there are complications that require cogent attention in such an analysis. Energy spending increases with income, but at an uneven rate (Jamasb and Meier, 2010). Therefore, Engel curves for energy expenditures are non-linear and in most cases, they resemble S-curves along which households' spending on energy may increase, stagnate or even follow a declining trend with income. Hence, policies that are targeting household energy use need to take into consideration this trend of relationship. With this, policies can be better channelled or implemented by taking into consideration the different household peculiarities and how they affect energy expenditure.

Precisely, the aim of this paper is to provide a comparative analysis of determinants of energy expenditures across different energy expenditure thresholds in Nigeria and from a gender perspective. The main research question that is considered in this study is: what are the determinants of household energy spending across different energy expenditure thresholds for Nigerian households. To test these relationships of interest, we first perform a non-parametric estimation using the local polynomial regressions that presents a graphical illustration of the regression lines across the different estimates of interest. We then specify and estimate a set of parametric regressions that explains the main socio-economic determinants and drivers of energy spending among Nigerian households, taking into consideration the different energy expenditure thresholds. The quantile regression approach was used at different energy expenditure thresholds of 0.10, 0.25, 0.50, 0.75, and 0.90. The quantile that represents the lowest energy expenditure group is 0.10, middle group is 0.50, and the higher income group is 0.90. We expect the energy expenditures to increase with higher household income. More so, we expect different effects from other household socio-economic variables across the different income groups. For instance, the average age of the household and the household head, the type of building of the household, the average years of schooling, and the share of female household members, are important household characteristics that will be examined across the income groups in relation to energy expenditure.

Our line of enquiry is motivated by the following reasons: first, there is a dwindling share of households in Nigeria that use electricity compared to other source of energy for household activities, which raises an important question on the efficiency of the energy sector to sustain household activities and the pecuniary effect of increasing electricity tariff in Nigeria. Most of the other source of energy are either unfriendly to the environment as a result of carbon emission, or could lead to further depletion of the environment in the form of deforestation, among others. For instance, Ndegwa et al (2011) observes that about 94 percent of the African rural population and 73 percent of the urban population rely on wood fuels as their primary energy source, with the urban settlements relying heavily on charcoal and rural areas being more dependent on firewood. Considering cooking activities, which consume a major chunk of energy within the household, less than one percent of Nigerian household rely on electricity for this activity. This is compared to about 72 percent that use firewood and 23.8 percent that use kerosene, and little wonder why Nigeria loses about 400,000 hectares of land on an annual basis. Therefore, the first step to resolve this diversion of energy source to eco-unfriendly means will be to consider those household factors that can sustain household expenditure on electricity in the face of rising tariff.

Second, there is the need to consider women in this kind of energy analysis because they consist of a large proportion of the household labour that engage with eco-unfriendly energy sources for household activities. Emissions from these kind of energy sources usually contain poisonous gases (such as particulate matter, carbon monoxide, nitrogen oxide, sulphur oxide and benzene) that has a damaging health effect on women and children, who are traditionally charged with the duty of cooking in Africa. Therefore, a change in electricity tariff may expose these groups of household members to a very high level of fine particulate matter, as well introduce other health risks due to the desire to seek for other energy alternative that may be eco-unfriendly. It is therefore paramount to understand those household factors that can have a significant impact on energy expenditure across income groups and then examine policies that can sustain electricity expenditure in the face of rising tariff. Sustaining household electricity expenditure, especially for women, is consistent with the growing literature arguing that reducing poverty and inequality among women will require a focus on energy access and expenditure (see Oseni, 2012).

The advocacy for household electricity expenditure is based on the numerous health hazard associated with other energy sources that are available to Nigerian households. So far, energy source from electricity is regarded as the safest, with less health hazards, compared to firewood, kerosene and even coal. More so, it has been established that households that use electricity as a major source of energy are confronted with no indoor smoke pollution, those using gas and liquid fuels (such as kerosene and liquid petroleum gas) are faced with medium pollution, while pollution increases to a high level when solid fuels (such as such as animal dung, crop residues and wood) are used (United Nations, 2010).

The contribution of this paper is twofold: first, it complements the growing theoretical literature on household energy expenditure, in particular, by considering the behaviour of energy expenditure to different household covariates, and considering such behaviours at different energy expenditure thresholds. To our knowledge, there are no empirical examinations that consider the determinant of energy expenditure across different household characteristics in Nigeria and with a focus on gender. Secondly, the paper provides recent evidence of the determinants of energy expenditure across households and gender in Nigeria. Considering the purpose of this study, we believe it is relevant and interesting to study Nigerian households as a case as it is well known that inequality is high[2], allowing for possible variation in determinant of energy expenditure across the different energy expenditure threshold of households. Understanding this variation is relevant as existing policy conclusions in Nigeria are usually based on peculiar classifications across households' characteristics. Furthermore, in many respect, Nigeria is a good representative for developing countries, especially in Africa.

Our study is situated in the broad literature of energy supply/expenditure and development. However, it differs in some respect from previous studies that, for example, have considered stylised facts from national statistics on household access to electricity and energy expenditure in Nigeria (e.g. Oseni, 2012), or the proliferous studies that have considered renewable energy, both for the household electricity expenditure and for national development (e.g. Oseni, 2012; Shaaban and Petinrin, 2014;

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[2] As at 2013, the period of our data, Nigeria had a Gini coefficient of 48.8/100.

Yamusa and Ansari, 2015). We use a real survey data that covers the post-privatisation era of the PHCN and also allows us to use estimation techniques that effectively captures household dynamics[3]. More so, our analysis differs because we are mainly interested in the household characteristics that explain energy expenditure among different household income groups, and how this is reflected in the gender of the household head. As earlier stated, this has not received any empirical attention in the growing literature where our study is situated.

The remainder of the paper is distributed as follows: the second section presents a brief stylised facts of the energy policy in Nigeria, which is immediately followed by the theoretical foundation for the study and literature review in the third section. The study design that considers data, empirical model and estimation technique is in the fourth section. The fifth section presents the results and discussions, while the sixth section concludes the study with recommendation for future research direction.

2. Energy Policy in Nigeria

Prior to 2013, when the Power Holding Company of Nigeria (PHCN) was privatised, there was an increasing agitation to evaluate the effectiveness of the power sector on households and firms, who require it for different commercial and domestic purposes. Some common conclusions include that more investment should be encouraged, as well as reducing inefficiency in the supply and use of electricity, as this can stimulate growth (Akinlo, 2009). Ibitoye and Adenikinju (2007) earlier highlighted the need for improving the magnitude of electricity generation, improved transmission and distribution infrastructure and a consistent investment and maintenance of the electricity generation plants. As a result of some of these issues, the Nigerian government was spurred to enact the Electricity Power Sector Reform (EPSR) Act in March 2005, with the sole aim of ensuring that Nigeria has an electricity supply industry that matches and surpasses its demand.

A major outcome from the EPSR was the division of the PHCN into splinter companies that will be managed by the Bureau of Public Enterprises and the Ministry of Finance. This paved way to the full fledge privatisation of PHCN in 2013. Following this move, there has been an improvement in the volume of power supply: in 2005, only 2,494 Mega Watts (MW) of power was generated, compared to 3,795MW in 2014 (i.e. over 52 percent increase)[4]. Despite the increase in power generation, some authors (e.g. Aliyu, Dada and Adam, 2015; Onochie, Obanor and Aliu, 2015) observe that the privatisation move may not have been an efficient way to transform the power sector, since about 60 percent of Nigerians are still not connected to the national grid, and those that are connected still experience frequent outages. This explains the reasons for an increasing agitation for a radical transformation in the power sector via the adoption of renewable energy in power generation (see Emodi and Boo, 2015; Mas'ud et al, 2015; Usman et al, 2015). Apart from tackling the power supply issue, the authors argue that moving towards renewable energy will bring about sustainable development and environmental protection.

Moving towards an efficient power sector is one aspect of the issue. Another important aspect is to identify the individuals/households who will be benefiting from this structural transformation. This includes asking some important questions: what income category will this transformation affect the most? Will this effect be differential across the gender of the household head? These important aspects require urgent policy attention. Apart from the paucity of empirical evidence that provides adequate

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[3] The choice of the period also takes into account that not all households are connected to the national grid, especially rural households. Hence, our analysis takes into account the location of the household.

[4] This data is gotten from Usman et al (2015).

guidance in answering them, they are of utmost importance considering the broader sustainable development tenet that pays cogent attention to reducing absolute poverty and empowering women. First, poverty rate in Nigeria has dropped from 35.2 in 2010/2011 to 33.1 in 2012/2013 (World Bank, 2015). However, the inequality has risen from 46.5 in 1996 to 48.8 in 2013, therefore implying that despite the reduction in the poverty rate, the rising inequality still creates concerns in terms of income distribution, and has provided more reasons to underscore possible factors that can reduce these rising gap. Second, considering inequality and poverty from a gender perspective has become a critical issue in the development field. Generally, women are poorer than their male counterparts and the inequality is seen in assets acquisition and ownership of land (Doss, Meinzen-Dick, and Bomuhangi, 2014). This trend is more pronounced in Nigeria: about 60-79% of the rural work force comprise of women but men are five times richer and are likely to own land (British Council, 2012). The statistics provide a good platform to pay serious attention to development policies that may affect women differently.

Considering these trends, research attention has not been focused on the rate at which the reform in the power sector affects different income groups and gender in the household. We follow a unique approach by considering household expenditure on electricity and to see how household income group explains these differences. With this, we are able to determine the households that will be most affected by the reform. We are persuaded by the argument of Obadan (2008) that privatisation drives the involvement of private investment to an increase in the price of the commodity being supplied, and which will be hurting to the consumers. Therefore, if privatisation of the energy sector is the way forward, we are able to know which household will be most affected across income groups, as well as across gender of the household individuals.

As a first check to understanding the relationship between energy expenditure and income group of the household in Nigeria, we present in Figure 1 a macro trend that shows the scatter plot between electricity power expenditure and the GDP per capita (constant US$ 2010). From the Figure, it is evident that there is no linear relationship between these two variables: the scatter plot in Figure 1 reflects that at some income thresholds, the electricity per capita expenditure tends to increase and then begins to reduce until it reaches a threshold, where it begins to increase again. The trend resembles an S-shape trend, which is best, explained by the Engel S-curve; this theoretical foundation will be subsequently discussed.

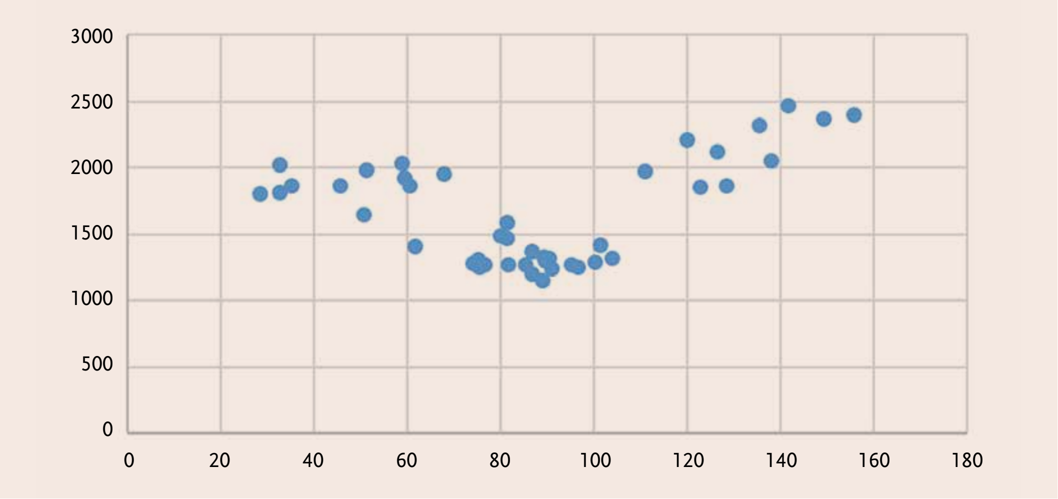

FIGURE 1: AVERAGE ELECTRICITY EXPENDITURE AND INCOME PER CAPITA (1971-2016)

Authors' computation from the World Bank - World Development Indicator - 2016

3. Theoretical Underpinning and Literature Review

The relationship between household income and energy expenditure is best explained with the Engel S curve for energy expenditure. The Engel curve relates the energy expenditure of individuals with their income, and predicts that the relationship follows an S curve. This is such that energy expenditure varies with income but not at a linear trend. The Engel S curve analysis was earlier presented by Bradshaw *et al* (1987) as a statistical technique to identify inflection points where expenditure allocated to necessity goods like energy, food, and clothing changes with income levels. In essence, income increases as well as spending on necessity goods in a less than proportional manner, until an inflection point is reached beyond which spending flattens (or even declines) and then regains its increasing momentum again (Jamasb and Meier, 2010). This theoretical prediction may suggest that at different income levels, the determinant of household electricity expenditure may change

Studies that analyse the pattern and determinants of energy expenditure have largely have considered certain household socio-economic variables influence on energy expenditure. Some of these variables include income, age, education, occupation, and location, gender of the household head, composition and number of households, among others. For instance, Reddy (2004) traced the variation in energy use for Indian households to different household characteristics. Jamasb and Meir (2010) traced energy spending of British households to income. The authors found that low-income households were less sensitive to electricity price changes but rather more sensitive towards other source of energy compared to the high-income households. This result is similar to that of Cashin and McGranahan (2006) who studied the United States of America energy spending of households and found that the impact of an energy price increase on households differs based on the household's specific energy expenditure patterns. Foster, Tre and Wodon (2000) also found an inverted-U relationship between energy expenditure and income per capita using data for Guatemala: the authors traced this energy pattern to social and environmental policy. While Elnakat, Gomez and Booth (2016) identified the vintage of home, size of home, socio-economic, demographics, and composition of household family as important determinant of household energy expenditure. Income is also seen as an important determinant, electricity intensity and usage: income earners will typically have homes that are less efficient in energy usage and electric intensity. This shows that there is a direct linkage between the income of the household and energy expenditure.

Eakins (2013) study for Irish households included household characteristics like income level and some dwelling characteristics such as number of persons in the households, age of the household heads, occupation, education, regional location of the home, and stock of appliances in the home. This finding is similar to Conniffe (2000) who traced different energy expenditure pattern to the geographical location of the household. An important pointer is that often times, increasing energy prices tends to discourage consumption of unsustainable traditional energy for environmental sustainability and are observed to be usually counterproductive. Households only redirect consumption towards cheaper energy such as firewood and kerosene which is damaging to the environment and human health. Kristiansen (2012) focused on the education level of the household head; this variable tends to reduce energy expenditure only when the educational attainment is beyond the high school category. The mechanism through which this is possible is that higher education would improve the individual's ability to optimise energy expenditure and usage, especially regulating the kilowatt hours of appliance usage. Grossman (1972), and Elnakat, Gomez and Booth (2016) study also shows that education increases the ability of individuals to be better sensitive to electricity usage.

In the case of Nigeria, Abd'razack*et al*(2012) observed that due to subsidy regime issues, pattern of consumption shifted to biomass in some states of Nigeria because of its availability, cheapness and traditional affinity. On the other hand, clean, healthier and environmentally friendly modern energy were gradually been abandoned. The study also found a significant relationship between the choice of energy and incomes as well as energy use and household size. In the same vein, Ogwumike, Ozughalu and Abiona (2014) identified household size, per capita expenditure and education as the major determinants of energy expenditure.

Focusing on energy and gender, efforts had also been made to understand how gender influences pattern of energy expenditure. Some authors like Khamati-Njenga and Clancy (2003) asserted that men and women do not have equal access to energy services and hence, will have different behaviour towards energy expenditure. Permana and Siong (2015) also ascertained that women were more energy efficient than their male counterpart. The authors also found that energy expenditure tend to be at the lowest when women make energy expenditure decisions. Thus, women may tend to be better energy managers and more cautious about household expenditures, while men may be careless with respect to energy expenditure. Similarly, Elnakat and Gomez (2015) argue that women's participation in domestic activities can have a significant role on energy intensity. The authors approximate 80% higher per capita energy expenditure with female activities within the household. One important element that needs to be considered is the age of the individuals in the household. Women who spend majority of their time at home will tend to use more energy than those that are outgoing for work or other businesses (Domene and Sauri, 2006). Invariably, there is the tendency for higher household energy expenditure in households where residents comprise of older individuals who require energy usage for lightning and conditioning (Gram-Hanssen *et al.,* 2004).

Two areas that have been given consideration in previous studies and which our study intends to do differently are to consider the determinant of the household energy expenditure across the different income groups of households. We also considered the gender of the household when examining the electricity expenditure determinants across income groups. These areas are specific considerations that our study intends to take up.

4. Study Design

Data

The data for this study is sourced from the World Bank's Living Standards Measurement Study (LSMS) - Integrated Household Survey 2012-2013 post-harvest survey. This survey was conducted in collaboration with Nigeria's National Bureau of Statistics. Nigeria is one of the seven countries in Africa that is covered by the LSMS[5]. The LSMS dataset contains a rich data of households across the different states of Nigeria, as well as other basic information that are required in our analysis. Information such as household income, consumption distribution, gender (including that of the household head), count of household asset and infrastructure, are also contained in the dataset.
The latest LSMS_ISA wave (i.e. 2012/2013) household data is used for our data analysis. The recent wave is preferred because it is an updated version of the previous LSMS_ISA data (i.e. 2010/2011). The LSMS_ISA data consist of 5,000 households and specifically, the second wave of the LSMS_ISA data was carried out in two visits (post-planting visit in September – November 2012 and post-harvest visit in February-April 2013). Specifically, we use the post-harvest data for this analysis: this data adjust for households that have changed location after the post-planting visit. This kind of data source is favoured by some authors like Ogwumike, Ozughalu and Abiona (2014) who used the 2004 Nigeria Living Standard Survey to examine some of the determinants of household energy use in Nigeria.

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[5] The dataset, structured questionnaires, manuals and codebook are available online at World Bank Webpage (http://go.worldbank.org).

Empirical Model

To study the relationship between income and energy spending, we begin by considering the Engel expenditure curves for energy spending and to see whether the differences that exist among income groups is in the form of S-curves.

After considering the income-energy expenditure relationship, we move ahead to estimate our empirical model of the following form:

$$Q_Y(\tau) = \sigma_i + \alpha_i X + \varepsilon_i \qquad (1)$$

The equation implies that energy expenditure (τ) is explained by household determinants (X) and across different expenditure quantile (Q_Y) The parameters "σ" and "α" are unknown parameters that are to be estimated, while the "ε" is the error term. It is important to note that that equation (1) will be estimated for the entire household and then for female-headed households and for women in general. This is to enable a clear understanding of the relationship that is been estimated on women.

The household electricity expenditure variable is measured as the average monthly amount in local currency that is paid by the household for electricity (see for example Bacon, Bhattacharya, and Kojima, 2010), which is based on the monthly recall household expenditure data in the LSMS_ISA survey. The households' determinant of interest include: the average age of the household, the average number of years of education of the household, the location of the household, the average size of the household, share of adult in the household, the type of the home that the household is living in and the average number of hours that the household head spend in their economic activities.

The motivations for the inclusion of these household determinants are two folds. First, these variables have been recurring in extant literature as the likely determinant of household energy expenditure in Nigeria and other developing countries (see Abd'razack *et al,*2012; Ogwumike, Ozughalu and Abiona, 2014). Second, most of the household determinants are measurable variables that can easily be identified and are used to stratify households in policy formulation that relates to household energy expenditure. The measures of these variables and their indicators are included in Table 1.

TABLE 1: EMPOWERMENT INDEX: DOMAINS, INDICATORS, AND WEIGHTS

Variable	Definition	Indicator
Electricity	This measures the monthly expenditure that is directed at the electricity expenditure in the household.	Pecuniary value of the monthly budget for electricity.
Income	Total income of the household. This is including food and none food expenditure.	Pecuniary value of the total expenditure of the household.
Head	Household head	Dichotomous variable, where 1=household head, and 0 otherwise.
Hh_age	This measures the average age of the individuals that are living in the household.	Average age of the individuals in the household.

Variable	Definition	Indicator
Hhead_education	This is the education status of the household head (i.e. whether the household head have ever attended school).	Dummy variable, where 1 is when the Hh head have attended school and 0 otherwise
Share_fem	Share of female in the household.	Computed as the ratio of the total number of female in household to the total number of household individual.
Female_head	Female headship.	A dichotomous variable where 1 implies female headship, and 0 otherwise.
Hh_location	This captures the location of the household.	It is a dichotomous variable, where 1 is for households in urban area and 2 for those in rural area.
Hh_size	This measures the size of the household. This is in terms of the number of individuals that are living in the household.	A count variable that captures the number of individuals in the household.
Hh_Adult	This measures the number of adults (those individuals that are above 18 years) and that are living in the household.	This is captured as the number of adult individuals in the household divided by the total number of individuals in the household.
Hh_type	This measures the size of the house that the household currently live in.	It is a count variable for the number of rooms that are in the house where the household live in.
Hh_assets	This measures the number of assets that the household currently own.	This is a count variables that captures the number of assets that can be identified in the household at the time of the survey.
Hr_publicelect	Number of hours that the household have access to public electricity.	A count variable that captures the number of hours that the household have access to public electricity.

Source: Authors

Estimation Strategy

Two main estimation strategies are applied in this analysis. The first is testing specific relationship between income and household energy expenditure using the non-parametric regression approach. This allows us to assess how changes in income explain the volume of electricity expenditure of the household. The non-parametric regression that is based on the local polynomial regression approach is preferred to test this relationship because of its merits. These merits include that this kind of regression fits the relationships between the variables of interest, such that separate fitted relationships are obtained at different values of the independent variable, so as to accurately predict the regression lines. More so, this form of regression, unlike the parametric linear regression technique, allows for a relaxation of the linearity assumption and can predict estimators and inference procedures that are less dependent on functional form assumptions (Yatchew, 1998; Frolich, 2006). The different forms of relationships can also be easily explored between variables of interest, which makes it useful for exploratory data analysis and for practical and policy relevant analysis. Finally, the non-parametric regressions permit, in many cases, an estimation of variables despite their endogeneity status (Frohlich, 2008).

The parametric regression approach, in the form of the Ordinary Least Square regression, is applied in this study. Our form of OLS allows for clustering the standard errors of the estimates around household. Clustering the standard error around household is preferred in order to have an accurate estimate of the standard errors of regression coefficients for covariates. In order to estimate this relationship using the OLS approach, we first of all categorise the household into three different income quantile (less than 25 percent, between 25 – 50 percent income, and between 50-75 percent income groups). Afterwards, the OLS estimation is then performed across the income groups. With this approach, we will be able to determine the extent to which the determinant of household energy expenditure varies across income groups of the household.

5. Econometric Results

Description of Hh Energy Expenditure across Different Hh Characteristics

Before estimating the parametric relationship between household incomes on energy expenditure across different thresholds of energy expenditure, we begin by considering the non-parametric regression graphs of how different households would be affected (in terms of electricity expenditure) by changes in their income. The first non-parametric regression is presented in Figure 2 across the gender of the household head (i.e. male – and female – headed household): it displays the fitted regression lines for female- and male-headed households separately, with each point on the regression line reflecting the average energy expenditure ratio for a given level of income (which is approximated using log total household expenditures).

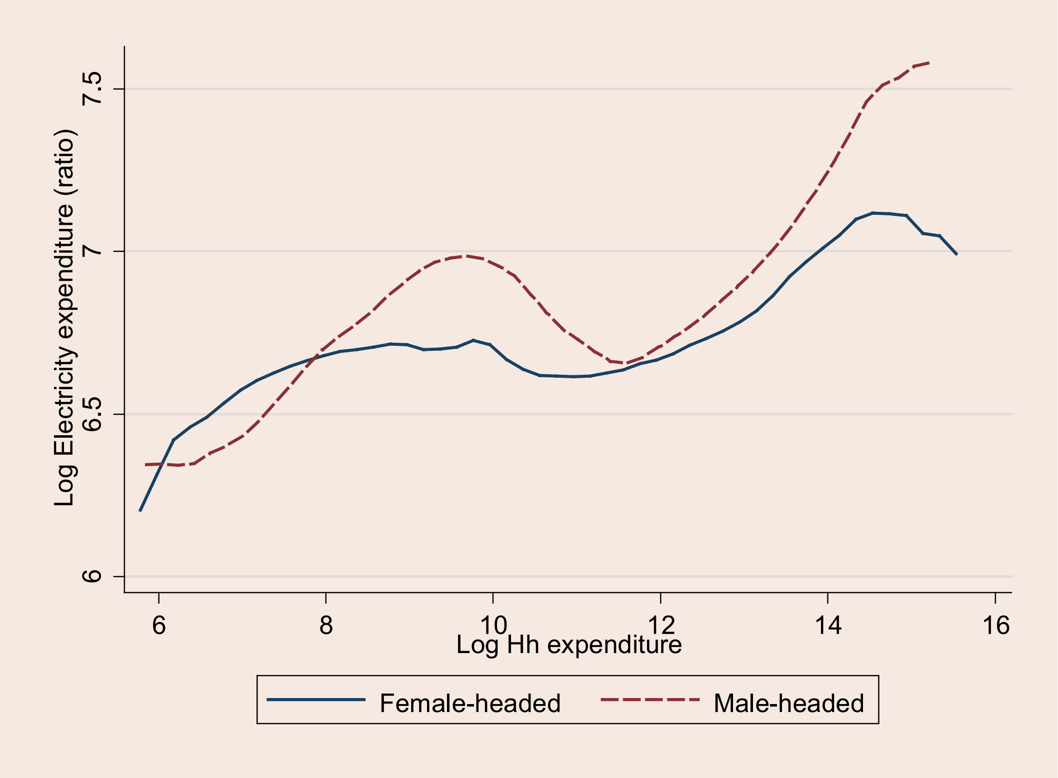

FIGURE 2: HOUSEHOLD ELECTRICITY EXPENDITURE AND INCOME

Evidently, poorer households with low income spend a small proportion of their income to purchase electricity. The importance of electricity expenditure in the household then constantly increases with rising income and then begins to decline as income further increases, until a certain point where energy expenditure further responds to additional income in the positive and then begins to decline again. From Figure 2, the positive relationship between energy expenditure and income is very visible for households within the 0 to 50th income percentile and those at 75th to 95th income percentile. However, for the middle-income households (i.e. >50th and <75th income percentile) and the extreme rich (i.e. households with income percentile that is higher than 95th percentile), declining energy expenditure is seen with additional income. This result agrees with the Engel expenditure curves for energy expenditure (see Jamasb and Meier, 2010), which says that the proportion of income spent on energy follows an S-curve such that household energy expenditure initially increases with income and then stagnate or declines with income and after which it increases again.

We also find some evidence of gender differences: except for the very poor households, female-headed households seem to spend less on energy than their male counterparts with similar total household income. This suggest that policies directed at increasing the price of electricity tariff in Nigeria will likely hurt the poorest female headed households since they tend to spend more of their income on electricity expenditure than the male-headed households. Generally and for other income percentiles, male-headed households will be hurt with increased electricity tariff compared to their female-headed households.

To provide a deeper perspective to the results, we provide the regression line across rural and urban households in Figure 3 to check if the trend is consistent or whether it changes, depending on the location of the households. The regression line of the urban households in Figure 3 is similar to Figure 2; for lower income households, the female-headed households spend more on energy and then consistently remain lower than their male counterpart as the income increases. For the rural households, however, a different trend is observed: female-headed households consistently spend more on energy than their male counterpart as the income rises. In both regions, the Engel curve is observed. A succinct policy implication from this disaggregation is that, with increased electricity tariff, lowest income earners with female households will be hurt more than the male counterpart in the urban area. But in the rural area, it is the higher income earner with female households that will be more hurt compared to their male counterpart.

Finally, we then test whether the number of women within the household drives the volume of energy expenditure and across different household locations. This inquiry is necessary considering the anecdote suggesting that women are largely involved in household non-paid activities and will most likely be involved in higher energy usage compared to their male counterpart that are mostly away from the home (due to work activities). More so, as earlier stated, the household sector accounts for a significant share of total energy use (Jamash and Meier, 2010); therefore, it will be reasonable to consider the impact of the concentration of female household member since this group of individuals are largely involved in the household. The result of this regression trend is presented in Figure 4.

FIGURE 3: HOUSEHOLD ELECTRICITY EXPENDITURE AND INCOME ACROSS HOUSEHOLD LOCATION

From Figure 4, the urban household with less or more female members evidently spend more on energy than their rural counterpart. Evidently, in the rural location, more female connotes lower spending on household energy expenditure: there is a declining relationship between these two indicators. However, for the urban location, a gallop trend is experienced: at lower numbers of female household members, the energy expenditure increases, but consistently decreases as the number of female household member exceeds the 50th percentile (i.e. more than 4 female in the household). A possible explanation is that as the number of female household member increases, there tend to be an optimisation of energy usage such that less expenditure is directed at energy expenditure. Therefore, policies that affect energy prices will hurt urban households with females than their rural counterparts and these findings should be carefully considered when energy related policies are made.

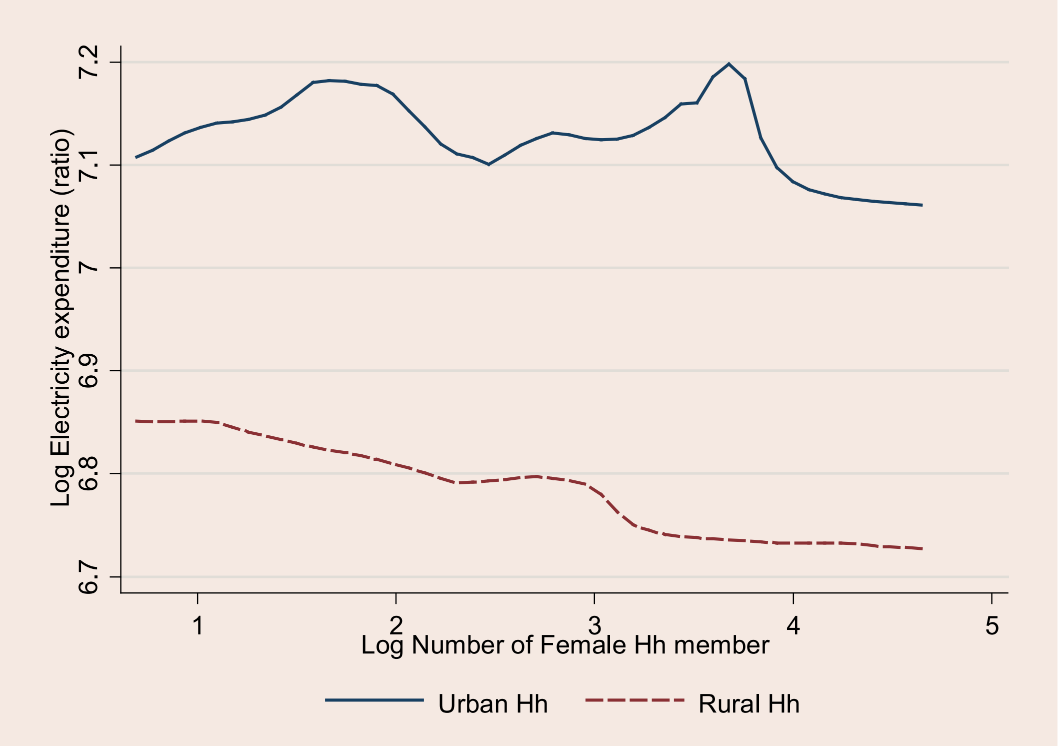

FIGURE 4: HOUSEHOLD ELECTRICITY EXPENDITURE AND NUMBER OF FEMALE HOUSEHOLD MEMBER

We go further to consider the relationship between income and energy expenditure by considering some heterogeneities that may exist among female household-head characteristics. Three heterogeneous characteristics of female-household heads are considered: the first is female heads with more education, older female heads and female heads with smaller building type. These three heterogeneities are considered because of their potential in influencing the rate at which energy expenditure is determined across the household heads. For instance, studies (e.g. Kristiansen, 2012; Sovacool, 2014; Elnakat, Gomez and Booth, 2016) have confirmed that more educated women, and building size and who are older are expected to consume less energy, depending on their income. We examined this prediction for Nigeria using the non-parametric regression and for its merit. The results are presented in Figure 5, 6 and 7.

In Figure 5 we present the regression graph between income and energy expenditure of female-headed household, while considering their level of educational attainment. The educational attainments of the individuals were classified into two groups: those with educational attainment below the secondary school level and those with educational attainment beyond secondary school level (e.g. University, college of education and post graduate). The regression line was then plotted to display the interaction between income and energy across these two groups of female-headed households. Evidently, for the female-headed household with lower educational attainment, a positive relationship is seen between income and energy expenditure. This is unlike the female-headed households with higher educational attainment, where we see a negative relationship. As the latter households earn more, their desire to conserve energy increases and they will rather channel their income to other expenditures than on energy expenditure. More so, these households are better efficient in managing energy with income growth, unlike those with lower educational attainment. This result supports predictions by Grossman (1972), and Elnakat, Gomez and Booth (2016) that educational attainment increases the ability of being increasingly sensitive to electricity usage.

An interesting policy issue from this presentation is that an energy policy that will increase the price of electricity tariff in Nigeria will have a stronger impact on lower income Female-headed households with higher education and on higher income Female-headed households with lower education. The incomes of these two categories of households tend to have a higher proportion spent on electricity. Most likely, the lower income educated female-headed households may not have sufficient income to purchase energy efficient appliances; as their income improves, it is evident that they will spend less on electricity. This is unlike the high income low educated Female-heads; they may tend to be more vagarious on electricity expenditure as their income increases.

FIGURE 5: INCOME AND ENERGY EXPENDITURE ACROSS THE EDUCATION ATTAINMENT OF FEMALE HH

A second heterogeneity of interest is the age of the female headed-household. This variable was categorised into two groups: the first was the younger women and the second was the older women. These classifications are based on the African Union Charter in 2012 and the Nigerian National Youth Policy in 2009definition of youths as individuals within the age bracket of 18-35 years of age; this implies that adults are defined as those individuals that are older than 35 years of age. With this classification, the regression line was drawn to see the relationship between income and energy expenditure across these two categories of female-headed households. We found both a positive relationship between income and energy expenditure across the households. Higher income younger and older female-headed households both spend more on energy expenditure: however, higher income and older female-headed households tend to spend more than the higher income and younger female-headed households. This trend supports the rhetoric that the former households may have more needs for energy expenditure than their younger counterpart. For instance, the need for heating, more appliances that consume energy and other energy needs that comes with age of the individuals are expected to explain the positive trend.

FIGURE 6: INCOME AND ENERGY EXPENDITURE ACROSS THE AGE OF FEMALE HH

Moving unto the building type of the female, we considered building type that are constructed with smooth cement, woods and even tiles. These types of construction provide an insight on the modern state of the building. This is unlike buildings that are constructed with sand, dirt and straw, and smoothed mud. About 69 percent of the sample size is living in buildings that we classified as modern, while 31 percent are living in buildings that are constructed with sand, straws and smoothed mud. The regression line in Figure 7 suggest that though a positive relationship is observed between income and energy expenditure across the building types of the female-headed households, those with modern buildings tend to spend less on energy expenditure than those with none modern types of buildings. One important point to note from this trend is that the building type matter for female-headed households: it is likely that modern types of buildings are more efficient energy users than their counterpart. Thus, explaining the reasons for a lower spending on energy despite that they have similar income with female-headed households in buildings that are not termed "modern".

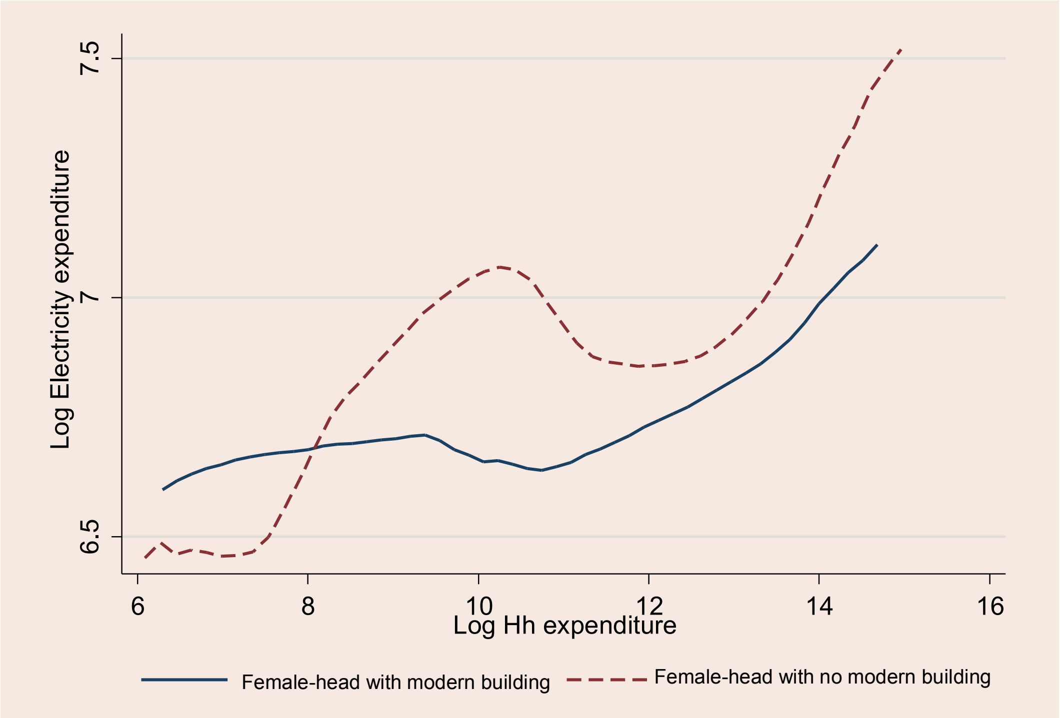

FIGURE 7: INCOME AND ENERGY EXPENDITURE ACROSS THE TYPE OF BUILDING OF THE FEMALE HH

As a summary of the non-parametric regression, some important points to note include the following. First, higher income female-headed households spend more on energy expenditure; however, they spend less than their male counterparts. Second, it is important to consider different heterogeneities that may exist across the female-headed households. These heterogeneities include the location of the household, the age and education attainment of the household head, and the type of building of the household. These variables are important explainer of the relationship that exists between income and energy expenditure. However, we go further to provide econometric estimations of the determinant of energy expenditure across different income quintiles taking into consideration the gender dimensions.

Parametric Regression Estimate

The parametric regression is conducted to estimate the relationship of interest based on quantile distributions in order to effectively understand the factors that determine energy expenditure at different income groups. As earlier stated, the quantile regression approach is applied in the econometric estimations to model the quintiles of the conditional distribution of the linear functions of the explanatory variables. It is also more efficient than the traditional Ordinary Least Square regression, especially with a presence of outliers and when the distribution of the dependent variable is a highly non-normal pattern (Okada and Samreth, 2012).

We see from Table 5.1 that the income of the household is an important determinant of household energy expenditure across the different quantile of household energy expenditure. This implies that the extent to which individual households consume energy is significantly and positively explained by their income. A further examination of the result shows that the there is a somewhat concave relationship between income and household energy. The coefficient between income and energy expenditure increases up to a certain point, and then begin to decrease with additional household energy expenditure.

We move on to some other household characteristics like the presence of both household heads, average age of the household, household location, average household size, household type, number of assets owned by the household, and the household connectivity to main electricity supply in the household community. It is evident from Table 5.1 that households with the presence of both household head, and the average size of the household have a negative and significant effect on the energy expenditure across energy expenditure quantile. This is apart from the household size that records a significant and negative relationship for only those groups of household in the 75th and 90th quantile of energy expenditure. Evidently, the presence of both the male and female household head has a negative relationship on the amount of money that are spent on energy expenditure across the different quantile. A close observation of the coefficient in Table 5.1 shows that this influence reduces with additional energy expenditure. Thus suggesting that the relationship between the presence of both household heads and energy expenditure is experiencing a positive decline with additional money spent on energy expenditure. For the average household size, the influence on energy expenditure is only significant at higher energy expenditure quantile.

The average age of the household is positive and significantly explaining household energy expenditure at the middle and lower quantile of energy expenditure. For households at the top energy expenditure quantile, there is no significant influence from the average age of the household. Thus, households that consume more energy do not take the age of its members into consideration in making such decisions. We found a positive and significant relationship between the household location, household type and the number of assets owned by the household, and the household energy expenditure across the different quantile of household energy expenditure. The results in Table 5.1 shows that households in urban areas are spend more on energy expenditure across the different quantile. Similarly, households that are living in larger houses and who have more assets spend more on energy expenditure across the different quantile. From the result we see that the effect of household location, household type, and the number of household asset does not considerably differ across different energy expenditure quantile.

TABLE 5.1: QUANTILE REGRESSION ON THE DETERMINANT OF ENERGY EXPENDITURE ACROSS HOUSEHOLDS

	OLS	Q(0.10)	Q(0.25)	Q(0.50)	Q(0.75)	Q(0.90)
Income	0.147*** (0.000)	0.121*** (0.000)	0.143*** (0.000)	0.189*** (0.000)	0.132*** (0.000)	0.086*** (0.000)
Head	-0.509*** (0.001)	-0.669** (0.018)	-0.567*** (0.000)	-0.521*** (0.007)	-0.428** (0.036)	0.227*** (0.000)
Hh_age	0.005** (0.012)	0.007* (0.090)	0.007*** (0.008)	0.006** (0.022)	0.004 (0.208)	-0.002 (0.596)
Hhead_education	0.023 (0.911)	-0.435 (0.182)	-0.213 (0.336)	-0.130 (0.556)	0.305 (0.194)	0.259 (0.306)
Share_fem	0.065 (0.510)	0.115 (0.525)	0.103 (0.403)	0.119 (0.330)	0.103 (0.428)	0.141 (0.317)
Female_head	-0.074 (0.220)	-0.118 (0.275)	-0.112 (0.127)	-0.143** (0.050)	-0.006 (0.940)	-0.014 (0.867)
Hh_location	0.269*** (0.000)	0.190*** (0.010)	0.268*** (0.000)	0.286*** (0.000)	0.237*** (0.000)	0.227*** (0.000)
Hh_size	-0.017 (0.150)	-0.007 (0.723)	-0.004 (0.789)	-0.022 (0.114)	-0.037** (0.013)	-0.032*** (0.000)

	OLS	Q(0.10)	Q(0.25)	Q(0.50)	Q(0.75)	Q(0.90)
Hh_Adult	-0.015 (0.320)	-0.025 (0.370)	-0.012 (0.547)	-0.024 (0.213)	0.005 (0.814)	0.018 (0.426)
Hh_type	0.060*** (0.000)	0.028 (0.119)	0.047*** (0.000)	0.084*** (0.000)	0.072*** (0.000)	0.064*** (0.000)
Hh_assets	0.012*** (0.003)	0.011*** (0.003)	0.011*** (0.000)	0.015*** (0.000)	0.019*** (0.000)	0.018*** (0.000)
Electricity_access	0.001* (0.070)	-0.002* (0.100)	0.001** (0.054)	0.002*** (0.004)	0.001 (0.500)	0.001 (0.936)
Constant	5.484*** (0.000)	4.907*** (0.000)	4.926*** (0.000)	5.109*** (0.000)	6.038*** (0.000)	6.806*** (0.000)

Note: Probability value in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6. Conclusion

In this study, we explored the determinants of energy expenditure in Nigeria, taking into consideration the different energy expenditure thresholds. We used survey data from the World Bank's Living Standards Measurement Study (LSMS) - Integrated Household Survey 2012-2013 post -harvest survey. The LSMS dataset contains a rich data of households across the different states of Nigeria. Both the parametric and non-parametric regression estimation techniques are applied in reaching our results and conclusions.

A summary of the result from the non-parametric regression include that the positive relationship between energy expenditure and income is very visible for households within the 0 to 50th income percentile and those at 75th to 95th income percentile. However, for the middle income households (i.e. >50th and <75th income percentile) and the extreme rich (i.e. households with income percentile that is higher than 95th percentile), a declining energy expenditure is seen with additional income. The result also include that there are some evidences of gender differences in the relationship between income and energy expenditure across households. Apart for the very poor households, female-headed households seem to spend less on energy than their male counterparts with similar total household income. We also found that urban household with less or more female members evidently spend more on energy than their rural counterpart. However, for the urban location, a gallop trend is experienced such that at lower numbers of female household members, the energy expenditure increases, but consistently decreases as the number of female household member exceeds the 50th percentile (i.e. more than 4 female in the household).

The results also show that for the female-headed household with lower educational attainment, a positive relationship is seen between income and energy expenditures. This is unlike the female-headed households with higher educational attainment, where we see a negative relationship. We also found that the pattern of relationship between income and energy expenditure varies across households depending on the age of the household head, and the household's building type.
One important limitation of this study is that we did not distinguish the energy spending across other sources of energy. This could not be implemented in this study because of data limitations. Probably, this should be taken up in future studies, where the variable that considers household expenditures on other sources of energy are complete. In the current dataset we used, this variable was not complete and it was difficult to use this variable in our current estimations.

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Energy Efficiency in Burkina Faso: An Analysis of the Determinants of Enterprises' Acceptance[1]

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Abstract

Energy is an essential component for economic and social development. This study attempts to elucidate the determining factors of the adoption by Burkinabe Small and Medium-sized Enterprises (SMEs) of measures of energy efficiency. Using data from the Electricity Consumption Survey on the SMEs 2015 of the Chamber of Commerce and Industry of Burkina Faso, the study is based on a combination of descriptive analysis methods and econometric analysis to identify the determinants of the adoption of energy efficiency measures. The findings indicate that the costs of searching for information, lack of knowledge of appropriate equipment suppliers and lack of knowledge about energy efficiency measures are major obstacles to the adoption of energy efficiency measures. Also, the age of the enterprise, its location and size significantly influence the decision to adopt energy efficiency measures.

KEYWORDS: ENERGY EFFICIENCY; ADOPTION DECISION; ENTERPRISE; PROBIT; BURKINA FASO

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1. Introduction

The access to energy has become a major concern of the development issue in modern economies. Marginalized for a long time in the production process, the issue of energy integration in analytic models of production based on the combination of three classic factors (labor, capital and land) began to be raised in the industrial revolution context at the end of the18th century. This inclusion of energy in the production activity depends on production increases allowed by the implementation of machines using energies from various sources. The industrial development, the increase of the motorized transport fleet and the multiplication of domestic appliances essential for Human life led to an important growth in energy needs. As matter of fact, energy has become an essential component of economic and social development. It is then used sometimes as final consumer good (light, cooking, heating, air conditioning…) sometimes as a production or intermediate consumption factor. The importance of energy in the economic activity sticks particularly to this last use.

Thus, the availability of this factor has become the Gordian knot of performance of every production system and a major challenge of the economic and social development issue, notably in developing countries. At the macroeconomic level, for instance, it is widely admitted that the Gross Domestic Product (GDP) per capita of the country is strongly correlated to its energy consumption per capita (Shiu and Lam, 2004; Altinay and Karagol, 2005 ; Narayan and Singh, 2007 ; Akinlo, 2009 ; Yoo and Kwak, 2010 ; Ouédraogo, 2010). Other analyses establish a close link between the human development indicator and the national electricity consumption (UNDP, 2008).

In this sense, the issue of energy supply has become a major concern in developing countries. In fact, most of these countries experience an important and often structural gap between energy supply and demand, notably of electricity by recurrent power outage[2] affecting the business of enterprises[3] (Scott et al. 2014, Frederick and Selase 2014, World Bank 2014).

A survey carried out by Databank Ghana estimates at about 1.4 billion the shortfall for the Ghanaian economy caused by the energy crisis impact on the manufacturing industry, informal services and sector in which Small and Medium-sized Enterprises (SMEs) play a very important role (Frederick et Selase 2014).

In developing countries, SMEs represent a significant part of the production system. They play a key role in valuing local resources, the employment and revenue creation as well as the availability of essential services to populations. The contribution of these enterprises to the Gross Domestic Product and to employment has been evaluated at respectively 60% and 70% in developing countries versus 55% and 60% in developed countries. These figures are established to 70% and 95% in transition economies (Ayyagari et al. 2003), showing thus the crucial role of SMEs in the transformation phase of developing economies. The experience of countries such as China, South Korea, and Taiwan is remarkable in this regard (Horn, 1995; Pang, 2008; Naudé, 2013; Motilewa et al., 2015).

Despite their commonly known importance, SMEs in developing countries are facing difficulties to fully play their role, in so far as they suffer more acutely from energy crisis. A World Bank research indicates that in Sub Saharan African countries, SMEs identify the access to energy as the main constraint that hinders their activities (World Bank, 2014). Nearly half (49.3%) of the enterprises of the region consider the electricity access issue as their major constraint. This proportion is by far

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[2] It comes out of a Word Bank research (2004) that southern Sahara enterprises face on average 8 power outages (versus a global average of 6.3) per month for an average duration of 4.6 hours (versus a global average of 2.8 hours).

[3] These power outages cause losses and various costs for enterprises. In Burkina Faso, Cote d'Ivoire, Niger, and Togo, the losses undergone are evaluated at 3.2%; 2.6%; 1.1%; and 6.1% of the turnover of enterprises.

higher than the global average (34.1%) and then those of the economic regions such as East Europe and Central Asia (17.9%), and East Asia and the Pacific (22.6%).

Burkina Faso, like most of the developing countries, has been, for some years, facing energy supply deficits of its economy and is seeking strategies aiming to reduce the impacts of these deficits on its economic competitiveness. The promotion of energy efficiency measures aiming to rationalize the consumption of this resource is one of the measures undertaken in this regard.

As a landlocked country without real potential concerning hydroelectric production, Burkina Faso is facing more acutely energy issues. So, the country experiences significant energy deficits and this despite interconnection agreements established with some neighboring countries, namely Côte d'Ivoire and Ghana which allowed the importation of 661 GWh in 2012 and 532 GWh in 2013 (or respectively 42.16% and 57.98% of the total amount of distributed electricity). From 2011 to 2015, the country accounted for an average deficit of 25 GWh per year and power deficits reaching 110 MW (ARSE). This situation is particularly critical during periods of strong demand in which the deficit may often reach 50 GWh (Ouédraogo et al, 2015).

To this insufficient energy supply is added the high cost of the kWh provided by the network. 17.68% of privileged people in Burkina Faso who had access to electricity in 2014 (International Energy Agency, 2016) faced the highest electricity tariffs around the world. Indeed, Burkina Faso has been identified by the Union of Producers, Transporters and Distributors of Electric Power in Africa (UPDEA) as the second country with the highest kWh cost in West Africa (ARSE 2014); and remains then the region with the highest kWh cost around the world.

These statistics which overall feature an unsatisfactory energy situation, notably electric power, set against the ambitions expressed by the country in its National Economic and Social Development Plan (PNDES), the governmental benchmark in economic and social policy by 2020. In this paper, energy policy is exclusively dedicated to the development of electricity which goes through "the guarantee of access to quality energy services and energy efficiency" (PNDES, 2016-2020). However, this objective is far from being achieved according to existing statistics. Also, in the institutional and regulatory field, the country has undertaken these recent years many reforms of which the most important are the creation of the National Agency for Renewable Energies and Energy Efficiency (ANEREE) and the adoption by the parliament of a new law regulating the energy sector which is very enabling for private sector development.

To contribute to solving the competitiveness issue of enterprises, energy efficiency measures are encouraged in various levels notably at the level of enterprises but, the observation in the field is that the enterprises seldom adopt these measures. This leads us to the following question: what are the determinants of the adoption by enterprises of energy efficiency behaviors?

The main objective of this research is to elucidate the determinants of the adoption of energy efficiency measures by SMEs in Burkina Faso. The ultimate aim is to elaborate recommendations likely to serve public decision makers and namely a body like the Chamber of Commerce in their aim of optimizing energy consumption to reduce the energy gap in Burkina Faso. More specifically, the purpose will be to undertake a diagnosis of energy consumption behaviors by enterprises in Burkina Faso and an identification of internal and external factors within enterprises that justify the adoption of energy efficiency measures.

This research aims to be empirical and adopts a methodology based on a substantial data collection work in the enterprises. Indeed, the research uses the data of the survey on electricity consumption in SMIs/SMEs conducted by the Chamber of Commerce and Industry of Burkina Faso in 2015. The survey covers 315 enterprises of Ouagadougou and Bobo-Dioulasso cities. Besides, the research uses a combination of descriptive analysis methods and econometric analysis based on a Probit model. The rest of the paper is divided into several sections. The first section deals with a detailed literary review on the issue of the adoption of energy efficiency measures. The second section deals with the methodology used. The third section presents the results. And the fourth section concludes the paper while pointing out economic policy recommendations.

2. Literature Review

The economic literature locates the energy efficiency issue in the core of energy policies and wonders on the necessity of such policies in a context of liberal economies where the search for efficiency is inherent to the production system in all its components. In this regard, Giraudet (2011) questions the necessity or utility of the energy efficiency measures promotion through energy policies in so far as the good functioning of the market mechanisms allows ensuring this efficiency.

According to this author, it is undoubtedly the most delicate issue in a context in which the prices of the global oil market are low and the competition stimulus seems sufficient to ensure efficiency and equity according to the classic principles of market economy. Such an analysis of the author is based on the understanding of the energy policy as “the overall objectives agreed by public powers to ensure the country’s energy supply in best cost and security conditions, and regulatory and incentive means established to achieve these objectives; objectives and means being coordinated in respect with priority choices set by the collectivity and under the limitation of existing physical, environmental, economic constraints”. This section presents first the definition of the concept of energy efficiency and other related concepts. Then, theoretical and empirical bases are presented in the light of various approaches combining thoughts in matters of industrial economy and also public economy.

2.1. Definition of Concepts: Energy Efficiency Concept and Related Concepts

Energy efficiency is a characteristic feature of energy usage goods. Lovins (2004) defines it as the ratio between the produced energy services and the amount of energy used or the conversion efficiency of final energy to useful energy. In the investment decision, various options of efficiency are competing, the investor having to choose between the less and more efficient options. The more the option is efficient, the more it reduces the final energy consumption for a given energy service. In case of energy usage of domestic goods, the more efficient option is generally the more expensive. Also, the option of energy usage goods can equally be oriented toward an absolute diminution of energy consumption: reduction of lighting duration, moderation of the heating temperature, etc. For many authors (Salomon et al., 2005; Alcott, 2008; Herring, 2009), the concept of energy sobriety (or energy saving) is frequently used to qualify this type of behavior.

According to Giraudet (2011), energy efficiency and sobriety corresponds to a particular orientation of investment behaviors and the use of energy usage goods. The author illustrates this idea by an isoquant curve (See Figure 1) that gathers overall trade-offs between energy consumption and the consumption of an aggregated efficient good that produces the same energy service. In this Figure, efficiency corresponds to a movement along the isoquant, which replaces energy consumption by a higher consumption of efficient good, while sobriety corresponds to a movement of the isoquant to the other towards a lower energy consumption, to a consumption of constant efficient good.

The third concept is that of energy control. This concept designates the joint search for energy efficiency and sobriety in the aim of maximizing energy savings relatively to a reference situation.

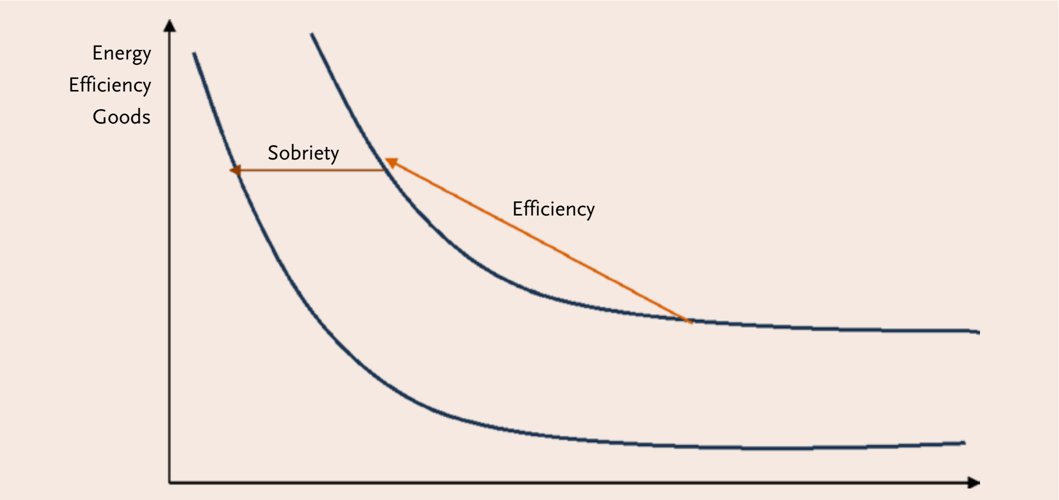

FIGURE 1: ENERGY EFFICIENCY AND SOBRIETY

Source: Giraudet (2011)

2.2. Theoretical Approaches

On the theoretical plan, energy efficiency measures have been analyzed sometimes through the perspective of adopting innovations in the tradition of the same theoretical approaches used in the agricultural sector, in Information and Communication Technologies (ICT) and others technologies or measures, sometimes that of market failures.

2.2.1. Energy efficiency measures under the perspective of innovations to be adopted

Among economic theories of acceptance and appropriation of new technologies, that one related to the TAM (Technology Acceptance Model) is unquestionably a fundamental reference (Brangier et al., 2009). Overall, the TAM suggests the acceptance and appropriation of a technology by users depends on two factors: the perceived utility (meet the population needs in terms of efficiency and effectiveness), and the perceived user-friendliness (technically non-complex for its appropriation and replication).

More precisely, the TAM establishes generally that the only perceptions users have of these two criteria determine the intentions influencing their use and appropriation behaviors and consequently their adoption.

From the TAM, others approaches tried to explain the success of appropriation of a technology mentioning that, rather than being limited to one's usage and usability perceptions, the users seek first to maximize their satisfaction. This quest of the user's satisfaction (User Satisfaction Theory) is herein found as a determining factor of appropriation and usage (Information Success Model de DeLone and Ephraim, 1992). According to Doll and Torkzadeh (1988), the satisfaction measures have been apprehended following two classes of criteria, namely the quality of the system (coherence, efficiency, maintainability) and the quality of training-information (relevance, adequacy, non-complexity, robustness of the system). Olson (1978) in the appropriation strategy teaches that, for the actor to engage an appropriation process and even adoption of technological and/or social innovation, he must perceive benefits of immediate and tangible gains related to this innovation.

In addition to these theories, that of the confirmation of expectations developed by Oliver (1981) explains the adoption of an innovation by an individual as well as its retention by a logical reasoning based on the expectations of the latter. First, the individual builds prior expectations to the usage or adoption of the innovation. Then, he experiences the adopted innovation and notices the reality. From the comparison of his expectations and the usage experience, the individual expresses a certain level of satisfaction which will finally determine his definitive behavior toward the innovation in question. The model known as confirmation of expectations consists then of a comparative evaluation of the quality of the expected service to the final benefit obtained by usage. Satisfaction is then well planned as the result of the positive evaluation of an interaction experience; even if some social determinants are far from being neglected.

2.2.2. Energy Efficiency: Energy Paradox and Market Failure

Giraudet (2011) uses the industrial economy tools and institutional economy theories to analyze the adoption or not of measures by economic actors of energy efficiency. So, he builds on the concept of "energy paradox" developed by Jaffe and Stavins (1994).

There is energy paradox, according to these authors, by the fact that if we rely on usual criteria of economic calculation, many investments in energy efficiency are profitable, yet real investments decisions do not follow the results of these elementary calculations. So, even if they seem profitable relatively to usual criteria of economic calculation, under-investment in some equipment of "rationalization" of energy consumption is frequent. Similarly, some "renewal" investments are not realized beyond the natural pace of declassification. This affects the energy efficiency of the overall system due to equipment deterioration.

As Huntington et al. explain (1994), this energy paradox is explained by market failures of energy efficiency, notably failures related to the information issue in these markets. In case these problems take various forms, the grids used to analyze them are rarely homogeneous and mobilize various concepts from the public goods theory (non-rival and non-exclusion information character) and the theory of agency (principal-agent problems, moral hazard, and anti-selection). Gillingham et al. (2009) retain, in their analysis, three concepts related to information failures that affect the decision of adoption of energy efficiency measures. It is about imperfect information concept, information asymmetry and positive externalities of adoption.

The concept of imperfect information in the analysis of Gillingham et al. (2009) is related to the fact that users, or energy-use equipment salesmen, are not aware of the benefits provided by energy efficiency, which is not perceived as an aspect valuing energy usage goods. The information on energy efficiency appears as a public good, systematically sub-produced by the market. This does not favor a greater adoption of energy efficiency measures.

The concept of information asymmetry in this analysis reflects the fact that characteristics of energy usage goods are not known before. Indeed, while energy can be characterized as a "search good" whose characteristics are known with certainty before purchasing, energy usage goods are considered as "credence goods" whose characteristics are not totally revealed during usage (Sorrell, 2004; Quirion, 2004).

It is the case, for example, of electric appliances that do not have an individual electric meter and of which it is difficult to know exactly the actual consumption level, or the quality. Accordingly, the consumer appears more reticent to spend high amounts of money for energy usage goods than for energy. This characteristic of "credence good" generates anti-selection problems, a situation in which salesmen of energy usage goods are not able to transfer the overall information to the purchaser. For instance, when the isolation works are achieved when building a house, their cost is still rarely impacted in the resale price of the house. Energy efficiency investments are often discouraged by the inability for the funder to reap the benefits.

Finally, the concept of positive externalities of adoption reflects, in this analysis, the fact that the information provided by the first users of a technology or an innovation is decisive for the global level of adoption of that technology/innovation. Indeed, “early adopters” of a new technology make known its performances to other potential adopters, inducing to imitation phenomena. The economic and sociological literature uses various concepts to designate this phenomenon. Thus, one distinguishes the concepts of learning-by-using (Jaffe et al., 2004; Gillingham et al., 2009), of neighbor effect (Mau et al., 2008; Axsen et al., 2009), of social contagion (Mahapatra and Gustavsson, 2008) or social learning (Darby, 2006).

According to Giraudet (2011), there are in the energy efficiency market failures traditionally related to innovation such as under-investment in research and development and positive externalities related to the learning at the technology supply side (learning-by-doing). The learning phenomenon is expressed by a decrease of the technologies cost with the increase of knowledge, generally approximated by accumulated production (Arrow, 1962; Wing, 2006; Gillingham et al., 2008).

Some energy efficiency markets are characterized by an imperfect competition structure. When the energy usage goods supply is segmented according to efficiency range, manufacturers with market power have the opportunity to discriminate consumers through prices and increase their margin on high end, which corresponds generally, in the residential and tertiary sector, to the most efficient options (Quirion, 2004). Financial constraints are a last type of failure for energy efficiency markets (Gillingham et al., 2009).

2.2.3. Some Empirical Analysis on the Adoption of Energy Efficiency Measures

Several studiess (Henry, 1974; Metcalf and Hassett, 1999; Timilsina et al., 2016; Liu, 2014; Trianni et al., 2013; Costa-Campi, 2015, etc.) attempted to analyze the energy efficiency gaps of enterprises. In fact, barriers that are not market failures, described herein as gaps in disseminating efficient technologies such as the uncertainty that surrounds, both, future energy prices and future technology costs on one hand, the irreversible character of the majority of energy efficiency investments, on the other, create an incentive to delay investment, generally qualified as option value (Henry, 1974). Similarly, some hidden costs inherent to normal operation of markets are not taken into account in the most elementary profit calculations, but “absorbed” by the implied discount rate of which they contribute to increase the value. These costs correspond to the research efforts of a product in the market, to the disturbance caused by the installation of internal equipment (particularly important in the case of isolation works), or to the loss of utility on some equipment features other than energy efficiency (ex: change of color for energy-saving bulbs compared to incandescent bulbs). It may happen that the actual efficiency of equipment does not match engineers' projections (Metcalf et Hassett, 1999), even if the sense of this bias does not seem systematic.

Timilsina et al. (2016), in a research on commercial and industrial firms in Ukraine, distinguish five barriers in the energy efficiency adoption: finance and economic barriers, information barriers, technical barriers, institutional barriers, barriers related to the lack of incentives. They use essentially a cross-sectional data analysis and a principal component analysis. They found that financial and economic barriers as well as institutional barriers play major role in Ukrainian firms' energy constraints. The economic and financial reasoning can be seen as a vicious circle of the access to energy. In fact, bad economic conditions cause an inefficient adoption of energy technology, involving in turn an unfavorable economic situation.

Liu (2014) reaches the same conclusion in a case study of 98 firms in China. He finds out that financial incentive constraints are the most important among all other barriers faced by those firms. However, other studies (Trianni et al.; 2013, Kostka et al.; 2013, Rohdin and Thollander; 2006) show that information barriers are the most important for enterprises. The lack of information and imperfect information increase the opportunity cost related to energy efficiency (Trianni and Cagno, 2012).

The study of Mattes et al. (2014) shows that the nature of goods produced by firms is an indicator of the adoption of the energy technology. Using the multiple logistic regressions, these authors, in a study on manufacturing industries in Germany, indicate that enterprises producing final consumer goods adopt the renewable energy technology compared to other manufacturing industries.

Another important aspect in the explanation of the energy choice is the size of the firms. With a logit model, Costa-Campi (2015) in a study carried out in Spain shows that the size of firms is an important indicator in the energy efficiency adoption. The same result was found in the works of Trianni et al. (2013) who use a semi-structured method of interviews and questionnaires in 20 manufacturing firms. Indeed, small-sized firms have many more difficulties or enough constraints to adopt energy efficiency measures because of organizational problems. Big-sized firms are often much more organized and are prone to adopt energy efficiency techniques. This could also be explained by economies of scale in the sense that big-sized firms withstand much more economic and financial barriers. However, Mattes et al. (2014) show, in their study, that the size of firm does not justify significantly the energy choice.

Cultural, social and political considerations can also justify the non-adoption of some energy techniques (Urmee and Md, 2016). Cultural and social beliefs influence strongly individuals' habits particularly in rural areas. Indeed, energy policies that do not take into account these dimensions are doomed to fail. Participatory approaches in elaborating and implementing these policies are therefore to be encouraged. Studies (Schleich, 2009; Sardianou, 2008) show that the energy efficiency adoption is determined by the perception of firms on the energy efficiency adoption as a priority or not for the firms. This perception could be explained by informal barriers concerning benefits related to energy technologies (Timilsina, 2016).

Figure 2 gives the synthesis of gaps related to the adoption of energy efficiency measures made by Jaffe et al. (2004) and Sorell (2004).

Despite this vast literature, the lack of research on energy efficiency is observed in the case of Burkina Faso to the best of our knowledge.

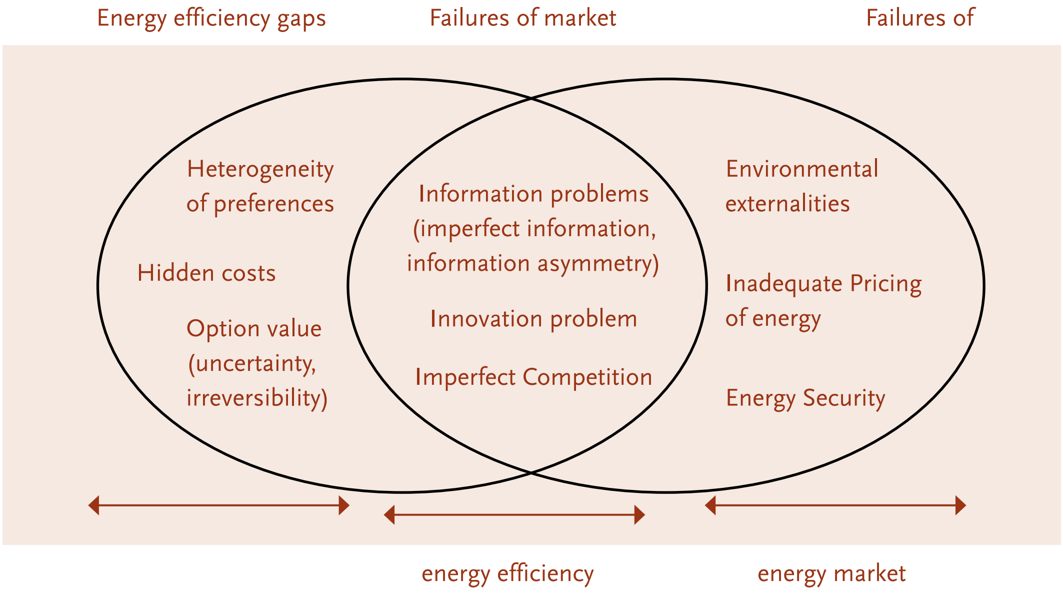

FIGURE 2: SYNTHESIS OF ENERGY EFFICIENCY ADOPTION GAPS

Source: Different Types of Barriers and Failures According to Sorell (2004), Jaffe et al. (2004)

3. Methodology of the Survey

The methodology used in this study is a combination of descriptive analysis and econometric analysis. These analyses are based on a database on electricity consumption collected on a SMIs/SMEs sample of Ouagadougou and Bobo-Dioulasso cities. This part presents in details the different stages of the methodology as well as the description of the different tools and approaches used.

3.1. Survey Methodology

The basis of the survey was composed of SMEs/SMIs of the National File of Enterprises and Groups of Enterprises (NERE File) performing activities identified as relevant for the addressed topic. It deals with enterprises whose production implementation requires the availability of electric energy. For that, firms performing the main following activities were selected: Hotel and catering, private education, fuel distribution (Stations-services), medical care services (private hospitals and private health centers), supermarkets, pharmaceutical product sales (pharmacies), edible oil production, butchery/sausage/fish-mongering, cereal processing, water conditioning, production, milk processing. These sectors concentrate the greater population of SMEs/SMIs in Burkina Faso where the activities depend strongly on electric energy.

Data were collected by the technical services of the Chamber of Commerce and Industry through the Prospective and Economic Intelligence Unit whose main actors are part of this study. This operation carried out in 2015 helped to make available a database that provides information about behaviors concerning consumption and energy efficiency of SMEs/SMIs in Burkina Faso. This collection concerned essentially SMIs/SMEs of Ouagadougou and Bobo-Dioulasso, which concentrate the bigger parts of SMEs in Burkina Faso. The collection was effected on a sample of 315 SMEs following the stratified sample survey method. The strata being professional sub-categories (main activity performed) selected as part of the survey. This stratification imposed itself because the purpose of the survey was to have specific information about electric energy consumption in the firms performing the aforementioned activities.

3.2. Analysis Methods

Two (02) types of analysis were conducted. A descriptive analysis using the descriptive statistics methods helped, on the one hand, to characterize the consumption and management behaviors of the energy issue, and on the other hand, to identify the first trends of the weight of the different factors of adoption of energy efficiency measures. The Probit method helped to deepen the analysis and to clearly identify the main determinants of adoption of energy efficiency measures.

3.2.1. The Model

To determine explanatory factors of the adoption of energy efficiency measures, a Probit model was used. Indeed, the variable measuring the energy efficiency measure is a binary variable that take the 0 and 1 value. Yet, one of the most adapted models when the dependent variable is binary is the Probit model (Greene, 2002)

$$Y_i = \begin{cases} 1 \text{ if the individual } i \text{ adopts the energy efficiency measure with probability } p \\ 0 \text{ if not; with probality } 1\text{-}p \end{cases}$$

Or $X_i = (X_{i1}, X_{i2}, \ldots, X_{ik})$ a matrix of explanatory variables and β a $Kx1$ parameter vector.

So, $p_i \equiv \Pr(Y_i = 1|X) = F(X_i'\beta)$ where

$F(X_i'\beta) = \Phi(X_i'\beta) = \int_{-\infty}^{X_i'\beta} \varphi(z)dz$ with.

$$\varphi(z) = \left(\frac{1}{\sqrt{2\pi}}\right) \exp\left(\frac{-z^2}{2}\right)$$

Marginal effects are given by $\frac{\partial p_i}{\partial x_{ij}} = \varphi(X_i'\beta)\beta_j$. The estimation s done through the maximum likelihood method.

3.2.2. The Analysis Variables

The variables used to estimate the Probit model result from the answers to the questions of the survey on electric energy/CCI-BF 2015.

The Dependent Variable

The variable accounting for the adoption of energy efficiency measures is a qualitative variable. The survey apprehended this variable through the behavior of firms in front of three main measures. It is first about the staff information and/or its incentive for an attitude oriented toward energy savings, then the implementation of an energy management system within the firm and finally the inclusion of energy consumption when purchasing new equipment as well as the isolation of buildings. Thus, firms are considered as having adopted energy efficiency measures relatively to these three measures when they have already implemented the measure or are implementing it. However, a firm does not adopt a given energy efficiency measure if the measure itself was not implemented yet therein or is not being implemented.

For each of these three variants, the dependent variable (energy efficiency) is then equal to 1 if the individual adopts the energy efficiency measure and 0 if not.

However, following the econometric model implementation, only the first two variants of the dependent variable appear to be relevant for the analysis of determinants of the adoption of energy efficiency measures. As a matter of fact, two specifications will characterize the econometric model and will deal with the first two measures indicated previously. Table 1 summarizes the information concerning the two dependent variables.

TABLE 1: DIFFERENT VARIANTS OF THE DEPENDENT VARIABLE

Variable name	Variants	Variable Description
Energy efficiency (Energ Eff_)	1= staff information and/or its motivation for a **Info Staff**	energy savings-oriented attitude; 0 if not
		1= implementation of energy efficiency measures management system; 0 = if not
	Energ_ Management	

The Independent Variables

The literature on the adoption of energy efficiency measures allows us to retain four groups of explanatory variables. It is about variables dealing with the characteristics of the firm, variables related to the firm area of activity, variables related to the management of the energy issue and finally variables related to energy costs. Table 2 gives the description of various independent variables retained for estimates.

TABLE 2 : INDEPENDENT VARIABLES DESCRIPTION

Variables	Description
Variables related to the enterprise's characteristics	
Age	The difference between the enterprise's creation year and the survey year (2015)
MiE_CA	Enterprise with a 2013 turnover lower than 30 million CFAF
PE CA	Enterprise with a 2013 turnover comprised between 30 million including and 150 million excluded
Location	1=Ouagadougou; 0= Bobo-Dioulasso
Variables related to the sector of activity	
Oil manufacture	1= the sector of activity concerns oil production; 0= if not
Supermarkets	1= the activity sector concerns the supermarket business; 0= if not.
Hotel_Catering	1= the activity sector concerns hotel trade/catering; 0= if not. 1= the activity sector concerns the operation of private health centers; 0=
Private_Health	if not.
Variables related to the firm's exploitation cost	
Monthly bill cost	Average monthly cost of the electricity bill
Maintenance cost_group	Annual maintenance cost of the generator
Energy Charge>20	1=Part of annual energy expenses > 20% of total expenses; 0 if not.
CM_annual_2011-2013	Average annual cost of the electricity bill on the period of 2011-2013
Variables related to the management of the energy issue	
Energ_Audit	1= Energy Audit conducted during recent three years; 0 if not.
Electricity_Production	1= produces all or part of consumed electricity; 0 if not.
Solar_ Energy	1= produces solar source electricity; 0 if not.
Electrician-Pres	1= presence of an electrician in the enterprise; 0 if not.
Bill_ Update	1= update electricity bills payment; 0 if not.
Working H Volum	Daily working hours volume in the enterprise

Source: The authors from the SMEs/SMIs 2015 survey database.

The choice of the variables is based on the "User Satisfaction Theory". This theory resulting from the acceptance and appropriation model of technology (Technology Acceptance Model) makes the satisfaction of the adopting entity in the core of the adoption decision of new technologies. Yet, according to the classic microeconomic theory, an important element affecting the satisfaction, notably the profit level, of an entity such as the enterprise remains its capacity to control its costs, some characteristics of it as well as the behavior it adopts in its environment.

4. Main Results

The detailed data analysis shows the behaviors of firms' consumption, the status of energy efficiency measures within these enterprises, as well as internal and external factors helping to influence their adoption decision of energy efficiency measures. The Probit model scores are generally indicated.

4.1. Diagnosis of Energy Consumption Behaviors by SMEs in Burkina Faso

Energy is a source of significant expenses in the operating costs of enterprises in Burkina Faso and its control is an important aspect in enterprises' competitiveness. This sub-item presents the results of the descriptive analysis related to energy consumption behaviors.

4.1.1. Electric Energy Consumption of Enterprises in Burkina Faso

In Burkina Faso, the electric energy supply is ensured by the National Electricity Enterprise of Burkina Faso (SONABEL) in the overall national territory. The survey findings show that almost all surveyed enterprises (99%) are connected to the distribution network of that enterprise. However, due to difficulties experienced by this supplier to regularly meet the electricity demand, some consumers, notably enterprises try to diversify their energy supply sources to avoid damages related to recurrent power outages. The survey finds out that only 34% of enterprises depend exclusively on the SONABEL energy supply. The major part of enterprises (66%) adds to the electricity provided by SONABEL the electricity they produce by themselves from photovoltaic installations and/or generators.

This strategy of diversification of electric energy supply sources by enterprises not only meets the needs of solving energy supply irregularity by SONABEL but also allows reducing the energy bill in the medium and long term. The survey reveals that energy expenses (SONABEL bill + purchase of fuel for generators) account for 32% of the firms, an item representing more than 20% of their operating costs, especially for enterprises of the sectors of health care, hotel and catering services, fuel distribution and supermarket exploitation.

In terms of level of consumption, it appears that supermarkets and oil manufacture sectors are the biggest energy consumers. They are followed by the hotel and catering sectors as indicated in Figure 3.

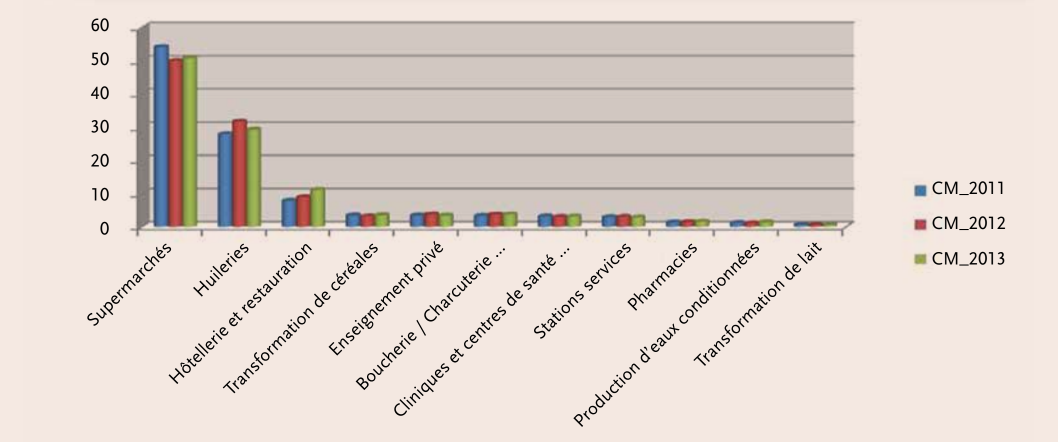

FIGURE 3: AVERAGE ANNUAL ELECTRICITY CONSUMPTION (MILLION CFAF) PER BUSINESS ACTIVITY BETWEEN 2011 AND 2013

Source: The authors, from the electric energy survey data/CCI-BF 2015.

Electric energy consumption in the sector of supermarket exploitation can be explained by the necessity of holding permanently a cold chain causing continuous functioning of refrigeration equipment. At the oil manufacture level, the situation can be explained by the equipment importance and power, notably oil presses, rather than the functioning duration. As far as the hotel sector is concerned, the high energy consumption can be explained, on the one hand, by the holding of the cold chain in restaurants and on the other, by the operation of air conditioners and electric water heaters.

4.1.2. Energy Consumption Level and Production of Goods and Services

This section aims at justifying, beyond the electric outages issue, the necessity of energy efficiency measures within enterprises in Burkina Faso, notably SMEs/SMIs. This ambition is based on a comparison of the firms' electric energy consumption evolution with that of the production of goods and services by these firms.

The survey data show that this relation is much more visible if the analysis is done regarding the size of firms in terms of turnover. In fact, it appears in the analysis that the gap between energy costs (SONABEL bill) of the firms and their turnover increase as the size of the firms increases (Figure 4). In other words, the ratio of the turnover on the amount of energy bills is remarkably higher for medium sized enterprises than for small ones.

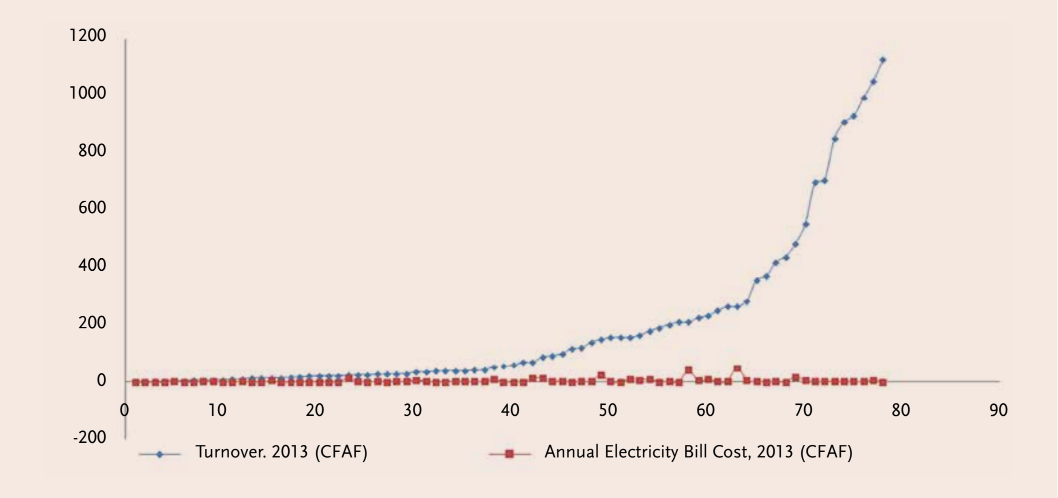

FIGURE 4: GAP BETWEEN THE 2013 TURNOVER AND THE 2013 ELECTRICITY BILL COST OF THE FIRMS ACCORDING TO THEIR SIZE (MILLION CFAF)

Source: The authors, from the electric energy survey data /CCI-BF 2015.

This explains the fact that energy expenses represent an important part of the production value in SMEs accounting for more than 1/3 of the firms of our sample. Smaller-sized enterprises seem to be better controlling their energy consumption than SMEs/SMIs according to this result. For these firms, the recourse to energy efficiency measures is as a solution to be encouraged.

4.1.3. Energy Issue Management within Firms.

The general observation resulting from the analysis of the survey scores is the weakness in professionally managing energy within the interviewed enterprises. Indeed, only 6% among them performed an energy audit during the last three years. Furthermore, less than 30% have an electrician in the staff employed and electricity bills management rest generally with the accountant (33% of the firms) or the manager himself (57%).

One also notices the poor interest of firms for a control of the billing method of their electricity consumption by SONABEL. In fact, less than 20% of the firms know SONABEL's billing method. The survey focused on the various kWh consumptions of firms and on the power of used devices. It appears that very few firms answered these questions, denoting thus a disinterest for these issues or an ignorance of internal consumptions and the linkage with the electricity bill.

However, faced with the electric energy supply issue, a great number of firms use energy efficient equipment. This equipment refers to energy saving bulbs (neon lamps without starter), TV sets, refrigerators, freezers, medical devices and computers. Refrigerating fluids (Freon gas), used in the cold producing equipment participate also in implementing energy efficiency and the global warming phenomenon.

4.2. Status of Energy Efficiency Measures in Burkina Faso's Enterprises

Within enterprises, energy efficiency measures are implemented in a global and scattered way. Yet, to be the most efficient possible, these measures must be distinguished according to the considered business sector: each has its own energy characteristics, and that must be taken into account before implementing energy efficiency measures.

The survey aimed at evaluating the adoption level of some energy efficiency measures within enterprises. The analyzed measures are essentially the staff information and/or incentive for an energy savings-oriented attitude, the implementation of an energy management system, the consideration of energy consumption when purchasing new equipment and the isolation of the building.

4.2.1. Staff Information and/or Motivation for Energy Savings Oriented Attitude

This measure is included in the energy management systematic and global approach aiming to optimize the energy consumption of the firm while eliminating all waste thanks to an equipment power supply management according to their usage.

Its role is to inform and sensitize the enterprise's main managers about the challenges related to energy management. It is by far the most shared measure among the interviewed enterprises. In fact, it positions itself as an already implemented or being implemented measure by 59% of the firms of the hotel sector, 57% of those of the fuel distribution sector, 56% of those of the medical care services sector, 60% of those of the supermarket exploitation sector, 60% of those of the water conditioning production sector and 50% of those of the milk processing sector. It should be reminded that an awareness-raising work was already undertaken by the energy management sector of the Ministry of Energy. This campaign consisted in sensitizing posters and advertising spots.

4.2.2. Implementation of an Energy Management System

As the preceding measure, it is part of the systematic and global approach of energy management within enterprises. This measure consists in evaluating the already implemented measures.

It is presented within interviewed firms as a not contemplated measure to date. Indeed, more than 40% of the interviewed firms addressed the measure as such; the greater numbers located in the sectors of oil manufacture (60% of the firms of the sector), of butchery (50% of the firms of the sector) of water conditioning (45% of the firms of the sector) of fuel distribution (43% of the firms of the sector).

However, 17% of the firms declare having already implemented or being implementing it. They evolve in a major part in the sectors of water conditioning production, milk processing, private education and butchery.

4.2.3. Consideration of Energy Consumption when Purchasing New Equipment

This measure is part of the approach based on the energy return of technical equipment. It aims at purchasing electric energy efficient equipment. It appears in the survey that about 38% of the firms declare using efficient equipment versus 62% that do not. This score could be explained by the lack of a specialist on energy issues in the enterprise or a lack of awareness about the equipment weight in the enterprise's energy bill.

This measure is implemented or is being implemented by 36% of the interviewed enterprises. The most concerned sectors are hotel and catering, supermarket exploitation, oil manufacture and cereal transformation sectors. It can be generally explained in its implementation by the recourse to economic lamps, the installation of timers, etc. Indeed, more than 34% of the enterprises had recourse to economic lamps of which the greater number is found in the sectors of hotel and catering, pharmacy and water conditioning production. Furthermore, a proportion no less significant (22% of the interviewed enterprises) state that it is an appropriate measure for the enterprise, but is not planned.
Among the three energy efficiency measures explored, the survey reveals that the measure concerning the implementation of an energy management system is the most neglected as confirmed in Figure 5.

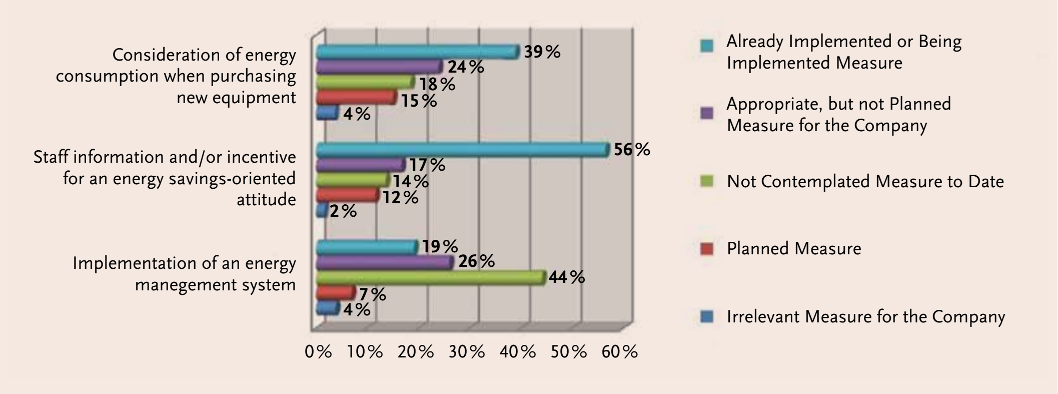

FIGURE 5: IMPLEMENTATION OF ENERGY EFFICIENCY MEASURES

Source: The authors, from Electric energy survey data/CCI-BF 2015.

4.3. Internal and external factors influencing energy efficiency measures

The answers to our questions given by the enterprises selected in our study sample helped to identify some internal and external factors likely to influence the adoption of energy efficiency measures. It appears that the costs related to the search for information, the lack of knowledge about adequate equipment suppliers as well as the lack of knowledge about energy savings opportunities are major obstacles to the adoption of energy efficiency measures (Figure 6).

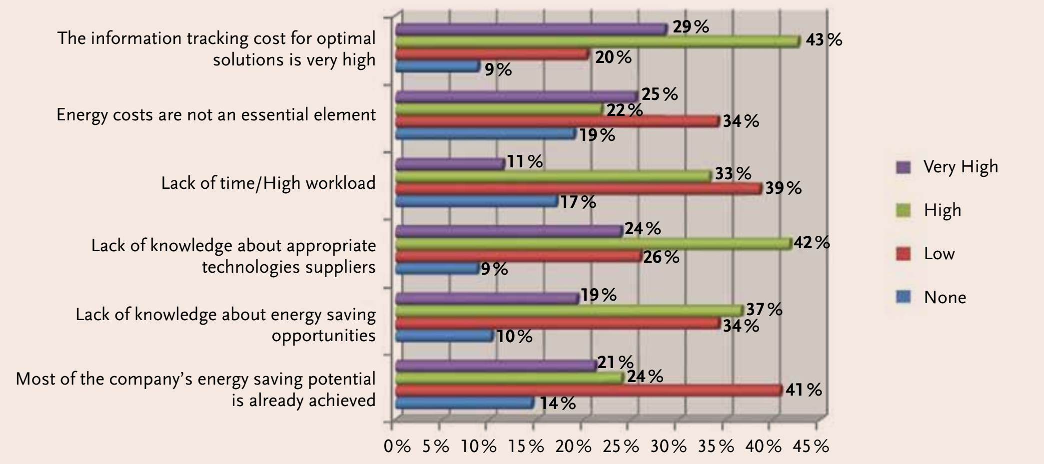

FIGURE 6: OBSTACLES OF THE IMPLEMENTATION OF ENERGY EFFICIENCY MEASURES

Source: The Authors, from electric energy survey data/CCI-BF 2005.

Another aspect of the analysis concerned the study of factors likely to influence the adoption of renewable energies such as a measure integrating the energy efficiency framework. It appears that financial factors (financial support and tax relief) and the information-related factor are very decisive in encouraging solar energy use. Factors related to education and training, as well as incentives such as public recognition and experience sharing are also important.

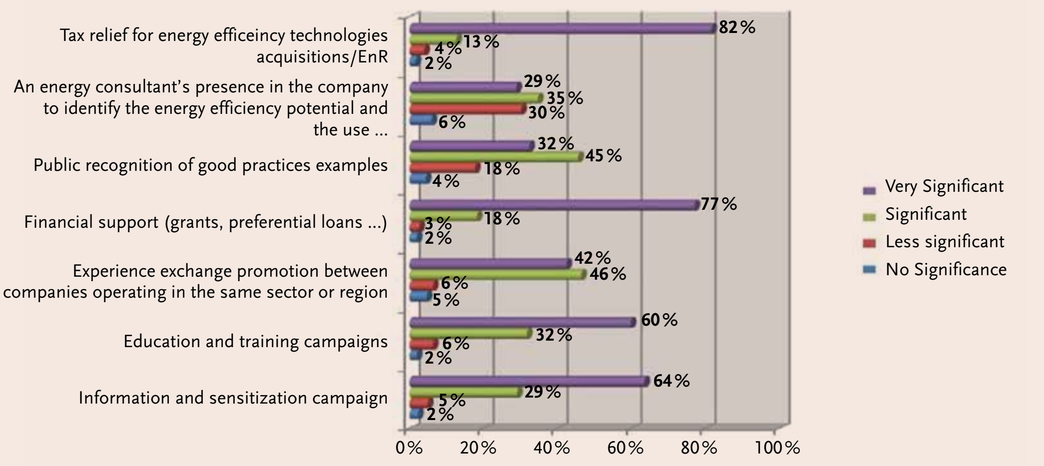

FIGURE 7: ENTERPRISES' EXPECTATIONS RELATED TO RENEWABLE ENERGY PROMOTION NOTABLY SOLAR ENERGY

Source: The authors, from electric energy survey data/CCI-BF 2015

4.4. Probit Model Scores

The scores of the model give an account of the determinants of two energy efficiency measures. It is about, on the one hand, the measure on staff information and/or incentive for an energy savings-oriented attitude and, on the other, that on the implementation of an energy management system. These scores are indicated in Table 3.

Compared to the first measure (specification (I), the estimation scores indicate that they are essentially variables related to the enterprise's characteristics, to the business sector and to the energy bill cost that affect in a way or another the adoption decision of the measure.

Thus, it appears that small-sized enterprises, more precisely those achieving an average annual turnover comprised between 30 and 150 million are prone to adopt the energy efficiency measure. This score is opposite to that of Costa-Campi (2015) as well as that of Trianni et al. (2013). But, it could be explained by the fact that small-sized enterprises adopt the energy efficiency measure to better withstand production costs and reduce disadvantages related to the weakness of economies of scale associated to their size. It will also deal with a kind of resilience concerning functioning charges of which the weight is more noticed on these small enterprises.

Concerning the business sector, it appears that the fact of operating in oil production, hotel and catering as well as supermarket exploitation increases the probability of the adoption of the energy efficiency measures, namely staff information and incentive for an energy savings-oriented attitude. Indeed, energy is a highly important production factor in these business sectors and requires a continuous availability of the supply of this resource. This situation could justify the behaviors of the actors of these business sectors toward energy efficiency measures in order to ensure a regular operation in their equipment for a lower cost.

TABLE 3: ESTIMATION SCORES

Energ_Efficiency	(I)	(II)
PE_CA	0,421* (0.215)	
Pres_Electrician	0.279 (0.243)	
Monthly Bill Cost_	-3.43e-07** (0.000)	
Oil Manufacture	1.227* (0.627)	
Supermarkets	1.143* (0.692)	
Hotel_Catering	0.646* (0.367)	0.498 (0.441)
Private_Health Care	0.152 (0.250)	0.273 (0.523)
Energy_Audit	0.532 (0.380)	0.668 (0.624)
Electricity_Product	0.189 (0.212)	0.415 (0.313)

Energ_Efficiency	(I)	(II)
Solar Energy	-1.447 (0.366)	-0.387 (0.503)
Age	-0.008 (0.010)	-.029* (0.017)
City		0.456*** (0.315)
MiE_CA		-0.189 (0.336)
Maint Cost_group		-1.77e-06** (7.60e-07)
Energy charge>20		0.239 (0.338)
CM_ annual_2011-2013		3.64e-09 (9.90e-09)
Bill_Update		0.136 (0.668)
Working_H_Volum		-0.055* (0.033)
Cons	0.141 (0.223)	-1.963*** (0.727)
Number of observations	192	123
Wald chi2	32.90	31.60
Prob > chi2	0.000	0.002
Pseudo R2	0.120	0.194

The behavior of the variable « *Monthly_Bill_Cost»* seems to refute this explanation. In fact, it appears that the average monthly cost of the energy bill affects negatively the probability of adoption of energy efficiency measures. This score could be explained by the fact that the adoption of energy efficiency measures is not the property of big enterprises that consume significant amounts of energy. This is similar to the above-mentioned score and it shows that these measures are more likely to be adopted by small-sized enterprises. This could be explained by the significance of the implementation cost of such measures, which end-up not providing incentives in that sense.

As far as the second energy efficiency measure is concerned, the scores show that characteristics of the firms such as its age and location affect the likelihood of adoption of energy efficiency. An increase of one point in age of the enterprise causes a decrease of probability of adoption of the energy efficiency measure of 0.6%. This score is explained by the fact that older enterprises are much more rigid to technological change compared to young enterprises. Policies aiming to encourage energy efficiency measures must be much more oriented toward these enterprises.

The location of the enterprise explains significantly and positively the adoption of energy efficiency measures. The likelihood of adoption of energy efficiency measures increases of 21% for enterprises located in Ouagadougou compared to those located in Bobo-Dioulasso. This score could be explained by the fact that enterprises located in Ouagadougou (capital city of the country) have easily more access to information and also greater availability of energy efficiency measures. Also, in the project conducted by CCI-BF through BRMN and of which one of the components was based on incentives for adopting energy efficiency measures there were more enterprises located in Ouagadougou.

The generator's maintenance cost and the daily number of working hours within the enterprise affect negatively the opportunities of adopting an energy management system at the level of enterprises. In fact, the recourse to a generator explains the enterprise's option for a permanent availability of energy services rather than optimizing the cost of that service. And, the more the enterprise's energy need is important, the more is the power of the generator to be installed as well as its maintenance cost in terms of fuel consumption and repair.

So, the more the installed power (respectively the maintenance cost) is important, the less the adoption of an energy management system is a concern. Concerning the daily number of working hours, its sign seems to be related to the preceding score. Indeed, the great deal of power outages impacts negatively on the daily number of working hours in the enterprises where this resource is essential. This causes resilient behaviors such as the recourse to generators or to solar energy in some enterprises. As explained previously, these behaviors, while allowing a permanent functioning of the enterprise even in case of power outage, reduce the necessity of recourse to energy efficiency measures.

4.5. Scores Adequacy Analysis

Before focusing on adequacy analysis, it is necessary to mention that estimation scores of the two models show that they are overall significant. The Pseudo R^2 analysis shows that these two models are different from the trivial model. This score is confirmed by Wald statistics on the significant input of these models, at the edge of 5% to the explanation of the adoption of the two energy efficiency measures.

Concerning the adequacy of the model as a whole, it is assessed through the Hosmer-Lemeshow test, the prediction table and diagnostic test (the ROC curve)

The Hosmer-Lemeshow test helps to test the global significance of both models. It rests on the null hypothesis of good adjustment versus that alternative of bad adjustment. The probability of significance of the test is higher than 5% for both retained specifications in this survey explaining thus a good adjustment of the model and a good explanatory capacity of our model.

The analysis by prediction aims to assess the capacity of models to predict the values of dependent variables. Indeed, the prediction assesses in percentage the number of times the predicted value of the dependent variable corresponds to its observed value (Gourieroux, 1989). It is currently admitted that beyond 50% of correct prediction on cross sectional data, the model is adequate to explain the studied phenomenon. Prediction tables for our two models indicate high values to 67% and 75% of good predictions rate (Annex 1). This shows the adequacy of models to explain the adoption of energy efficiency measures.

The ROC curve (Receiver Operating Characteristic) helps to represent the discriminatory capacity of a model. The area under the ROC curve summarizes the capacity of the model to discriminate enterprises adopting energy efficiency measures from those that do not. These areas designated under the name of AUC (Area Under Curve) are established to 0.71 and 0.79 (annex 2) showing thus a good discriminatory power of the models.

In short, the overall scores of these three tests help to confirm the econometric validity of our analyzing models for the adoption of energy efficiency measures and consequently the robustness of the results we have reached.

5. Conclusion

This research on energy efficiency of SMEs in Burkina Faso helped, on the one hand, to analyze the behavior of SMEs in managing the energy issue, and on the other to clarify determining factors of the adoption or not of energy efficiency behavior by these SMEs. The main theoretical thoughts on the topic helped to build a theoretical framework essentially based on new technologies acceptance and appropriation theories (Theory of acceptance model) and the approaches of the energy paradox and market failures. These various theories inspired a lot the elaboration of the econometric model notably the identification of the model's key variables.

The descriptive analysis helped to obtain useful information on the behavior of SMEs energy consumption in Burkina Faso and on the determinants of these behaviors. So, at the end of the analysis, we can retain in terms of behaviors that SMEs adopt various measures attempting to control the energy burden among which the most popular is that consisting in staff information and incentive on good practices concerning energy efficiency. However, very few enterprises implement in a formal way an energy management system within the enterprise or the systematic consideration of energy consumption when purchasing new equipment.

As far as main determinants are concerned, such behaviors, the econometric study through the estimation of the Probit model helped to show that factors such as the costs related to the searching of information, the lack of knowledge about adequate equipment suppliers as well as the lack of knowledge about energy savings opportunities are the major obstacles to the adoption of energy efficiency measures. In addition, the age of the enterprise, its location as well as its size influence significantly the decision of adopting energy efficiency measures.

As perspectives and recommendations for a greater adoption of energy efficiency behaviors, it is necessary to focus on two main axes: a first one oriented toward reducing information asymmetry in the market through a quality control system or of certification of the equipment at the national level, a better communication on benefits/costs of energy efficiency solutions provided by the market.

The second one is oriented toward building the capacities of stakeholders with a particular focus on enterprise managers and their staff but also on equipment suppliers and installers.

Finally, in terms of perspectives for future surveys, the present work can be deepened by attempting to go beyond a static analysis of the behavior in a given period to analyze the dynamic of behaviors and resilience behaviors over time of company' managers toward the energy issue.

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Assessment of the penetration capacity of renewable energy

Electrical network of the island of Boa Vista – Cape Verde[1]

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Abstract

Recently, the electricity sector has undergone major changes in the way energy is produced, distributed and consumed. One of the major stages of its restructuring is the decentralization of its production, which has contributed to the participation of various technologies based on renewable sources (wind, photovoltaic, hydroelectric, geothermal, waves and tides, etc.). In a network, particularly isolated networks, the penetration capacity of these renewable sources has a strong influence on both the technical safety of the network and the minimization of energy production costs. This makes its real-time analysis interesting in a dynamic simulation platform using mathematical models in order to evaluate the penetration capacity of renewable energy, without compromising the stability and security of the network. This study, applied to a real case, such as the case of the Cape Verde Islands, where renewable energies are a strategic vector of the economic growth of the country, the results obtained could possibly play an important role in the national formulation of energy planning. In this way, the challenges of penetrating renewable energy in these networks, as well as their transmission and distribution needs in technical security, can be identified a priori. Given the methodology, this article aims to evaluate the behavior of the Boa Vista - Cape Verde grid with the penetration of renewable energies, taking into account all the eventualities of the current architecture of the island network in the panorama of penetration of 50% renewable energy by 2020.

KEY WORDS: DECENTRALIZATION, RENEWABLE ENERGY, STABILITY, MATHEMATICAL MODELS, ENERGY PLANNING.

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1. Introduction

The use of fossil fuels has always been present in the development of humanity from the steam engine of antiquity to the present day, and with the growing need of the industrialized countries these forms of energy have been exhausted since they are finished. On the other hand, the scientific evidence has concluded that they are very harmful to the environment, the worsening of which will lead to unpleasant consequences such as the release of greenhouse gases, rising temperatures and climatic disturbances on the planet. Once decision-makers become aware of environmental issues, an international treaty called the Kyoto Protocol and subsequently designated the Paris Protocol2, with the aim of reducing global fossil fuel consumption and hence encouraging use of sustainable models based on clean and / or renewable energies. An excellent example of the need for a paradigm shift is the adoption of the 20-20-20 European targets, which aims to implement an energy model setting the ambitious targets for 2020, including the reduction of greenhouse gases 20% below 1990 levels, establishing a 20% share of renewable energy in gross final consumption, and an increase in energy efficiency of around 20% [1]. Another example is the ECOWAS vision for 2020, which is also fully aligned with sustainable development and has taken steps to integrate renewable energy and energy efficiency into its regional activities and policies in West Africa.

Therefore, energy is a crucial element for any nation, and today is the basis for sustainable economic development, global prosperity and high standards of living. As such, Cape Verde's transformation agenda cannot be achieved without a secure and sustainable energy supply [2].

The electricity generating system of Cape Verde's electricity networks is currently mainly based on the insulated network of thermal power plants in which diesel and fuel oil are preferred energy sources, characterized by high reliability, low efficiency and a great need for maintenance. On the other hand, an expensive pollutant sensitive to fluctuations in market prices, including transport between islands becomes a major challenge, given that Cape Verde does not have this type of resource on its national territory and that the country must import all the necessary fuel. This factor, coupled with insularity and inefficiency in the sector, leads to a high cost equivalent to about 70% higher than in the European Union [3].

There is still a significant particularism that significantly impacts the national energy paradigm: drinking a simple glass of water requires the production of electricity that is to say that we must proceed with the desalination of water to feed the populations and that this process consumes a lot of energy representing about 10% of the total consumption of the country [4].

In addition to this problem, due to the economic dynamism that the country has presented over the past 15 years on the African continent, an exponential demand for electricity has been encountered. Average growth was slightly above 8.5% per year between 2000 and 2011, reaching 302 GWh of energy consumption and forecasting an increase in consumption that will double by 2020 (670 GW) [5]. Faced with this reality, technical and economic studies for the evaluation of the penetration capacity of renewable energies have been intensified. According to Figure 1, the potential of renewable energies in Cape Verde is estimated at 2,610 MW, photovoltaic (PV) being the most abundant resource estimated at 2,068 MW, with a cost of less than 38% at current production cost and L Wind energy, the most economical resource with an estimated potential of 306 MW, costs less than half the cost of diesel and fuel oil. Solid urban resources (MSW) can be a competitive source of energy in some islands, while wave energy and geothermal energy have high uncertainty [5].

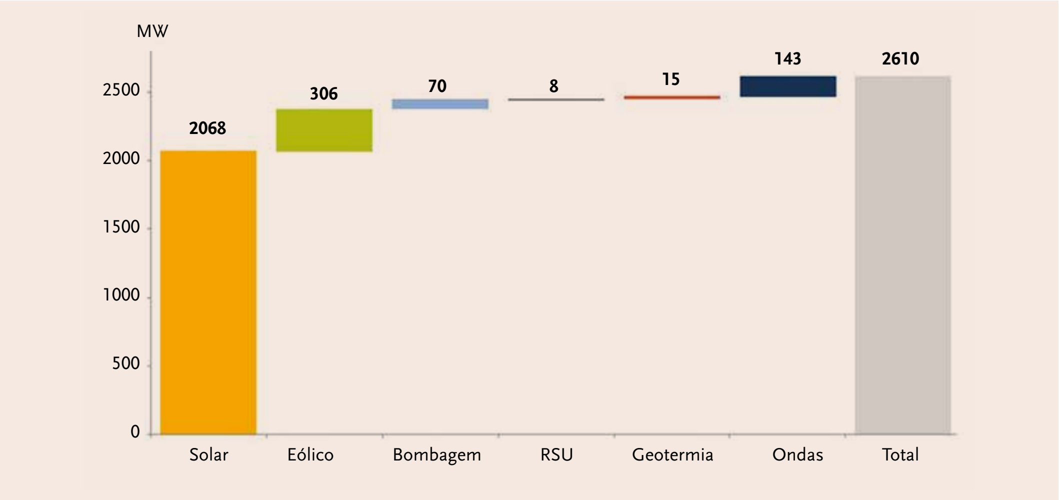


FIGURE 1: RENEWABLE POTENTIAL BY TECHNOLOGY IN CAPE VERDE [6]

Currently, Cape Verde has 26 MW of installed wind energy and 7.5 MW of photovoltaic energy as well as several future projects, with the ambition to reach 50% of renewable energy by 2020, as shown in Figure 2 [7].

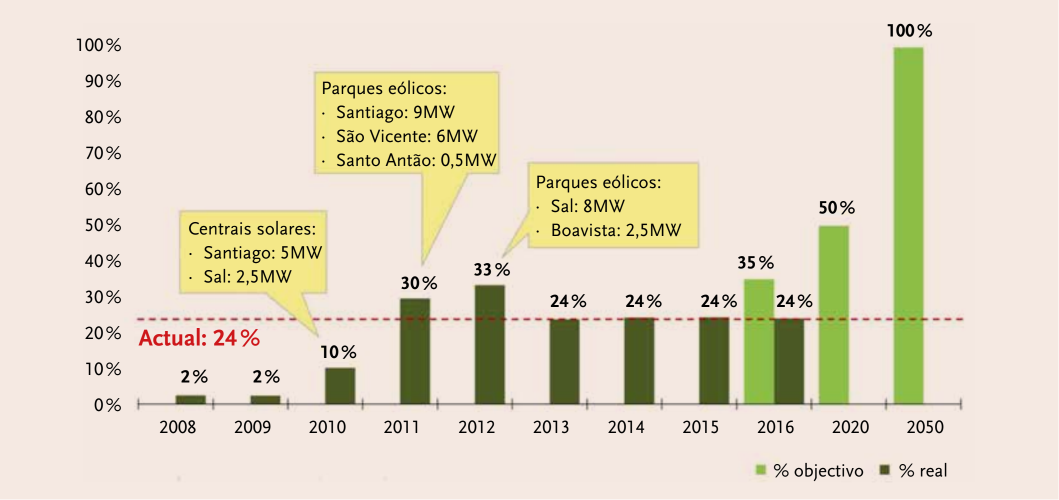


FIGURE 2: PLAN FOR PENETRATION OF RENEWABLE ENERGY IN CAPE VERDE [8]]

After a decade of preparation, Cape Verde is considering the migration of almost 100% Diesel to a hybrid Diesel-wind / FV system, reaching a penetration of around 33% in 2011. With the deactivation of the parks of the STEP 1 project Wind Farm in 2013, currently has a penetration of about 24%, and is now the largest producer of wind energy in the ECOWAS region [9].

Faced with this reality, Cape Verde clearly assumes that renewable energy production is one of the strategic drivers of its growth, especially the country that experienced average growth in the use of wind energy in 2011, which becomes relevant for a country with a GDP as low as Cape Verde [4].

As a result, the country has extremely favorable weather conditions for the exploitation of renewable energy sources, particularly wind and photovoltaic energy, where its penetration is a potential for reducing the price of electricity production, improvement of the environment and, consequently, for the trade balance due to the reduction of imports of fuels and the sale of carbon credits (CDM).

However, there are certain technical constraints that condition its injection into the network, i.e. resulting from the possibility of causing dynamic safety problems such as short circuits, the variability of natural resources (wind, sun, etc.), frequency regulation, voltage levels and system reserve management [10]. Compared to interconnected networks such as the Ibero-Portuguese-Spanish network, with their interconnections to France and Morocco, isolated networks are weak because they have constant decreases in inertia [11]. The problem is even more serious with the increase in the penetration of renewable energies, especially the wind which tends to replace the diesel units involved in the regulation of the voltage and the frequency of the network by wind turbines presenting forms of control dissociating practically mechanical and electrical quantities and prevent the wind turbine from reacting to variations in the system [12].

2. Case Study Characterization

Boa Vista is the third largest island in Cape Verde and the closest to the African coast. It belongs to the group of Barlavento Islands and has a high potential for economic growth adapted to the development of tourism. The most recent studies indicate that the island has a very high K (factor of adaptation to the needs of energy consumption) compared to the remaining islands [13]. In 2009, the island's energy demand reached 13.9 GWh and by 2020, an aggressive consumption trend of around 98 GWh is expected, with the tourism sector dominating almost all energy consumption on the island [14]. On the other hand, the island of Boa Vista is one of the Renewable Energy Development Zones in Cape Verde (ZDERCV) with a high renewable potential compared to the others, estimated at 56 MW (22.95 MW - wind power). , 30 MW solar and 3.5 MW marine currents), as shown in Figure 3 with its distribution on the island [5].

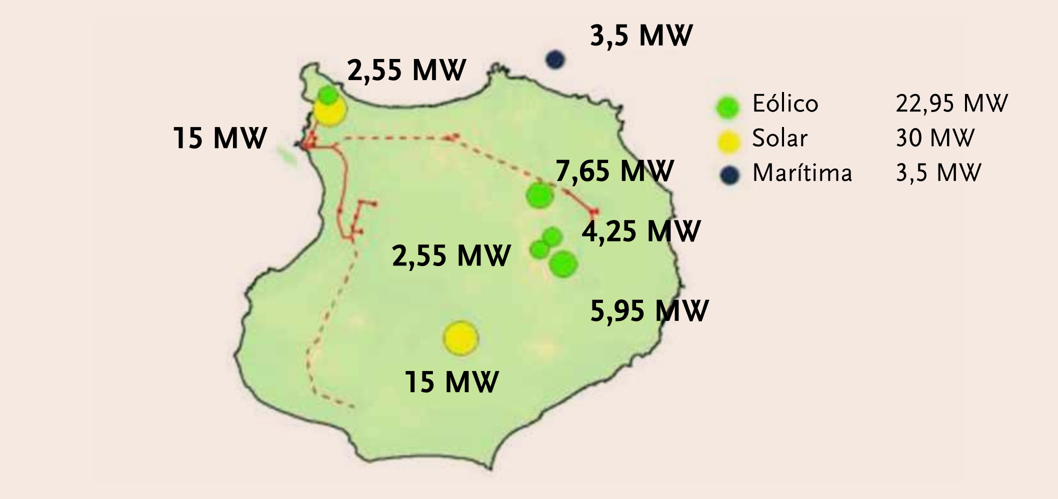


FIGURE 3: DISTRIBUTION OF THE RENEWABLE POTENTIAL ON THE ISLAND [5]

Therefore, the main objective of this work is to analyze the potential of renewable energy in the island of Boa Vista, taking into account the 2020 investment plan, current data provided by the management company of the network studied, forecasts of the evolution of consumption, renewable production and the definition of certain restrictions of the architecture of the current electricity network of the island.

In order to obtain an overview of the system, several numerical tests were carried out with Matlab / Simulink software. As a first step, the current operation of the electricity grid was simulated to validate the results obtained in the simulation platform with the actual values available, thus giving more certainty to the results in order to predict the 2020 scenario.

2.1 Scenario 2015 - Current network operation

The current Boa Vista Island production system consists of a 2.55 MVA installed capacity wind farm (Boa Esperança wind farm - PEBE) and two thermal power plants with fuel and diesel generators (Central de Boa Vista). Chaves - CC and Central de Lacacão - CL with an installed capacity of 13.4 MVA. As an illustration, it is shown in Figure 4, the map of the island with the location of the current system of energy production.

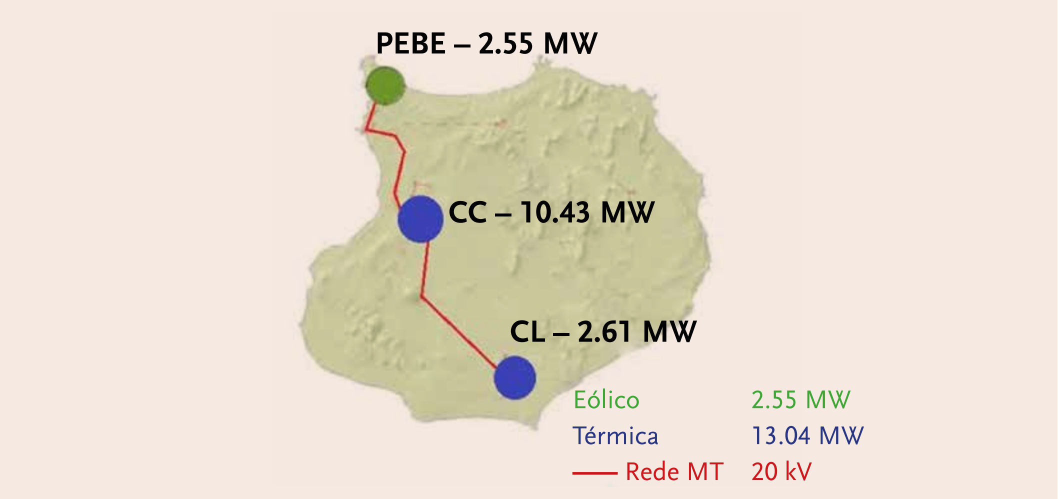


FIGURE 4: POWER SYSTEM OF ILHA DA BOA VISTA (2015)

For each scenario, there is a production equal to the sum of all the loads connected to the grid and according to the available data; the total consumption was 30,935 GWh of energy during the year. Figure 5 shows the production chart of the island recorded throughout the year 2015.

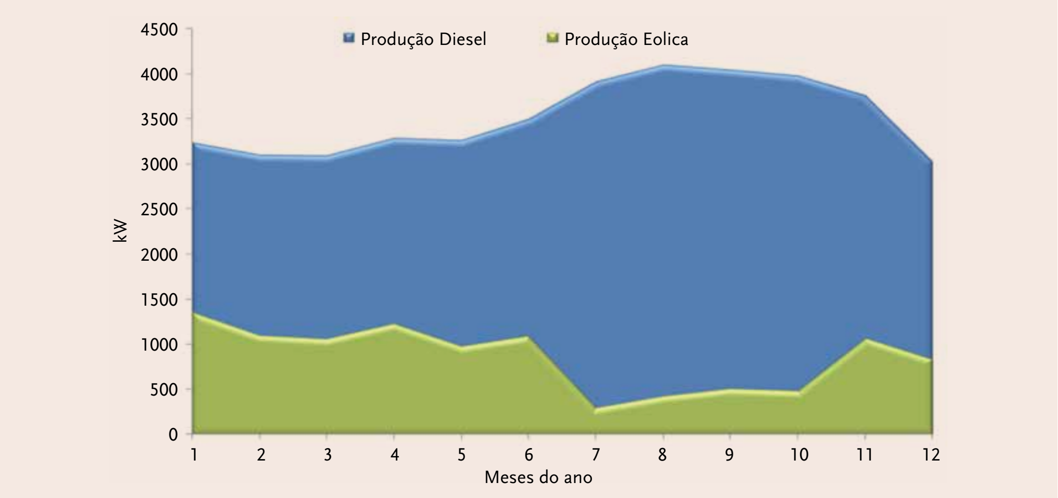


FIGURE 5: DIESEL AND WIND GENERATION DURING THE YEAR 2015

In the diagram of Figure 5, we can verify that the consumption is more intense during the summer period, especially during the months of August, September and October. In contrast to the ideal, wind generation during these months has its lowest output due to reduced wind speed. This is another important factor in the case study, since when wind generation is higher; the consumption in the grid is lower. While there is still room for wind penetration on the island, this is a critical scenario for the operation of the system when it is planned to increase it further.

Step 2015 is the baseline situation and reference scenario for the case study where the goal is to show that the model builds in the simulation platform, witnessing the actual situations of the current load diagram of the Boa Vista Island as the data available. The simulated current operating condition of the power grid has been verified, where in the peak period a consumption of 6.13 MW and 1.5 MVAr of reactive power has been recorded. During the vacant hours, the network consumes 2.2 MW of active power and 0.55 MVAr of reactive power. The system has been adjusted with the wind speed of the season itself (hours of vacuum), where it compares to the same amount of energy presented in the data provided by the network operator under study.

Compliance with NP EN 50160 voltage quality levels in large dams was also observed with an average of 0.97 p.u. during the peak period and 1.03 p.u. during the vacancy period, due to the highest level of buoyancy in the network and high wind speed.

2.2 Scenario 2020 - Energy Planning 2020

The 2020 scenario is the main axis of this research, which aims to study the network in the scenario of penetration of renewable energies by 2020 and with the same methodology of the scenario 2015, analyzing the scenarios of peak and vacuum with the respective powers and voltage levels of the network.

For the 2020 scenario of the 20 kV MV grid of Boa Vista, the national government has planned in PERCV the construction of two other wind farms with a total capacity of 10.2 MW (PEM - Mesa wind farm of 7.65 MW and PEF - Falcão wind farm of 2.55 MW) [15]. In order to transport this wind energy to Central Chaves (CC), there is also a project for the execution of a 23 km line in the 20 kV network and the remodeling of a single thermal power plant (CC) [15].

With an expected consumption of around 98 GWh by 2020, over the same time horizon, it is also planned to increase the thermal capacity by approximately 14 MW (4 generators of 3,500 kW in fuel oil) [15]. All of these eventualities were taken into account in the model simulation platform for the 2020 scenario.

Figure 6 presents the map of Boa Vista Island with the network architecture for the 2020 scenario.

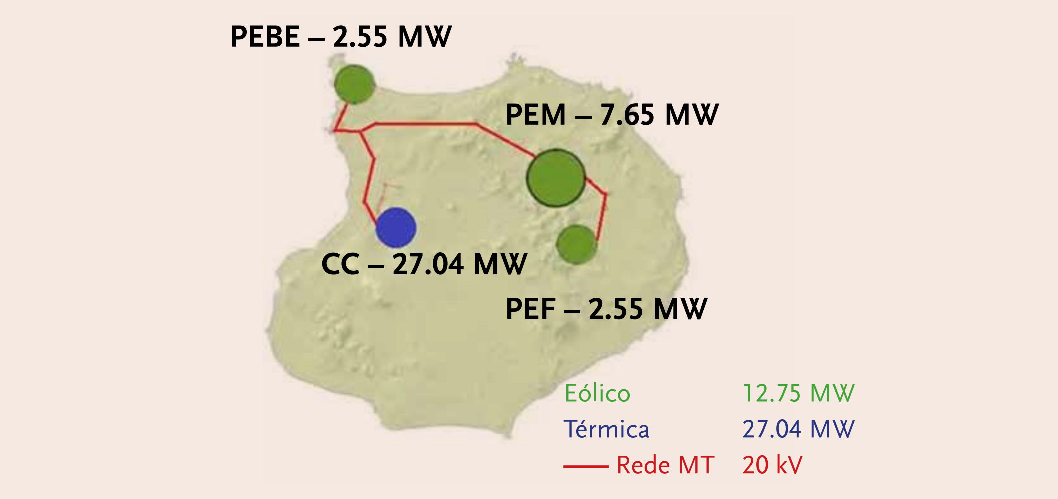


FIGURE 6: ELECTRICITY GRID OF BOA VISTA ISLAND PREDICTED FOR THE 2020 SCENARIO

The peak period of the 2020 scenario corresponds to a load capacity of 18.08 MW as foreseen in the PERCV. The Falcão wind farm (PEF), because it has the same installed capacity as the Boa Esperança wind farm (PEBE) and with the same wind regime, as expected, provides approximately the same amount of active power over the year. Almost all the Diesel group is connected to the grid supplying 14.8 MW of active power, the shares of Mesa Eólica Park (PEM) with an average power of 1.6 MW and the remaining 20% are provided by wind farms with a capacity of installed capacity of 2.55 MW and PEF).

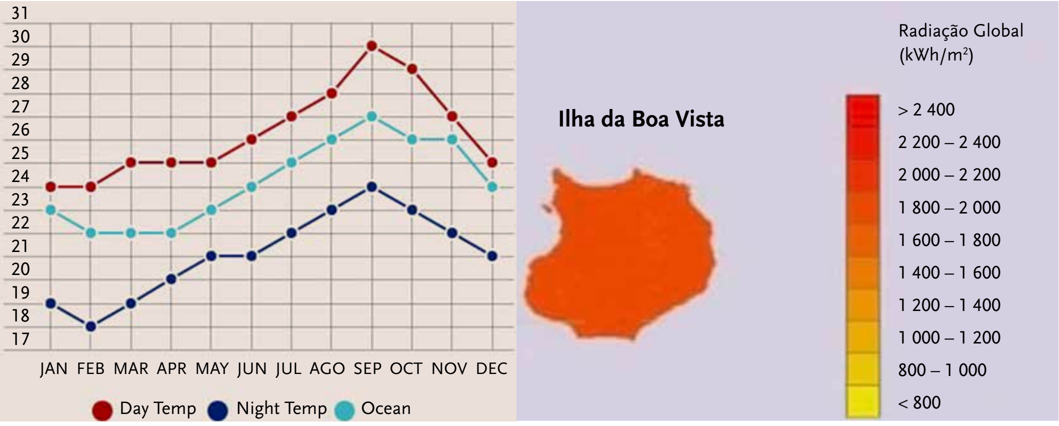
A strong wind and a lower load, of the order of 8 MW, characterize the vacuum period. Although it exhibits greater fluctuation due to the low system inertia and high wind availability, for this scenario, the model has also been able to provide the amount of power demanded giving a positive response to the system. The amount of wind energy supplied is much greater than the thermal quantity, the diesel system, more precisely the DC, has only 3 MW of active power, and the wind farms have provided the remaining 60% of the requested energy. by the charges. Central CC and PEBE for having associated higher downstream loads as planned provide a lower voltage level than the PEF and PEM wind farms.

2.3 Penetration of Photovoltaic Energy in the Network

Although photovoltaic energy is not yet available on the island of Boa Vista, it can be a renewable energy source with greater ease of penetration in this network, more favorable in periods of higher consumption and with more consistent and predictable characteristics.

In terms of annual average, the largest part of the national territory has an overall radiation between 1800 and 2000 *kWh / m2 / an*, which is much higher than in Europe, where they have only values of around 1700 *kWh / m2 / an*.

As can be seen in Figure 7, in terms of solar resources, the average temperature in months with the lowest wind reaches 30ﬄC with direct solar radiation of about 7 hours a day. [15].



(a) (b)

FIGURE 7: AVERAGE TEMPERATURE (A) AND GLOBAL RADIATION IN KWH / M² (B) ON THE ISLAND OF BOA VISTA [16]

Conclusion

In line with Boa Vista's energy planning to 2020, the result shows that the expected penetration of wind energy does not pose technical problems in terms of voltage level. This analysis of the dynamic behavior of the network was carried out for the most severe scenarios in terms of network stability (peak and vacuum scenario), the latter being the most critical operating scenario, characterized by a reduced load, a constant of lower inertia and the rotating reserve present in the system and are more vulnerable to changes in wind generation. However, diesel units have proven to be able to maintain stability in the grid even in disturbance scenarios with high wind output. The great advantage of the modeling work is that all the factors that can influence the penetration of renewable energy sources into a network can be assessed in the planning phase, providing the opportunity to work on the preparation and integration of new technologies and forms of energy. In this way, it becomes an indispensable tool and a means to study and prevent transient effects that could compromise the normal operation of the electrical system.

In general, the results showed that Boa Vista's electrical system is currently operating normally and that the projected wind energy penetration (10.2 MW), taking into account the conditions and limits stipulated until 2020, does not check stability and safety issues. Therefore, in all cases compliance with NP EN 50160 is observed, which states that the average rms values must not exceed the ą 10%.

The topology of the wind turbine used in the network offers good integration with performances somewhat similar to diesel units in terms of voltage stability, with a rapid response to transient and dynamic situations independent of the energy required in the network. On the other hand, they also have improvements in the quality of electrical energy with advantages in reducing the level of flicker, the filtering of low-order harmonics and the limitation of the starting current [17].

Wind energy, especially in Boa Vista Island, is quite intermittent and with wind changes inversely proportional to the needs of the loads. Given that there are no water resources for energy storage, nor projects for the use of specific control equipment (Steering wheel, STATCON, etc.) to ensure the reliability and stability of energy supply, It is advisable to limit the technical penetration of wind energy production according to the peak system time. Photovoltaic energy that occurs during periods of higher consumption with more constant and predictable characteristics can be considered as a source with greater ease of penetration in this network, but this does not alter the penetration space of wind energy, whose recovery of investments is expected in less time.

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Energy Efficiency in West Africa Economies: Implication for sustainable Energy use[1]

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YASMINE FOUGNIGUÉ TOURÉ[b]

Abstract

In recent years, energy efficiency figures prominently in energy policies of African countries. This study analyzes the total-factor energy efficiency in West Africa economies over the period 1990-2013 using DEA model. The empirical analysis is carried out in two steps. In the first step, energy efficiency scores are calculated with and without undesirable output such as CO_2 emission. In the second step, excesses in energy, capital, labor and CO_2 and shortfall in GDP are determined through scenarios representing objectives that an economy can set regarding energy use. Average energy efficiency scores over the study period showed that the five most energy-efficient countries are Senegal, Niger, Benin, Burkina Faso, and Ghana, whereas the five least energy-efficient countries are Guinea, Nigeria, Togo, Mali and Liberia. For all most of the countries, energy efficiency changed over time. Energy efficiency scores with and without undesirable output are identical for Ghana, showing that she seem to be the best in sustainable energy utilization. Based on DEA scenarios, we found that, all the countries generate excesses in energy use causing shortfall in Gross Domestic Product. The slack based DEA model highlights that if countries reduced excesses in energy use and CO_2 as well as used efficiently capital and labor, they would have increased the Gross Domestic Product. A decrease of energy consumption from traditional biomass and a better exploitation of renewable energy from biomass will adjust energy consumption and improve energy efficiency and environmental quality.

KEYWORDS: ENERGY EFFICIENCY, DATA ENVELOPMENT ANALYSIS, SLACK BASED MODEL, WEST AFRICA

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1. Introduction

In recent years, energy efficiency features prominently in energy policies of African countries. Energy is a key factor in their economic and social development and the causal effects between energy and growth have been well demonstrated (Esso and Keho, 2016; Esso, 2010; Ouedraogo, 2010). Faced with a growing population and increase in economic activities, countries must provide sufficient energy to increase economic output while preserving the environment. A growing volume of research has focused on energy efficiency measurement in the macro-level by comparing the performance trends of countries in terms of energy utilization in the economy.

As in any economy, energy is consumed in transportation, industry, commercial activities, utilities, agriculture and households. From primary sources (biomass, petroleum, natural gas, hydroelectricity, etc.), it is transformed into final energy at the stage of use (electricity, fuel, etc.). Available in various forms, the promotion of policy for an efficient and sustainable management of energy use is necessary. The concept of energy efficiency is defined under different ways. According to the International Energy Agency (IEA), energy efficiency is the way to manage and restrict economic growth in energy consumption. This definition corresponds to the indicator of energy intensity that is energy consumption divided by the economic output (Gross Domestic Product). Economists have proposed another indicator of energy efficiency that combine energy consumption, capital and labor to produce an economic output and is well known under the concept "total-factor energy efficiency" (Hu and Wang, 2006; Zhou and Ang, 2008; Honma and Hu, 2009). With regards to these indicators, an economy is energy-efficient if the country shows a low level of energy intensity or has a total-factor energy efficiency score close to one. In other words, energy consumption is efficient if it offers more services for the same amount of energy, or the same service for less energy.

In West Africa, primary energy consumption is mainly dominated by traditional use of biomass. The ECOWAS White Paper[2] on access to energy services indicated that biomass represents 80% of domestic energy consumption in the region. The share of biomass among ECOWAS states vary from 22% in Cape Verde to 94% in Liberia. Other countries with figures in excess of the regional average are Burkina Faso (91%), Nigeria (83%) and Sierra Leone (81%) (Adenikinju, 2008). The World Energy Outlook[3] 2014 also indicated that in West Africa, 80% of the population was relied on traditional use of biomass for cooking in 2012. These share also vary from 31% in Cape Verde to 98% in Liberia. The high access to energy in traditional form can be a threat to the health of populations, degradation and pollution of the environment. Moreover, energy intensity in West Africa is one of the highest in the world and was estimated to 0.56 ktoe / million$, while it is 0.46 ktoe / million$ in China, 0.16 ktoe / million$ in United Nations, 0.13 ktoe / million$ in Latin American, 0.11 ktoe / million$ in European Union and 0.09 ktoe / million$ in Japan (ECREEE, 2014). The high energy intensity indicates an inefficient use of energy. This means that, the countries use more energy per unit Gross Domestic Product (The total value of goods produced and services provided in a country during one year).

In the region, countries differs in terms of economic development, investment capacity and labor force. In addition, they differ in energy supply. Some are net energy exporters, others are largely importers. In pursuit of sustainable growth, countries needed to combine energy, capital and labor in the production process in the best way that is friendly to the environment protection. Indeed, while Africa countries are smaller CO_2 emission, energy consumption is correlated to the quantity of CO_2 generated (Figure 1). According to the objectives of ECOWAS Renewable Energy Policy, countries should improve energy security and energy sustainability as well as reduce the negative environmental externalities of the current energy system.

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[2] In 2006, ECOWAS/UEMOA adopted the White Paper on regional policy on access to energy services for populations on rural and peri-urban areas. The white paper provided a clear vision regarding the role of energy services for the achievement of the Millennium Development Goals (MDGs) particularly and socio-economic development in general.

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This study aims to analyze energy efficiency in West Africa countries using a standard DEA and Slacked Based DEA models over the period 1990-2013. In the literature, energy intensity and total-factor energy efficiency are commonly used in macro-level policy analysis. Energy intensity, known as partial-energy efficiency is defined as energy consumption divided by the Gross Domestic Output (GDP), while the total-factor energy efficiency through DEA models combines energy consumption with economic inputs (capital and labor) to produce the economic output (GDP). An increase number of researchers have demonstrated that the measurement of energy efficiency by partial-factor could result in a misleading of estimates (Hu and Wang, 2006; Zhou and Ang, 2008; Honma and Hu, 2009).

Following these studies, we use total-factor energy efficiency to measure and compare energy efficiency level among West African countries. Indeed, countries in Africa are faced with low capital investment capacity, misallocation of capital and labor and limited access to clean energy. Analyzing energy efficiency taking into account these three factors is adequate to show how energy use can be improved regarding a good economic performance. This study uses labor, capital and total primary energy consumption as input variables, Gross Domestic Product (GDP) as the only desirable output and the CO_2 emission from energy consumption as the undesirable output.

The contributions of this present study are three-fold. Firstly, the study shows an empirical evidence of the total-factor energy efficiency in the 15 Countries of West Africa. Many other studies have been conducted in regional level as well as economic zones like European Union, BRICS[4] and G-20[5]. Energy efficiency analysis in regional level is so important to find similarities and heterogeneities among countries in order to identify lessons to be learned from the most energy-efficient countries. Furthermore, ECOWAS Centre on Renewable Energy and Energy Efficiency (ECREEE) drawn up a regional energy efficiency policy and actions to be adopted and implemented to improve energy efficiency and security. Such empirical study could help policy makers to formulate policies for the countries. Secondly, we compute energy efficiency scores in two ways. The first way does not consider undesirable output while the second take it into account. Energy consumption in all the countries are dominated by biomass source, however they are heterogeneous in CO_2 emission. A country can be the most efficient output and less efficient with undesirable output. The interest of this contribution is to show how energy efficiency scores are overestimated without taking into account CO_2 emission from energy consumption. Thirdly, the study does not limit energy efficiency analysis to efficiency scores. In addition to them, excesses in energy consumption, capital, labor and CO_2 emission and the shortfall in the economic output were calculated through three scenarios that an economy can set (*Scenario-1*: the economy wants to use less energy for a given GDP growth; *Scenario-2*: the economy wants to achieve a maximum of GDP growth for a given quantity of energy and *Scenario-3*: The economy considers a reduction in energy consumption and an increase in GDP simultaneously while reducing CO2 emissions). The purpose of this contribution consists of determining the GDP surplus that can be achieved if excess inputs (energy, capital and labor) and excesses in bad output (CO_2 emission) were reduced.

The remainder of this paper is organized as follows: The next section presents the review of literature. Section 3 describes the methodology and the data of the study. The empirical results and discussion are presented in section 4. The final section presents the conclusion and some policy implications.

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[4] The five major emerging national economies: Brazil, Russia, India, China and South Africa.

[5] The G20 (or G-20 or Group of Twenty) is an international forum for the governments and central bank governors from 20 major economies.

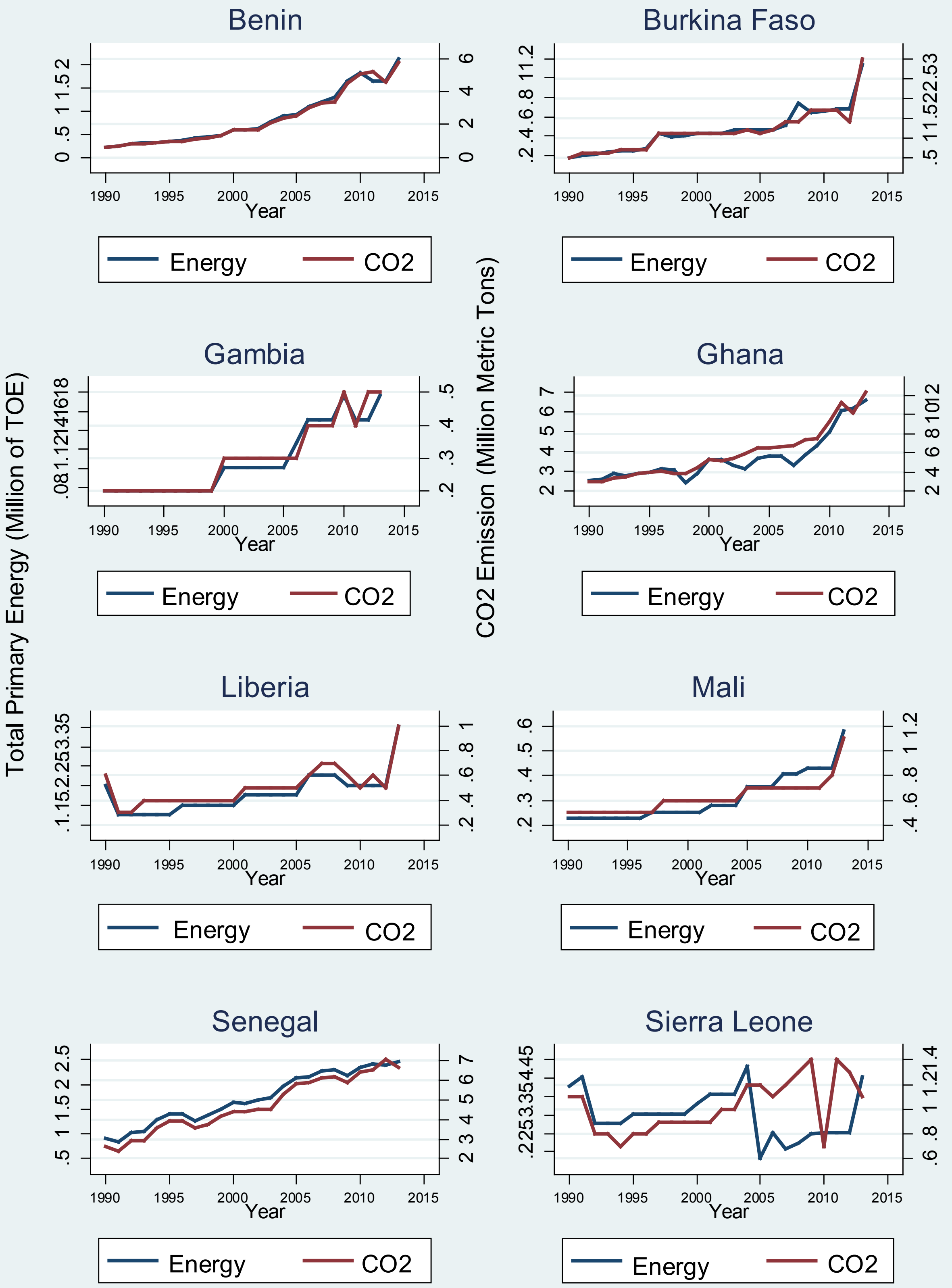
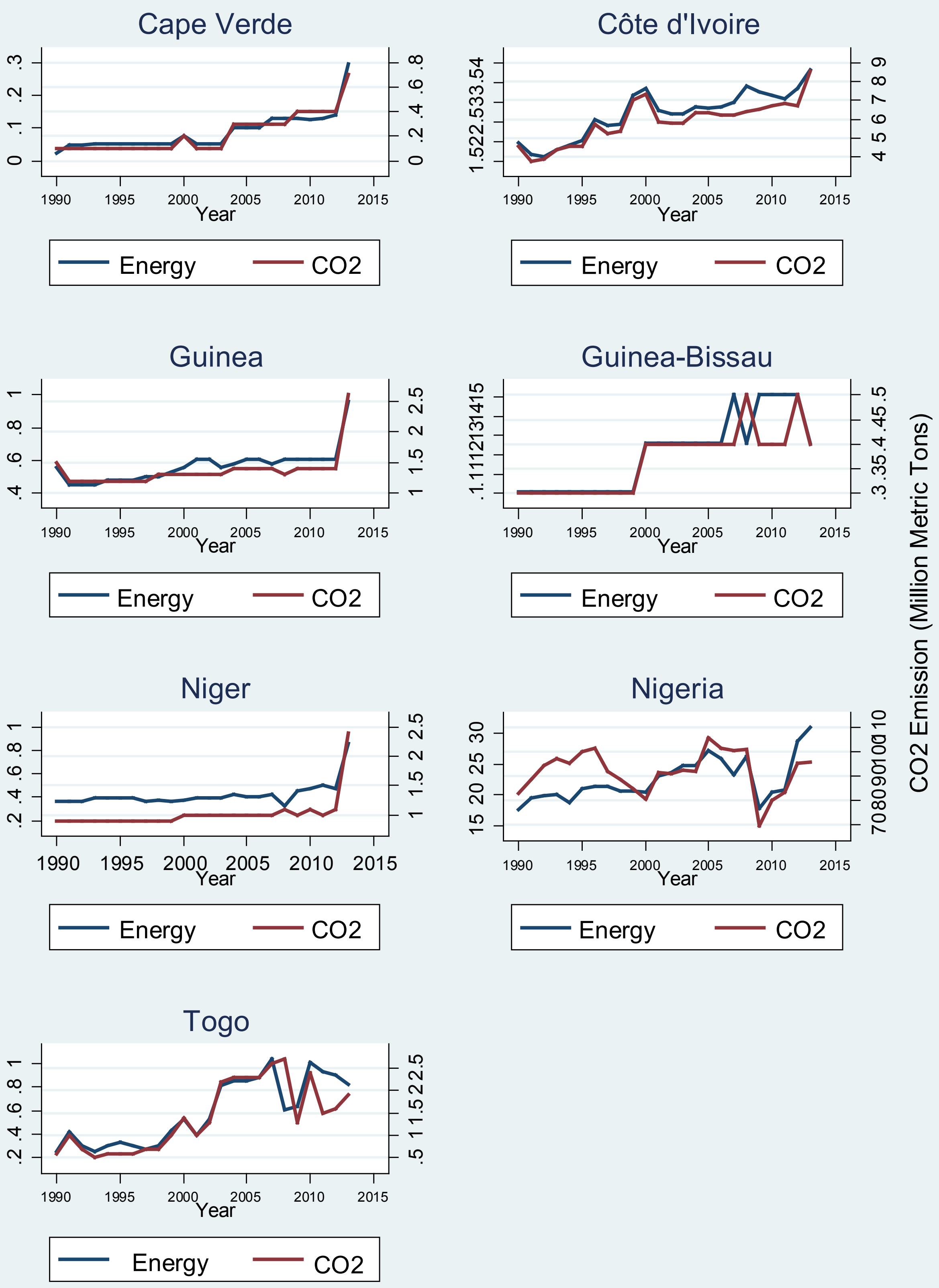


FIGURE 1: TREND OF ENERGY CONSUMPTION AND CO_2 EMISSION IN WEST AFRICA COUNTRIES OVER THE PERIOD 1990-2013 (AUTHORS FROM IEA DATABASE)


Cape Verde
0 .1 .2 .3
0 .2 .4 .6 .8
Côte d'Ivoire
1.522.533.54
4 5 6 7 8 9
Guinea
.4 .6 .8 1
1 1.5 2 2.5
Guinea-Bissau
.1111213141 5
.3 .35 .4 .45 .5
Niger
.2 .4 .6 .8 1
1 1.5 2 2.5
Nigeria
15 20 25 30
708090100110
Togo
.2 .4 .6 .8 1
.5 1 1.5 2 2.5
1990 1995 2000 2005 2010 2015
Year
Energy
CO2
CO2 Emission (Million Metric Tons)

2. Literature Review

This section first presents the concept of energy efficiency, the non-parametric approach of efficiency measurement and the empirical review on energy efficiency analysis.

2.1. The concept of energy efficiency

The concept of energy efficiency emerged in the early 1970s in developed countries as a matter of sustainable economic growth. Improving energy efficiency has become a crucial step for several countries to reduce greenhouse gas emissions. Energy efficiency is a relative concept and is defined from several angles. On the economic level, energy efficiency is the ratio of a performance indicator (goods, services, energy) or a product from a production process to the energy as a production factor. It can be written as follows:

$$\frac{Useful\ product\ of\ a\ process}{Energy\ input\ in\ a\ process}$$

Three indicators are used to measure energy efficiency, namely, thermodynamic, physical and monetary indicators. The latter refer to the amount of energy required per unit of economic output. In addition, physical and monetary indicators are most often used in energy policy analysis in macro-level. These indicators measure energy efficiency over time at the national level and make country comparisons. Significant research has emerged on measurement of energy efficiency, both in methodology and in empirical applications. Two methodologies for measuring energy efficiency are commonly used: single input-output measure and multiple inputs-outputs. The first method concerns the energy intensity indicator. It is defined as the ratio of the amount of energy consumed (Energy) to gross domestic product (GDP), which measures the amount of energy consumed per unit of GDP. This ratio is used by the International Energy Agency (IEA) and the World Bank to assess energy efficiency across countries and to evaluate energy policies.

Besides this method, the measurement of energy efficiency through multiple inputs-outputs using the Data Envelopment Analysis approach, have been developed by some authors (Zhou and Ang, 2008, Hu and Wang, 2006). They criticized that energy is not the only factor in the production process (Zhou and Ang, 2008). It must be combined with other factors of production, such as labor and capital. Hu and Wang (2006) have argued that measuring energy efficiency using multiple inputs-outputs is preferable than the simple ratio of energy intensity, because it provides a measure of energy efficiency based on total-factor. In addition, this method takes into account the environmental impact (CO2 emissions) that represents an undesirable product from energy consumption. In most DEA applications on energy efficiency measurement; energy, capital and labor are used as inputs to produce GDP (desirable output) and the environmental factor such as CO2 emissions (undesirable output). This method provides an energy efficiency measure that is obtained by a better combination of factors of production (energy, capital, labor) that maximizes output (GDP) and at the same time reduces environmental impacts (CO2).

2.2. Data Envelopment Analysis (DEA): Nonparametric approach of efficiency measurement

The efficiency measurement began with the work of Farrell (1957) inspired by those of Koopmans (1951) and Debreu (1951). It is intimately related to the estimation of the production frontier based on distance function. Farrell (1957) distinguished between technical efficiency and allocative efficiency. The concept of technical efficiency refers to the ability to produce maximum output from a given set of inputs. The allocative efficiency is defined as the ability of the production unit to combine the inputs in optimal proportion, given their respective prices and the technology of production.

In practice, two approaches can be used to measure efficiency: The Stochastic Frontier Analysis (parametric approach) and Data Envelopment Analysis (nonparametric approach). In presence of multiple outputs, DEA approach proposed by Charnes et al. (1978) is the most appropriate. It allows one to calculate the efficiency scores, input and output slack values, and to identify the production units which are fully efficient. The efficiency score are determined by optimizing DEA model either in constant returns or in variable returns. In addition DEA model can be optimized following the production unit objective's orientation. The input-oriented DEA models consider the possible (proportional) input reduction while maintaining the current levels of outputs. The output-oriented DEA models consider the possible (proportional) output augmentation while keeping the level of inputs. However, these standard DEA models do not take into account the slacks in the "objective function". Charnes et al. (1985) developed an additive DEA model which considers a possible input decrease as well as output increase simultaneously. This model provides a measure of non-equiproportional efficiency scores, unlike the standard models that provide equi-proportionate efficiency scores. It identifies the efficient units of those inefficient. However, it does not measure the intensity of inefficiency, as well as standard models (Tone 2001). In these respects, Tone (2001) developed a slack based model (SBM) that optimize the input and output slacks and provide a pure measure of efficiency and propose a new non-parametric DEA approach scheme for measuring efficiency in the presence of undesirable output (Tone, 2004). The assessment of efficiency with undesirable output was first treated by Färe et al (1989). They exposed that when evaluating the performance of producer it makes sense to credit them for their provision of desirable outputs "good output" and penalize them for their provision of undesirable outputs "bad output". For that, "good" and "bad" output should be treated asymmetrically in gauging producer performance.

2.3. Empirical review

The nonparametric DEA approach has been widely used to analyze total-factor energy efficiency (multiple inputs-outputs) at the national and regional level as well as in economic zones. A first wave of these empirical studies did not take into account the environmental impact from energy consumption.

For example, Hu and Wang (2006) assessed the energy efficiency of 29 administrative regions in China over the period 1995-2002. They considered energy consumption, capital, labor and total sown area of farm crops as proxy of biomass energy (as inputs) and GDP as output, to calculate the energy efficiency index based on total factor production. They found that this index was better suited to reality than the simple measure of partial-factor energy efficiency index. Their results showed that East and Central regions have improved their energy efficiency by adjusting the amount of energy use through improving technology and production processes. Moreover, they showed that there is a U-shaped relationship between energy efficiency and per capita income in the regions of China, confirming that energy efficiency improves economic growth.

Chien and Hu (2007) analyzed the effects of renewable energy on the technical efficiency of OECD[6] and non-OECD economies during the 2001-2002 period through data envelopment analysis (DEA). They found that increasing the use of renewable energy improves an economy's technical efficiency. Comparing the efficiency scores of the two groups of countries, they showed that OECD countries are more technically efficient than non-OECD countries. This is due by the fact that OECD countries have a higher share of geothermal, solar, tide and wind fuel in renewable energy although non-OECD countries have a higher share of renewable energy in their total energy supply than OECD economies.

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[6] Organisation for Economic Co-operation and Development (OECD)

NelaVlahinić-Dizdarević and Šegota (2012) examined the trend of energy efficiency in all the European Union countries over the period 2000-2010 and compared their results with the traditional energy intensity indicator. They applied the DEA model with constant return of scale using three factors (capital, labor and energy consumption) and a product (GDP). Their empirical results confirmed that the traditional indicator of energy efficiency (energy intensity) is too simple and could be misleading. They showed that the energy efficiency scores of total factor production reflect the possibility of substitution of medium-term factors of production and a change in the composition of energy consumption. In addition they found that countries with the higher share of quality fuels like electricity and natural gas are more efficient, while the lower quality energy sources (wood and coal) are the worst energy efficiency performers. Their results revealed that all countries are inefficient and suggested that energy efficiency could be improved by reducing some of the inputs.

Zhang et al (2011) used the total factor production to investigate energy efficiency in 23 developing countries during the period of 1980–2005. Their empirical results indicated that Botswana, Mexico and Panama perform the best in terms of energy efficiency, whereas Kenya, Sri Lanka, Syria and the Philippines perform the worst during the entire research period. In addition, they found that seven countries showed little change in energy efficiency over time; eleven countries experienced continuous decreases in energy efficiency and among five countries witnessing continuous increase in total-factor energy efficiency, where China experienced the most rapid rise. This study argued that China's success in improving energy efficiency is due to the implementation of effective energy policies such as improving technological level and restructuring industries and energy products.

Another wave of the studies analyzed energy efficiency by considering negative effects of CO_2 emission as "undesirable output". Based on Input-Oriented DEA approach, Dogan and Tugcu (2015) estimated the technical and super efficiency scores of G-20 countries in terms of electricity production over the period 1990-2011. Their findings revealed that China and Russia appear at the top of energy efficiency while France and the European Union are inefficient. However, the study demonstrated a change in energy efficiency across countries showing that G-20 has been experiencing a transformation from monopolar structure to multipolar one in terms of energy production. The authors supported that G-20 produces or consumes approximately 85% of the world's total electricity, for that this transformation is also important for the world economy. They suggested that policy makers should aware this progress in order to avoid unexpected outcome for the future energy.

Recently, Camioto et al (2016) measured and analyzed total factor energy efficiency in BRICS countries (Brazil, Russia, India, China and South Africa) using DEA Slack Based Model. It is well known that BRICS group has shown rapid economic growth and played an important role in the world economy. The study showed that Brazil is the country with the highest energy efficiency score, followed by South Africa, China, India and Russia. They explained that the good positioning of Brazil may be the result of support mechanism for energy efficiency promoted by the federal government. Indeed, Brazil has implemented in previous decades important national programs of energy polices which are still in operation such as energy conversation, energy rationalization and good regulation. These previous studies demonstrated that energy efficiency depends on development of new sources of energy (renewable energy). In line with the second wave of the literature on energy efficiency, our study aims to investigate energy efficiency in West Africa countries. It differs from the previous ones by comparing energy efficiency with and without undesirable output and calculates the excesses in inputs and shortfall in the economic output.

3. Methodology

In this section, we measure the energy efficiency using standard DEA and Slack Based DEA models. In the first approach, energy efficiency is analyzed without undesirable output while the second take into account of undesirable output. Before presenting the mathematic program using to estimate the energy efficiency, we show through a simple scheme to explain how we measure the energy efficiency.

3.1. Analytics framework

The relationship between energy and economic growth and more generally the role of energy in economic production has been widely discussed in the economic discipline. Initially, the traditional neoclassical growth theory usually think of capital, labor and land as the primary factor of production. Energy that represents an important natural capital has been neglected. Resource and Ecological economists have criticized the theory that energy plays a minor role in economic growth, for example the implications of thermodynamics for economic production and the long-term prospects of the economy (Stern, 2004). This debate started from 1970s where authors exposed the existence of biophisical 'limit to growth' which would eventually bring economic growth down. From these criticisms, models of economic growth have included energy, and several empirical evidences have been developed subsequently, with particular emphasis on environmental aspects.

Some economists tested the causality links between energy and economic growth with or without CO_2 emission. Others authors analyzed energy efficiency, environmental efficiency or ecological efficiency by coupling energy consumption with traditional factors of production and an economic output (Gross Domestic Product). In recent years, researchers have attached great importance to measuring energy efficiency in economies.

The idea is that net investment made in the country (capital stock), labor force (economically active population) and total primary energy consumption are combined to produce the Gross Domestic Product (Figure 2). Technically, the Data Envelopment Analysis which is a linear mathematical model and is used to compute a ratio called "energy efficiency score". Two hypothesis are made. Firstly, the economy consumes energy without worrying about the negative effect of energy use which is the emission of CO2 (energy efficient without CO_2 emission). Secondly, the economy is anxious to reduce the emission of CO2 caused by the consumption of energy and then improvement environment quality. The idea behind the second analysis is to understand the country is energy efficient is he shifts towards modern energy use.

The DEA model is implemented according the objectives (orientations) that the Decision Making Unit can set: output-oriented, input-oriented and input-output-oriented. In the case of our study, we suppose that the economy aims to:

- use less energy, capital and labor for a given level of GDP (input-oriented)
- reach a maximum level of GDP for a given amount of energy, capital and labor (output-oriented);
- Use less energy while maximizing GDP and reducing CO2 emission given capital and labor available (input-output-oriented).

The outputs of the linear mathematic model provide the energy efficiency score which is the ratio of observed to the maximum potential GDP. The observed or actual GDP is what the country realizes while the potential GDP is what the country can realize if she combine in the best way the inputs: energy, capital and labor. The model outputs also provide the input and output slacks representing the excesses or wastes in inputs and shortfall in output. The most energy-efficient economy will have an energy efficiency score equal to one with null excess in energy, capital, labor and CO_2 and null shortfall in GDP. The less energy-efficient economy will have an energy efficiency score lower to one and the presence of excesses in energy, capital, labor and CO_2 and shortfall in GDP.

This section showed the analytics framework to understand how energy efficiency is analyzed. The following presents more technically the Data Envelopment Model.

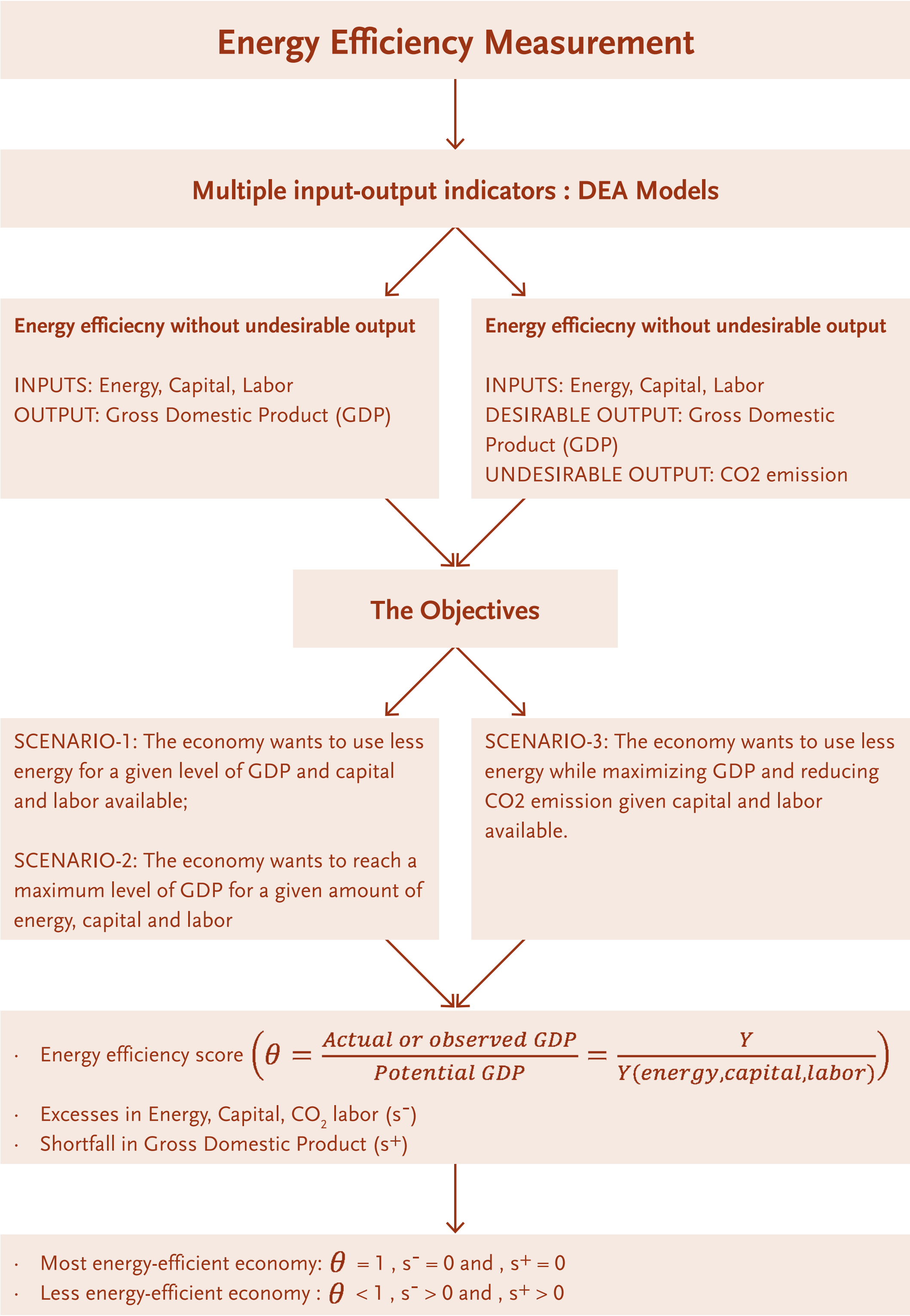

FIGURE 2. ANALYTICS FRAMEWORK OF ENERGY EFFICIENCY MEASUREMENT (AUTHOR)

3.2. Standard DEA model

We first briefly introduce the basic DEA method to be used to estimate energy efficiency score without undesirable output. Consider that there are n countries ($DMUs$)[7] need to be evaluated and each DMU_j utilizes m inputs x_{ij} $(1,2,\dots,m)$ to produce s outputs, y_{rj} $(r = 1,2,\dots,s)$. In the case of our study, the m inputs are (Energy consumption, capital stock and labor)[8] and the sole output is the Gross Domestic Product (GDP). The relative efficiency scores for the DMU_{j0} are determined by the mathematical program below developed by Charnes, Cooper and Rhodes (1978):

$$\min_{\theta,\lambda} \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \qquad (1)$$

$$s.t \begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- \leq \theta x_{ij0}, & i = 1,\dots,m \qquad (2) \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ \geq y_{rj0}, & r = 1,\dots,s \qquad (3) \\ s_i^- \geq 0, s_r^+ \geq 0, \lambda_j > 0, & j = 1,\dots,n \qquad (4) \end{cases}$$

θ is the energy efficiency score to be estimated by combining the inputs (energy, capital and labor) and is comprise between 0 and 1. S^- and S^+ are slack variables representing the excess in inputs (energy, capital and labor) and shortfall in output (GDP). λ_j is scalar positive vector. ε is called non-Archimedean, which is defined as infinitely small, or less than any real positive number. The presence of ε is to take into account in the minimization of the efficiency score the optimization of the slacks S^- and S^+. The optimal solution of the program above is to determine $(\theta^*, \lambda_j^*, s_i^{-*}, s_r^{+*})$. DMU_{j0} is efficient if $\theta^* = 1$, and $s_i^{-*} = 0, s_r^{+*} = 0$. DMU_{j0} is weakly efficient if $\theta^* = 1$ and $s_i^{-*} \neq 0, s_r^{+*} \neq 0$. If $\theta^* < 1$, DMU_{j0} is said inefficient. The model (1) can be estimated under the directions Input-Oriented or Output-Oriented. In the first case, this means that the Decision Making Unit minimizes the input to obtain a given level of output. In the second case, this means he maximizes the output given the inputs. In the case of our study, the direction Input-Oriented is explained by the fact that the economy will obtain given level of GDP by minimizing energy, capital and labor available in the country. The direction Oriented-Output means that the economy seeks to realize a maximum of GDP given the amount of energy, capital and labor.

3.3. Slack Based DEA model with undesirable output

We use the Slack Based DEA Model developed by Tone (2001) to estimate energy efficiency in presence of undesirable output. It takes into account of input and output slacks in the efficiency measure unlike standard DEA models. It allows maximizing the outputs while minimizing the inputs. We now consider that each country (DMU) utilizes m inputs x_{ij} $(1,2,\dots,m)$ to produce not only s desirable outputs, y_{rj}^g $(r = 1,2,\dots,s)$ and q undesirable outputs y_{pj}^b $(r = 1,2,\dots,q)$. In the case of our study, the economy utilizes three inputs (Energy, capital and labor) to produce an economic output (Gross Domestic Product) while produce a bad output or environmental output (CO_2 emission). When analyzing energy efficiency with undesirable output, the first difficulty is how to treat undesirable outputs jointly with the desirable outputs, and this leads to impose assumptions

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[7] Decision Making Unit

[8] Capital and labor are the two main factors of production in an economy. Capital stock is the total amount of physical capital at any particular moment in time. Labor is the nation's labor force representing the amount of physical, mental and social effort used to produce goods and service in an economy.

about the disposability of undesirable outputs (Yang and Pollitt, 2007, 2009). Undesirable outputs can be weakly disposable (e.g. Fare et al., 1989, 1996; Tyteca, 1996) or strongly disposable (Korhonen and Luptacik, 2004). The first assumption supposes that if one wishes to reduce undesirable outputs, good outputs must be also reduced for a given level of inputs. The second assumption means that undesirable outputs can be reduced without reducing any desirable outputs. In the case of our study we accept weak assumption and adopt the second model of Tyteca (1996) which minimizes the ratio of the weighted sum of inputs and undesirable outputs over the desirable outputs. Energy efficiency through the Slack Based DEA Model can be measured as (Chu et al., 2016).

$$\min \rho^* = \frac{1-\left(\frac{1}{m+q}\right)\left(\sum_{i=1}^{m} s_i^-/x_{ij} + \sum_{p=1}^{q} s_p^b/y_{pj}^b\right)}{1+\frac{1}{s}\sum_{r=1}^{s} s_r^g/y_{rj}^g} \qquad (2)$$

$$s.t\begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} = x_{ij0} - s_i^-, & i = 1,\dots,n \\ \sum_{j=1}^{n} \lambda_j y_{rj}^g = y_{rj0}^g + s_r^g, & r = 1,\dots,s \\ \sum_{j=1}^{n} \lambda_j y_{pj}^b = y_{pj0}^b - s_r^b, & p = 1,\dots,q \\ s_i^- \geq 0, s_r^g \geq 0, s_r^b \geq 0, \lambda_j > 0, & j = 1,\dots,n \end{cases}$$

ρ represents the SBM efficiency score. The ratio ρ is defined as the mean reduction rate in inputs and undesirable output to the mean expansion rate to output. In other words, the SBM efficiency is interpreted as the product of output and inputs inefficiencies. S_i^-, S_r^g and S_r^b are the slacks corresponding respectively to inputs, desirable outputs and undesirable outputs of the $(DMUs)$. S_i^- and S_r^b are excesses in inputs and bad outputs and S_r^g is the shortfall in good output. The model (2) is nonlinear programming problem and cannot be solved directly. In order to determine the efficiency score ρ, the model (2) is transformed into a linear programming problem (model 3) using Charnes-Cooper transformation (Charnes and Cooper, 1962). The model (3) is written as follows:

$$min\ \rho_d^* = t - \left(\frac{1}{m+q}\right)\left(\sum_{i=1}^{m} S_i^-/x_{ij} + \sum_{p}^{q} S_p^b/y_{pj}^b\right) \qquad (3)$$

$$s.t\begin{cases} \sum_{j=1}^{n} \mu_j x_{ij} = t x_{ij0} - S_i^-, & i = 1,\dots,m \\ \sum_{j=1}^{n} \mu_j y_{rj}^g = t y_{rj0}^g + S_r^g, & r = 1,\dots,s \\ \sum_{j=1}^{n} \mu_j y_{pj}^b = y_{pj0}^b - S_r^b, & p = 1,\dots,q \\ t + \frac{1}{s}\sum_{r=1}^{s} S_r^g/y_{rj}^g = 1 & \\ S_i^- \geq 0, S_r^g \geq 0, S_r^b \geq 0, \lambda_j > 0, & j = 1,\dots,n \end{cases}$$

Transforming model (2) into (3), $t = \frac{1}{1+\frac{1}{s\sum_{r=1}^{s} s_r^g / y_{rj}^g}}$; $S_i^- = ts_i^-$; $S_r^g = ts_r^g$; $S_r^b = ts_r^b$ and $\mu_j = t\lambda_j$.

By resolving the model (3), the optimal solution obtained is $\left(\rho_d^*, t^*, \mu_j^*, S_i^{-*}, S_r^{b*}, S_p^{g^*}, \forall\, i, r, p\right)$.

From the optimal solution of model (2), the optimal solution is found as follows:

$$(\rho^*, \lambda_j^* = \mu_j^*/t^*, s_i^{-*} = S_i^{-*}/t^*,\ s_r^{g^*} = S_r^{g^*}/t^*, s_r^{b^*} = S_r^{b^*}/t^*, \forall\, i, r, p)$$

The DMU_{j0} is efficient in presence of undesirable output id only if $\rho^* = 1$, i.e., $s_i^{-*} = 0 s_i^{-*} = 0$, and $s_r^{b^*} = 0$. The DMU_{j0} is said inefficient is $\rho^* < 1$.

3.4. Resource Efficiency Analysis

An inefficient DMU_{j0} can be improved and become efficient by deleting the excesses in input and bad outputs, and augmenting the shortfall in good outputs by the following projection:

$$\hat{x}_{j0} \leftarrow x_{j0} - s^{-*}$$
$$\hat{y}_0^g \leftarrow y_0^g - s^{g*}$$
$$\hat{y}_0^b \leftarrow y_0^b - s^{b*}$$

We analyze resources efficiency use by calculating excesses in energy, capital, labor and CO_2 and shortfall in Gross Domestic Product. This analysis will highlight in which proportion the excesses should be reduced to increase simultaneously Gross Domestic Product in the economy. The analysis of resource efficiency is based on input slacks (excesses) and output slacks (shortfalls). We estimated the slacks following three objectives that the economy can set and defined as scenarios:

- Scenario 1: The economy uses less energy, capital and labor for a given level of GDP (input-oriented) **[Objective oriented-input];**
- Scenario 2: The economy maximizes the Gross Domestic Product given the resource (energy, capital and labor) **[Objective oriented-output];**
- Scenario 3: The economy maximizes the Gross Domestic Product while minimizing the resources (energy, capital and labor) **[Objective oriented input-output].**

The resource efficiency analysis consists of determining the GDP surplus that can be achieved if excess inputs (energy, capital and labor) and excesses in bad output (CO_2 emission) were reduced.

4. Empirical Analysis

4.1. Data

This study employs the data of fifteen (15) West Africa countries to empirically estimate the total factor energy efficiency over the period 1990-2013. The fifteen countries include Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. Data are collected for each country on the same period. The study considers five (05) variables, namely three inputs (capital, labor and energy), one desirable output (Gross Domestic Product) and one undesirable output (CO2 emission). The selected variables are described in the Table 1. The data on total primary energy consumption (in millions of tons equivalent oil) and CO2 emission (million Metric tons) are collected from the International Energy Agency (IEA). Labor force (in millions of people) is defined as the economically active population ages 15 and older.

TABLE 1: DESCRIPTION OF THE SELECTED INDICATORS AND DATA

	Variables	Indicators	Unit	Sources
Inputs	Capital	Gross Fixed capital	Million US$ in 2005[9]	UNTACD
	Labor	Total labor force	Million of people	World Bank (WDI)
	Energy	Total primary energy consumption	Million of tons equivalent oil (Mtoe)	International Energy Agency (IEA)
Desirable Output	Economic output	Real Gross Domestic Product (GDP)	Million US$ in 2005	World Bank (WDI)
Undesirable Output	Environmental output	CO_2 Emission	Million Metric Tons (MMT)	International Energy Agency (IEA)

Source: Authors

The descriptive statistics of all the variables are shown in the Table 2. In average, the total primary energy consumption on the period 1990-2013 for all the countries is around 2.302 million of tons equivalent oil (Mtoe) and the CO_2 Emission is around 7.908 Million Metric Tons. The countries that consume the most energy in the region are Nigeria, Ghana and Côte d'Ivoire with average consumption level of 22,433 Mtoe, 3.687 Mtoe and 2.698 Mtoe, respectively. These countries are also the ones that emit the most CO_2 with production level of 91.718 MMT, 5.972 MMT and 5.875 MMT, respectively. Countries with a low level of consumption of primary energy are Cape Verde, Guinea-Bissau and Gambia with average value of 0.171 Mtoe, 0.120 Mtoe and 0.108 Mtoe, respectively. The average quantity of CO_2 emission for these countries is 0.220 MMT, 0.300 MMT and 0.366 MTT, respectively.

The average GDP for all the countries over the period of our study is 14.965 Million US$ (constant 2005). The average capital is 1.647 Million US$ (constant 2005) and the average number of active population is 5.666 million.

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[9] Real Gross Domestic Product (real GDP) is the value of economic output adjusted for price changes (i.e., inflation or deflation), base year 2005.

TABLE 2: DESCRIPTIVE STATISTICS OF THE OUTPUT AND INPUT VARIABLES (1990-2013)

DMU	Countries	Capital	Labor	Energy	GDP	CO2
1	Benin	0.979	2.981	0.857	4.291	2.350
2	Burkina Faso	1.100	5.528	0.458	4.782	1.162
3	Cape Verde	0.360	0.171	0.087	0.948	0.220
4	Côte d'Ivoire	3.366	6.348	2.698	16.705	5.875
5	Gambia	0.143	0.551	0.108	0.571	0.300
6	Ghana	3.571	8.558	3.687	16.054	5.972
7	Guinea	0.738	3.630	0.565	3.714	1.366
8	Guinea-Bissau	0.050	0.564	0.120	0.576	0.366
9	Liberia	0.130	1.021	0.179	0.608	0.504
10	Mali	1.179	3.569	0.308	6.099	0.625
11	Niger	0.727	3.948	0.421	3.170	1.029
12	Nigeria	9.971	40.729	22.433	155.559	91.718
13	Senegal	1.801	3.374	1.723	7.647	4.723
14	Sierra Leone	0.230	1.714	0.301	1.672	1.020
15	Togo	0.359	2.291	0.581	2.081	1.048
	Max	21.935	54.159	30.967	287.810	105.601
	Min	0.012	0.113	0.025	0.116	0.096
	Average	**1.647**	**5.665**	**2.302**	**14.965**	**7.909**
	Std.dev	3.153	9.854	5.567	41.724	22.633

Max: Maximum; Min: Minimum and Std.dev: Standard deviation.

5. Empirical Results and Discussion

This section presents the results of energy efficiency scores and the DEA scenarios analysis of the resource efficiency of 15 member countries within ECOWAS.

5.1. Energy efficiency Scores

Tables 3 and 4 below show the energy efficiency scores without and with undesirable output by means of standard DEA and Slack Based DEA models, respectively. The first is calculated using energy, capital and labor as inputs and GDP as the sole output, while the second, in addition to these previous variables, take into account of CO_2 as undesirable output. Table 3 shows that for all the countries energy efficiency changed over time. Countries are fully energetically efficient with a score equal to 1 for a small number of years and are inefficient for the other years. No one of the countries showed a constant trend of full energy efficiency over the period of the study. The results indicate that in average on the period of the study, Benin, Guinea and Senegal, Burkina Faso and Gambia have the highest efficiency score in absence of consideration of CO_2 emission, while Sierra Leone, Togo, Nigeria, Mali and Liberia are the less energetically efficient (Fig.3). The highest average energy efficiency score over the study period is 0.98 (for Benin, Guinea and Senegal). Mali and Liberia present the lowest average energy efficiency scores with respectively 0.78 and 0.69.

TABLE 3: ENERGY EFFICIENCY WITHOUT UNDESIRABLE OUTPUT

Year	Benin	Burkina Faso	Cape Verde	Côte d'Ivoire	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Niger	Nigeria	Senegal	Serria Leone	Togo
1990	1.00	1.00	0.93	1.00	0.97	0.80	1.00	0.90	0.76	0.61	1.00	0.66	0.95	1.00	1.00
1991	0.98	0.97	0.86	1.00	0.96	0.78	0.98	0.91	0.71	0.61	1.00	0.65	1.00	0.92	1.00
1992	0.94	0.97	0.87	1.00	0.95	0.86	0.96	0.92	0.49	0.71	1.00	0.65	0.93	0.93	0.99
1993	0.94	0.95	0.80	0.93	0.97	0.87	0.95	0.92	0.35	0.72	0.94	0.64	0.97	1.00	1.00
1994	0.94	0.86	0.72	0.90	0.98	0.83	0.94	0.93	0.34	0.72	0.91	0.64	1.00	0.99	0.97
1995	0.98	0.93	0.83	0.92	0.94	0.87	0.94	0.97	0.34	0.62	0.92	0.67	0.98	0.92	0.93
1996	0.98	0.94	0.77	0.93	0.96	0.85	0.96	1.00	0.20	0.65	0.93	0.66	0.95	0.66	0.97
1997	0.98	0.83	0.87	0.96	1.00	0.86	0.97	1.00	0.38	0.67	0.92	0.66	0.93	0.91	1.00
1998	0.98	0.87	0.93	0.99	0.96	1.00	1.00	0.93	0.45	0.84	1.00	0.67	0.94	0.82	0.91
1999	0.99	0.93	0.92	0.97	1.00	1.00	0.99	1.00	0.52	0.87	1.00	0.67	0.94	1.00	0.94
2000	0.98	0.92	1.00	0.94	1.00	0.80	0.99	0.92	0.84	0.82	0.94	0.68	0.95	0.60	0.85
2001	0.99	0.98	1.00	1.00	0.98	0.84	1.00	0.93	1.00	0.80	0.94	1.00	1.00	0.59	0.82
2002	1.00	1.00	0.98	1.00	0.95	1.00	1.00	0.88	1.00	0.82	0.95	1.00	0.99	0.68	0.77
2003	0.98	0.99	1.00	0.94	0.94	1.00	1.00	0.84	0.85	0.82	0.98	1.00	0.99	0.71	0.77
2004	0.99	0.97	0.91	0.94	1.00	0.93	0.98	0.88	0.78	0.73	0.91	0.86	0.99	0.69	0.77
2005	0.99	0.96	0.97	0.93	0.97	0.96	0.98	0.90	0.65	0.74	0.94	0.84	1.00	0.99	0.75
2006	1.00	1.00	0.99	0.96	0.93	0.97	0.96	0.89	0.68	0.77	0.96	0.81	1.00	0.87	0.74
2007	0.98	0.99	0.96	0.93	0.92	1.00	0.99	0.88	0.71	0.79	0.95	0.93	1.00	1.00	0.76
2008	1.00	1.00	1.00	0.91	0.95	0.98	1.00	0.91	0.79	0.80	1.00	0.96	0.99	1.00	0.74
2009	0.98	0.98	0.99	0.94	0.98	1.00	0.97	0.90	0.89	0.84	0.90	1.00	1.00	0.97	0.73
2010	0.97	1.00	0.96	0.91	1.00	0.96	1.00	0.91	0.92	0.87	0.93	0.98	0.99	0.84	0.72
2011	0.97	1.00	0.98	1.00	0.94	1.00	0.99	0.96	0.95	0.92	0.92	1.00	0.96	0.88	0.73
2012	0.98	1.00	1.00	0.91	0.98	0.98	1.00	0.90	1.00	1.00	1.00	0.99	0.99	1.00	0.73
2013	1.00	1.00	1.00	0.94	0.97	1.00	0.91	1.00	1.00	1.00	0.97	1.00	0.99	1.00	0.75
Mean	**0.98**	**0.96**	**0.93**	**0.95**	**0.96**	**0.92**	**0.98**	**0.92**	**0.69**	**0.78**	**0.95**	**0.82**	**0.98**	**0.87**	**0.85**

Source: Author's calculation

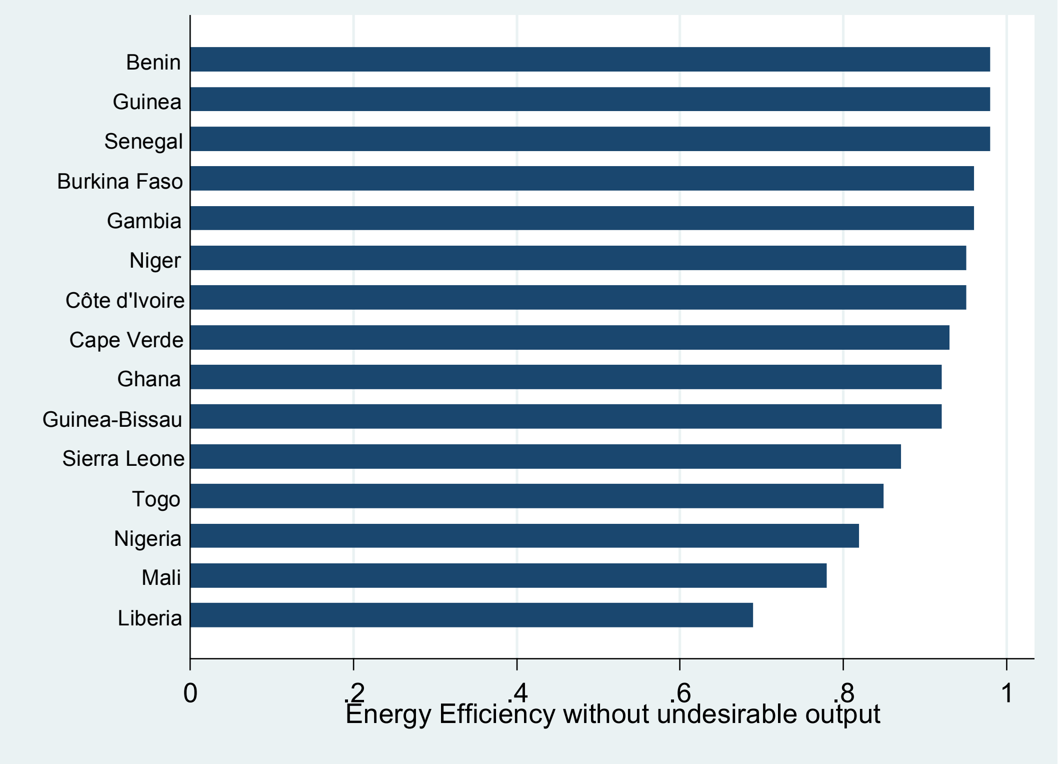


FIGURE 3: RANKING OF THE AVERAGE ENERGY EFFICIENCY SCORE (WITHOUT UNDESIRABLE OUTPUT) BY COUNTRY OVER THE PERIOD 1990-2013

Like the results of table 3, those of table 4 show that for all the countries energy efficiency changed over time. Countries are also fully energetically efficient with a score equal to 1 for a small number of years and are inefficient for the other years. The five first countries with a high level of energy efficiency score are Senegal, Niger, Benin, Burkina Faso, and Ghana (Fig.4). Nigeria, Togo, Mali and Liberia remained the less efficient in energy use. Senegal presents the highest average energy efficiency score over the study period with a value of 0.92, while Mali and Liberia still present the lowest average energy efficiency score with a value of 0.68 and 0.65, respectively.

With regard to the figures 2 and 3, we observe that some countries rose in rankings in energy efficiency, while other fell in ranking when we take into account of the undesirable output (CO_2 emission). For example, Senegal moved up from the 3th rank (efficiency score without CO_2 emission) to the 1st rank (efficiency score with CO_2 emission). Niger moved up from the 6th rank to the 2nd rank. Ghana moved up from the 9th rank to the 5th rank. Benin fell from the 1st rank to the 3th rank. Guinea fell from the 2nd rank to the 10th rank. Burkina Faso and Côte d'Ivoire kept the 4th rank and the 7th rank in terms of energy efficiency.

The inconstant trend of the energy efficiency scores in the countries can be explained by energy consumption pattern, the instable energy supply and the inefficient use of inputs (capital and labor). Indeed, energy consumption in the region is dominated by the use of biomass-based energy source. An increase of biomass consumption generates more (CO_2) and pollutes the environment. As indicated our results, the assessment of energy efficiency without taking into account CO_2 emissions overestimates the efficiency scores. Prior studies on energy efficiency analysis have not shown this particular result by comparing energy efficiency without undesirable output and with undesirable output in order to show that CO2 emissions reduce energy efficiency. However, these studies found that the countries or regions that emit more CO_2 are energetically inefficient (Bampatsou et al., 2013; Li and Wang, 2014; Wang et al., 2013).

TABLE 4: ENERGY EFFICIENCY WITH UNDESIRABLE OUTPUT

Year	Benin	Burkina Faso	Cape Verde	Côte d'Ivoire	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Niger	Nigeria	Senegal	Serria Leone	Togo
1990	1.00	1.00	0.75	1.00	0.90	0.82	0.66	0.75	0.58	0.49	1.00	0.60	1.00	1.00	1.00
1991	0.95	0.90	0.64	1.00	0.88	0.82	0.66	0.77	0.71	0.49	1.00	0.57	1.00	0.85	1.00
1992	0.87	0.90	0.65	1.00	0.88	0.83	0.79	0.77	0.48	0.54	1.00	0.56	0.91	0.86	1.00
1993	0.89	0.88	0.65	0.89	0.93	0.86	0.81	0.82	0.33	0.55	0.89	0.56	0.89	1.00	1.00
1994	0.86	0.80	0.64	0.85	0.93	0.81	0.75	0.85	0.27	0.56	0.84	0.57	0.82	1.00	0.92
1995	0.93	0.85	0.70	0.85	0.89	0.84	0.81	0.92	0.26	0.53	0.87	0.57	0.82	0.89	0.91
1996	0.95	0.90	0.70	0.77	0.90	0.83	0.80	1.00	0.18	0.56	0.89	0.57	0.84	0.64	1.00
1997	0.96	0.73	0.77	0.84	1.00	0.86	0.81	1.00	0.32	0.57	0.89	0.59	0.92	0.65	1.00
1998	0.96	0.79	0.83	0.89	0.95	1.00	0.85	0.90	0.40	0.62	1.00	0.62	0.91	0.62	0.87
1999	0.97	0.87	0.86	0.77	1.00	1.00	1.00	1.00	0.46	0.64	1.00	0.63	0.92	1.00	0.80
2000	0.93	0.85	1.00	0.77	1.00	0.79	0.68	0.77	0.82	0.63	0.91	0.66	0.92	0.52	0.65
2001	0.95	0.96	1.00	1.00	0.94	0.83	0.71	0.79	1.00	0.68	0.91	1.00	0.96	0.56	0.73
2002	1.00	1.00	0.96	1.00	0.78	1.00	1.00	0.75	1.00	0.70	0.93	1.00	0.94	0.64	0.62
2003	0.90	1.00	1.00	0.81	0.79	0.98	0.90	0.73	0.82	0.76	0.98	1.00	1.00	0.67	0.52
2004	0.94	0.93	0.68	0.82	1.00	0.91	0.80	0.78	0.75	0.68	0.92	0.78	0.98	0.64	0.52
2005	0.99	1.00	0.80	0.80	0.91	0.95	0.84	0.82	0.67	0.66	0.95	0.71	1.00	0.94	0.51
2006	1.00	1.00	0.96	0.92	0.81	0.96	0.82	0.81	0.58	0.70	1.00	0.71	1.00	0.83	0.51
2007	0.90	0.95	0.90	0.83	0.75	1.00	0.79	0.76	0.59	0.73	1.00	0.86	1.00	1.00	0.50
2008	1.00	1.00	1.00	0.76	0.84	0.96	0.81	0.79	0.65	0.72	1.00	0.89	0.98	1.00	0.55
2009	0.84	0.89	0.91	0.81	0.92	1.00	0.89	0.81	0.83	0.79	0.90	1.00	1.00	0.92	0.61
2010	0.74	0.98	0.84	0.78	1.00	0.93	0.88	0.83	0.90	0.83	0.89	0.95	0.98	1.00	0.49
2011	0.75	1.00	0.87	1.00	0.85	1.00	1.00	1.00	0.91	1.00	0.91	1.00	0.95	0.76	0.56
2012	0.86	1.00	1.00	0.84	0.90	1.00	1.00	0.79	1.00	1.00	1.00	0.97	0.96	1.00	0.54
2013	1.00	1.00	1.00	0.79	0.92	1.00	0.77	1.00	1.00	1.00	0.79	1.00	1.00	1.00	0.54
Mean	**0.92**	**0.92**	**0.84**	**0.87**	**0.90**	**0.92**	**0.83**	**0.84**	**0.65**	**0.68**	**0.93**	**0.76**	**0.94**	**0.83**	**0.72**

Source: Author's calculation

Moreover, apart from Côte d'Ivoire, Ghana and Nigeria, the countries in West Africa region are largely energy importers. Fuel and oil supply problems, dysfunction and obsolescence of energy equipment and infrastructure, capacity constraints in neighboring energy exporting countries, political crises and civil wars have limited the continued availability of energy needed to support economic activities. As a result, all of these factors have reduced energy consumption during some periods. Another reason is that insufficient and inadequate investments in physical and human capital are associated with low modern energy consumption and access to energy. All this affects the economic growth opportunities of these countries. As said Schultz (1961): "the capacity to absorb physical capital may depend on investments in human capital". We will see in the following sub-section, through the DEA scenarios models, how the inefficient use of the resources of the economy leads to shortfalls in Gross Domestic Product (GDP).

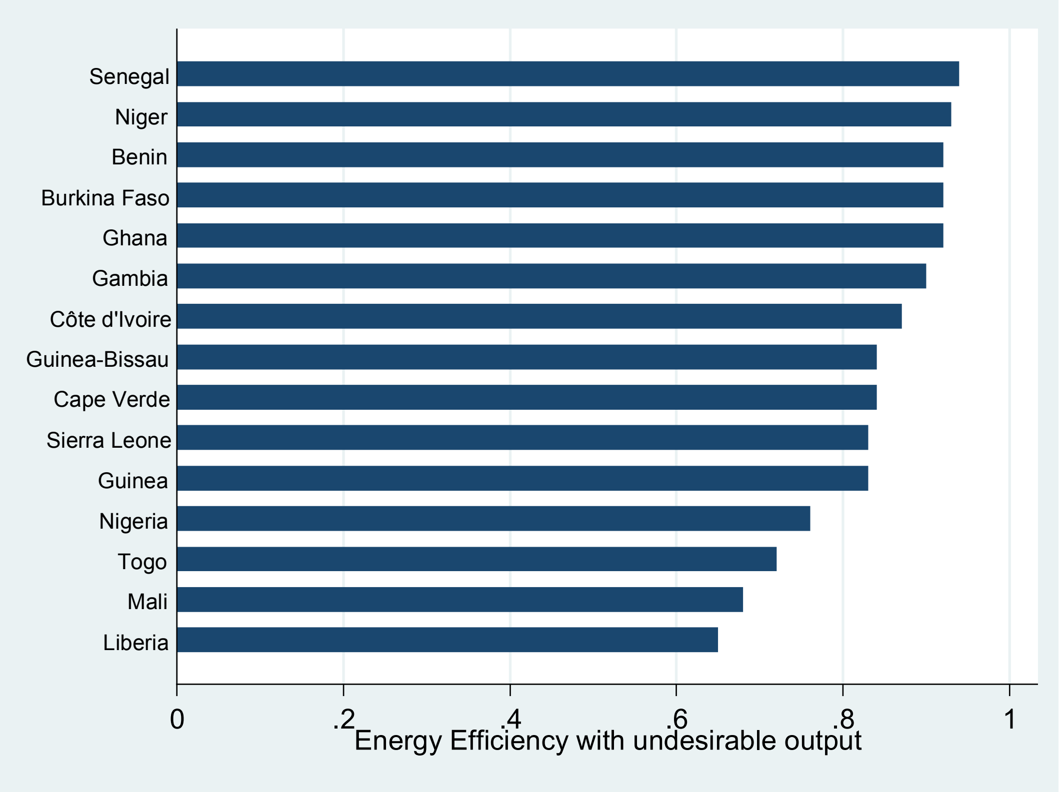


FIGURE 4: RANKING OF THE AVERAGE ENERGY EFFICIENCY SCORE
(WITH UNDESIRABLE OUTPUT) BY COUNTRY OVER THE PERIOD 1990-2013

We observe that the energy efficiency scores without undesirable output is greater or equal than the energy efficiency scores with undesirable output in all the country over the study period (Fig.4). Indeed, DEA standard models (CCR and BCC) measure the technical efficient in terms of the maximal radial contraction to its inputs level (input orientation) or the expansion to its outputs level under feasible under efficient operation (output orientation). Unlike to the standard DEA model, which are based on the proportional reduction of inputs or expansion of outputs, Slack Based Model deal directly with input excesses and output shortfall in the efficiency score measurement (Tone, 2001). It provides a pure measure of technical efficiency score and could take into account of undesirable output.

These results confirm the importance to take into account of negative impact of energy consumption when analyzing energy efficiency. Energy efficiency does not depend only on the optimization of total production factor in order to achieve a good economic performance but also on an important reduction of CO_2 emission. These results highlight that a better assessment of energy efficiency should not neglect CO_2 emission in the analysis in order to show the environmental efficiency in energy consumption.

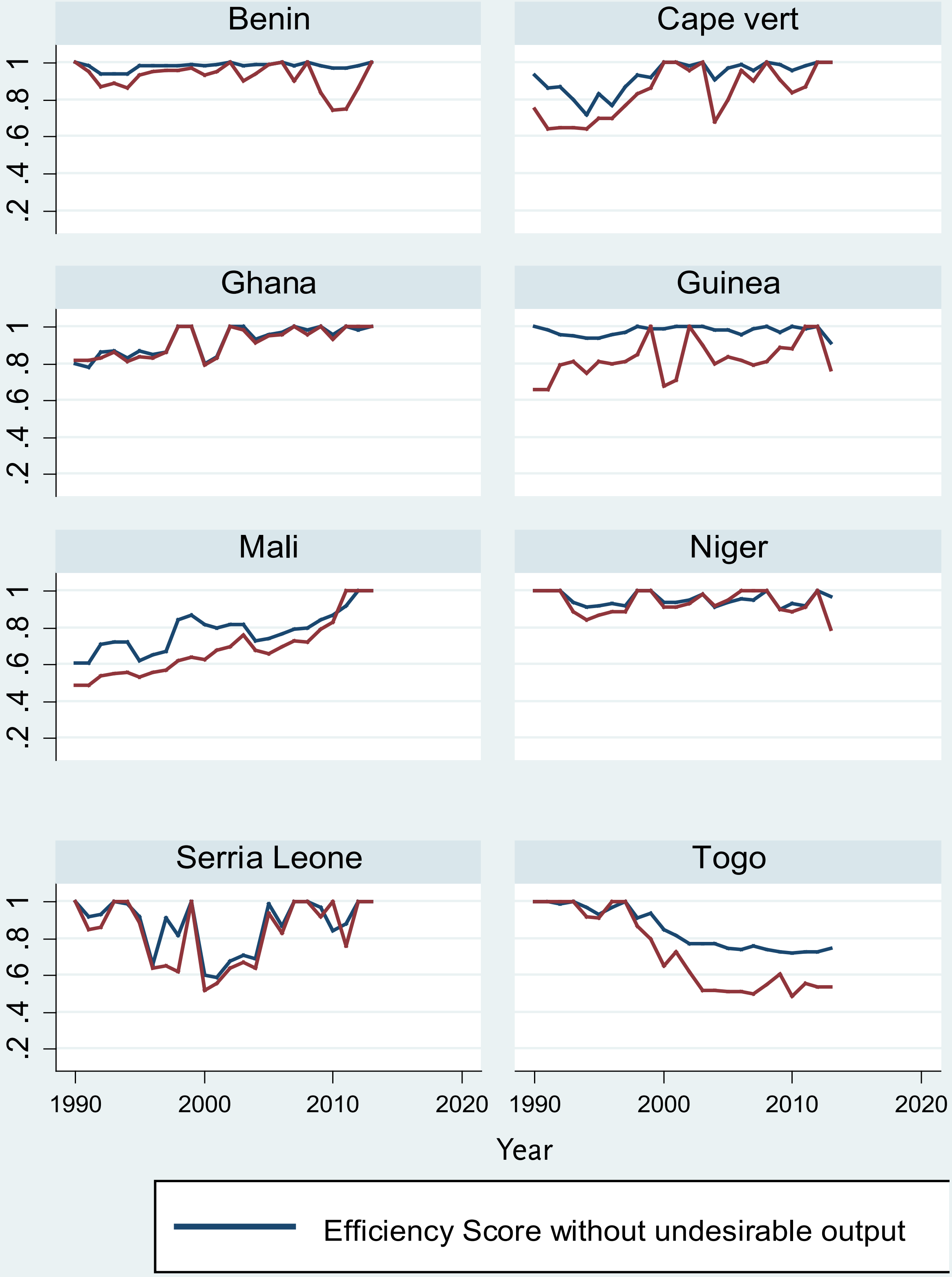
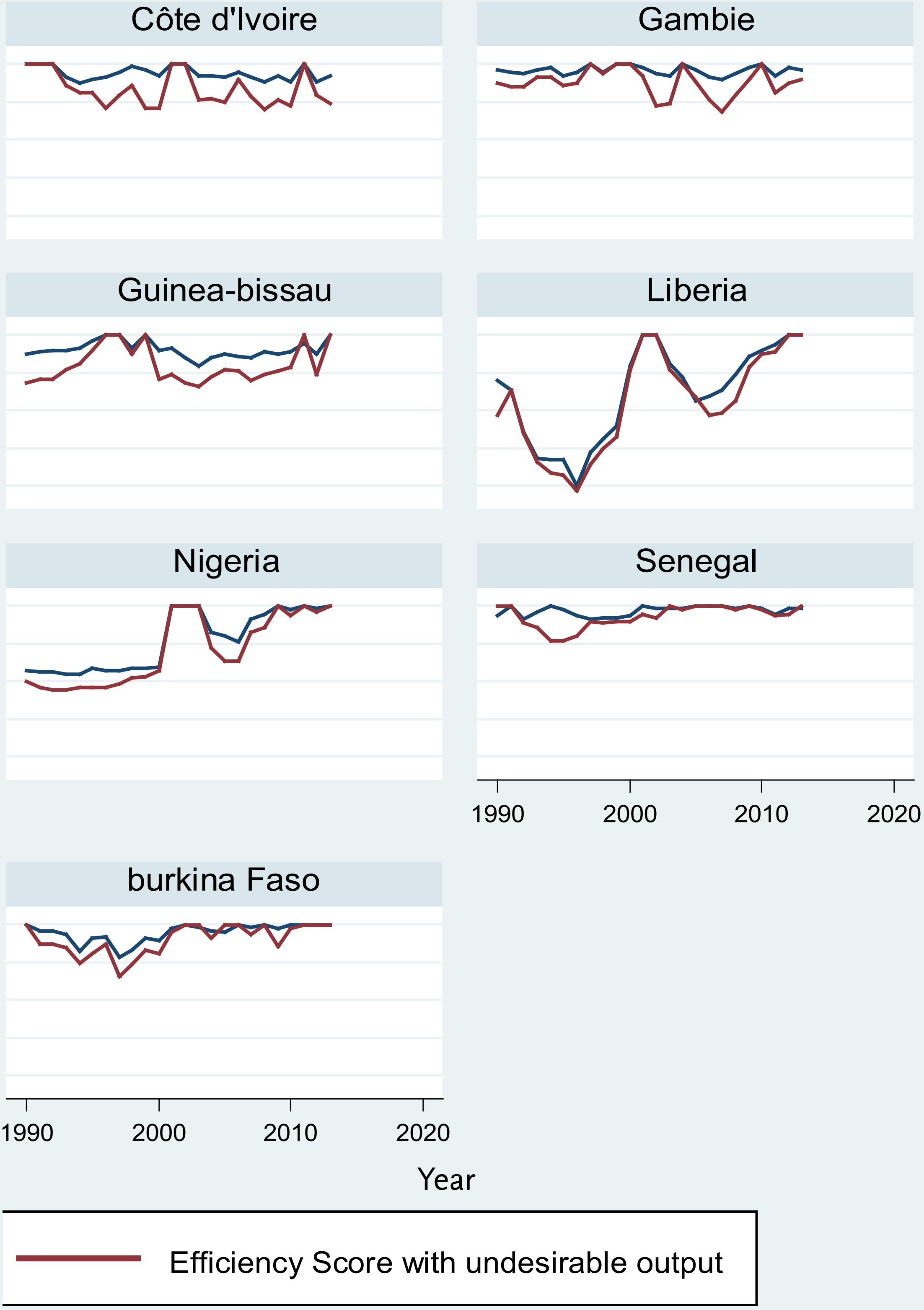


FIGURE 5: TREND OF ENERGY EFFICIENCY WITH AND WITHOUT CO2 EMISSION IN ECOWAS COUNTRIES, OVER THE PERIOD 1990-2013


Côte d'Ivoire
Gambie
Guinea-bissau
Liberia
Nigeria
Senegal
burkina Faso
1990
2000
2010
2020
Year
Efficiency Score with undesirable output

5.2. Resource efficiency

In this section, we analyze the resource efficiency using input slacks (energy, capital and labor), undesirable output slacks (Co_2 emission) and desirable output slacks (GDP). Input and undesirable output slacks are defined as excesses (s^-) and desirable output slacks are defined as shortfall (s^+). We estimated the slacks following three objectives that an economy can set regarding the management of the resources (energy, capital and labor) to realize a good economic performance. The objectives are defined by the following scenarios:

- **Scenario-1:** The economy wants to use less energy for a given level of GDP and capital and labor available;
- **Scenario-2:** The economy wants to reach a maximum level of GDP for a given amount of energy and capital and labor available.
- **Scenario-3:** The economy wants to use less energy while maximizing GDP and reducing CO2 emission given capital and labor available.

The results presented in Table 5 show that excesses in energy, capital, labor and CO_2 are lower in the scenarios 1 and 2 and shortfalls in GDP are null. However, the excesses in inputs and Co_2 and shortfall are higher in scenario 3. This scenario based on Slacked Based DEA model allow one to see the proportion of waste generated in resources utilization and the economic performance that could be achieved if the resources were used efficiently. Excesses in energy use are higher in Togo (39.9%), Guinea (22.4%), Benin (15.4%), Mali (14.9%) and Cape Verde (13.7%). The countries with lower excesses in energy use are Burkina Faso (5.6%), Côte d'Ivoire (5.6%), Senegal (6.6%) and Ghana (6.9%). The countries with higher excesses in energy use are those with higher excesses in CO_2 emission: Togo (58.1%), Guinea (24.9%), Mali (22.2%), Cape Verde (21.8%) and Benin (17.5%). Ghana, Côte d'Ivoire, Burkina Faso and Niger and Senegal showed low excesses in CO_2 emission with 2.8%, 5.2%, 7.4%, 7.5% and 7.6%, respectively. The countries showing higher shortfall in GDP are: Liberia (25.6%), followed by Mali (20.8%), Nigeria (8.9%), Sierra Leone (8.7%), Guinea (8.7%) and Togo (8.6%). Benin, Senegal, Gambia, Ghana and Côte d'Ivoire are low proportion in terms of GDP shortfall with, 0.04%, 0.06%, 0.17%, 0.40% and 0.92%, respectively.

TABLE 5 : INPUT SLACKS, OUTPUT SLACKS AND PROJECTION OF GDP

Benin					
Scenarios	**Energy** **s-**	**Capital** **s-**	**Labor** **s-**	**CO2** **s-**	**GDP** **s+**
Average	**0.857**	**0.979**	**2.981**	**2.350**	**4.291**
Scenario 1	0.031 (3.61%)	0.014 (1.37%)	0 (0%)		0 (0%)
Scenario 2	0.023 (2.74%)	0.015 (1.52%)	0 (0%)		0 (0%)
Scenario 3	0.132 (15.4%)	0.041 (4.18%)	0 (0%)	0.413 (17.57%)	0.002 (0.04%)

Burkina Faso					
Scenarios	**Energy** **s-**	**Capital** **s-**	**Labor** **s-**	**CO2** **s-**	**GDP** **s+**
Average	**0.458**	**1.100**	**5.528**	**1.162**	**4.782**
Scenario 1	0.007 (1.52%)	0.001 (0.09%)	0.128 (2.31%)		0 (0%)
Scenario 2	0.008 (1.74%)	0.001 (0.09%)	0.135 (12.27%)		0 (0%)
Scenario 3	0.025 (5.67%)	0.008 (0.72%)	0.385 (6.94%)	0.086 (7.40%)	0.05 (1.10%)

Cape Verde

Scenarios	Energy s-	Capital s-	Labor s-	CO2 s-	GDP s+
Average	**0.087**	**0.360**	**0.171**	**0.220**	**0.948**
Scenario 1	0.0002 (0.23%)	0.005 (1.38%)	0.004 (2.33%)		0 (0%)
Scenario 2	0.0003 (0.34%)	0.005 (1.38%)	0.004 (2.33%)		0 (0%)
Scenario 3	0.012 (13.79%)	0.014 (3.88%)	0.008 (4.67%)	0.048 (21.81%)	0.021 (2.21%)

Côte d'Ivoire

Scenarios	Energy s-	Capital s-	Labor s-	CO2 s-	GDP s+
Average	**2.698**	**3.366**	**6.348**	**5.875**	**16.705**
Scenario 1	0.071 (2.63%)	0.465 (13.81)	0.001 (0.01%)		0 (0%)
Scenario 2	0.075 (2.77%)	0.481 (14.28%)	0.001 (0.01%)		0 (0%)
Scenario 3	0.153 (5.67%)	1.209 (35.91%)	0.078 (1.22%)	0.308 (5.24%)	0.154 (0.92%)

Gambia

Scenarios	Energy s-	Capital s-	Labor s-	CO2 s-	GDP s+
Average	**0.108**	**0.143**	**0.551**	**0.300**	**0.571**
Scenario 1	0 (0%)	0.012 (8.39%)	0 (0%)		0 (0%)
Scenario 2	0 (0%)	0.013 (9.09%)	0 (0%)		0 (0%)
Scenario 3	0.009 (8.33%)	0.032 (22.37%)	0.0001 (0.01%)	0.029 (9.66%)	0.001 (0.17%)

Ghana

Scenarios	Energy s-	Capital s-	Labor s-	CO2 s-	GDP s+
Average	**3.687**	**3.571**	**8.558**	**5.972**	**16.054**
Scenario 1	0.033 (0.89%)	0.024 (0.67%)	0 (0%)		0 (0%)
Scenario 2	0.038 (1.03%)	0.024 (0.67%)	0 (0%)		0 (0%)
Scenario 3	0.257 (6.97%)	0.424 (11.87%)	0.062 (0.72%)	0.168 (2.81%)	0.065 (0.40%)

Guinea

Scenarios	Energy s-	Capital s-	Labor s-	CO2 s-	GDP s+
Average	**0.565**	**0.738**	**3.630**	**1.366**	**3.714**
Scenario 1	0.003 (0.53%)	0 (0%)	0.001 (0.02%)		0 (0%)
Scenario 2	0.003 (0.53%)	0 (0%)	0.001 (0.02%)		0 (0%)
Scenario 3	0.127 (22.47%)	0.144 (19.51%)	0.410 (11.29%)	0.341 (24.96%)	0.325 (8.75%)

Guinea-Bissau

Scenarios	**Energy**	**Capital**	**Labor**	**CO2**	**GDP**
	s-	**s-**	**s-**	**s-**	**s+**
Average	**0.120**	**0.050**	**0.564**	**0.366**	**0.576**
Scenario 1	0.006 (5%)	0.002 (4%)	0.0005 (0.08%)		0 (0%)
Scenario 2	0.007 (5.83%)	0.002 (4%)	0.0006 (0.10%)		0 (0%)
Scenario 3	0.01 (8.33%)	0.017 (34%)	0.0008 (0.14%)	0.040 (10.92%)	0.023 (3.99%)

Liberia

Scenarios	**Energy**	**Capital**	**Labor**	**CO2**	**GDP**
	s-	**s-**	**s-**	**s-**	**s+**
Average	**0.179**	**0.130**	**1.021**	**0.504**	**0.608**
Scenario 1	0.004 (2.23%)	0.003 (2.30%)	0.013 (1.27%)		0 (0%)
Scenario 2	0.007 (3.91%)	0.004 (3.07%)	0.024 (2.35%)		0 (0%)
Scenario 3	0.015 (8.37%)	0.039 (30%)	0.043 (4.21%)	0.048 (9.52%)	0.156 (25.65%)

Mali

Scenarios	**Energy**	**Capital**	**Labor**	**CO2**	**GDP**
	s-	**s-**	**s-**	**s-**	**s+**
Average	**0.308**	**1.179**	**3.569**	**0.625**	**6.099**
Scenario 1	0.026 (8.44%)	0.081 (6.87%)	0.165 (4.62%)		0 (0%)
Scenario 2	0.036 (11.68%)	0.094 (7.97%)	0.251 (7.03%)		0 (0%)
Scenario 3	0.046 (14.93%)	0.092 (7.80%)	0.234 (6.55%)	0.139 (22.24%)	1.2689 (20.80%)

Niger

Scenarios	**Energy**	**Capital**	**Labor**	**CO2**	**GDP**
	s-	**s-**	**s-**	**s-**	**s+**
Average	**0.421**	**0.727**	**3.948**	**1.029**	**3.170**
Scenario 1	0 (0%)	0.038 (5.22%)	0.004 (0.10%)		0 (0%)
Scenario 2	0 (0%)	0.040 (5.50%)	0.005 (0.12%)		0 (0%)
Scenario 3	0.033 (7.83%)	0.046 (6.32%)	0.069 (1.74%)	0.078 (7.58%)	0.032 (1.01%)

Nigeria

Scenarios	**Energy**	**Capital**	**Labor**	**CO2**	**GDP**
	s-	**s-**	**s-**	**s-**	**s+**
Average	**22.433**	**9.971**	**10.729**	**91.718**	**155.159**
Scenario 1	0.243 (1.08%)	0.094 (0.94%)	0.020 (0.18%)		0 (0%)
Scenario 2	0.334 (1.48%)	0.096 (0.96%)	0.030 (0.28%)		0 (0%)
Scenario 3	1.875 (8.35%)	2.037 (20.42%)	1.398 (13.03%)	14.314 (15.62%)	13.925 (8.97%)

Senegal

Scenarios	Energy	Capital	Labor	CO2	GDP
	s-	s-	s-	s-	s+
Average	**1.723**	**1.801**	**3.374**	**4.723**	**7.647**
Scenario 1	0.004 (0.23%)	0.178 (9.88%)	0 (0%)		0 (0%)
Scenario 2	0.004 (0.23%)	0.180 (9.99%)	0 (0%)		0 (0%)
Scenario 3	0.117 (6.67%)	0.048 (2.66%)	0.004 (0.11%)	0.362 (7.66%)	0.005 (0.06%)

Sierra Leone

Scenarios	Energy	Capital	Labor	CO2	GDP
	s-	s-	s-	s-	s+
Average	**0.301**	**0.230**	**1.714**	**1.020**	**1.672**
Scenario 1	0.006 (1.99%)	0.012 (5.21%)	0.005 (0.29%)		0 (0%)
Scenario 2	0.008 (2.67%)	0.014 (6.08%)	0.005 (0.29%)		0 (0%)
Scenario 3	0.029 (9.63%)	0.033 (14.34%)	0.089 (10.42%)	0.102 (10%)	0.147 (8.79%)

Togo

Scenarios	Energy	Capital	Labor	CO2	GDP
	s-	s-	s-	s-	s+
Average	**0.581**	**0.359**	**2.291**	**1.048**	**2.081**
Scenario 1	0.103 (17.72%)	0 (0%)	0 (0%)		0 (0%)
Scenario 2	0.135 (23.23%)	0 (0%)	0 (0%)		0 (0%)
Scenario 3	0.232 (39.93%)	0.141 (39.27%)	0.003 (0.13%)	0.609 (58.11%)	0.180 (8.65%)

Source: Author's calculation

6. Conclusion and Policy Recommendation

In this study, we investigated total-factor energy efficiency in the fifteen West Africa economies over the period 1990-2013. We employed standard DEA and Slack Based DEA model to estimate energy efficiency scores with undesirable output (CO_2 emission) and without undesirable output, respectively. We consider capital, labor and primary energy consumption as inputs, CO_2 emission as undesirable output and Gross Domestic Product as desirable output. Energy efficiency was examined in two steps. In the first step, efficiency scores were estimated and in the second step we computed the slacks in inputs and outputs regarding the target that an economy can set about energy use.

Benin, Guinea and Senegal, Burkina Faso and Gambia were the most efficient when CO_2 emissions are not taken into account in the DEA model. Sierra Leone, Togo, Nigeria, Mali and Liberia are the less energetically efficient. However, country rankings changed when CO_2 emissions are included in the

Slack Based DEA model. Senegal, Niger, Benin, Burkina Faso, and Ghana became the most efficient whereas Nigeria, Togo, Mali and Liberia remained the less efficient. For all the countries energy efficiency changed over time. No one of the countries show a constant trend of full energy efficiency over the period of the study. Energy inefficiency and inconstant trend are explained by some factors such as: Fuel and oil supply problems, dysfunction and obsolescence of energy equipment and infrastructure, capacity constraints in neighboring energy exporting countries, political crises and civil wars. All these factors limited the continued availability of energy needed to support economic activities. Based on DEA scenarios, we found that, all the countries generate excesses in energy use causing shortfall in Gross Domestic Product. The slack based DEA model highlights that if countries reduced excesses in energy use and CO2 as well as used efficiently capital and labor, they would have increased the Gross Domestic Product.

Policy lessons that could be drawn from this study is that countries should decrease energy consumption from biomass and fuel fossil and better develop renewable energy in order to improve energy efficiency. Countries have potential in biomass energy that can be used to produce renewable energy. Energy policies that encourage the production of secondary energy from biomass can increase the availably of clean energy and support a sustainable growth.

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Factors Influencing the Use of Non–Food Agricultural Biomass for Renewable Energy Generation:

A Stakeholders' Analysis in the Gambia, West Africa

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Abstract

Imbalance in energy production and consumption by some developing countries contribute to their low economic development. In this article, a new Bioenergy Acceptance Model with six constructs and 52 items was tested using The Gambia as a case study. The uncorrelated factors in each construct were extracted through Principal Component Analysis. These were tested for relationship with the respondents' demographic variables such as age, gender, religion, level of education, and institution using Pearson's Chi-square. Eleven (11) main factors influencing the use of non-food agricultural biomass for bioenergy generation were identified. These were tagged as feedstock, technological, social, institutional, deciding, motivating, environmental, crosscutting, comparative, economic, and inducing. Many key stakeholders are involved in The Gambian energy sector but some differ in terms of their key roles. Significant relationship ($p<0.05$) between stakeholders' gender and social factors and also between stakeholders' age groups and factors such as technology and relativity was observed. There was no significant relationship ($p>0.05$) among all the identified factors and stakeholders' institutions categorized as Government and public sectors, private sectors, university and research institutions, international organizations, non-governmental organizations, farmers and rural dwellers. There are diverse opinions among the stakeholders concerning the use of non-food agricultural biomass for renewable energy generation. Information generated in this study is relevant for developing countries in terms of formulating evidence-based policies and projects on bioenergy.

KEYWORDS: BIOENERGY ACCEPTANCE MODEL, AGRICULTURAL BIOMASS, RENEWABLE ENERGY, THE GAMBIA, FACTOR, STAKEHOLDER

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1. Introduction

There is still energy deficiency in many developing African countries. Amigun et al. (2008) indicated that up to 70% of countries in Africa were getting their energy supply through importation. Such gaps in energy production and consumption by developing countries contribute to their low economic development. The social, economic and industrial development goals of West African countries such as The Gambia are still being hampered by energy insufficiency, weak regulatory frameworks for exploring alternative sources of energy generation, and climate change (EREP, 2012; Ouedraogo, 2013). Furthermore, heavy reliance on conventional fossil fuels for energy generation often predisposes consumers in those countries to price fluctuations. There is therefore a need for urgent actions to reduce importation of fuels by exploring alternative renewable sources (Amigun et al., 2011). Also, inadequacy in terms of availability and accessibility to reliable energy sources in African countries have led to certain health and environmental challenges such as deforestation (Amigun et al., 2011; Brew-Hammond, 2010). It is therefore important for governments to explore alternative forms of energy generation including the use of non-food agricultural biomass as a source of bioenergy.

Agricultural biomass remains one of the most promising sources of renewable energy for cooking and heating in developing countries (Field et al., 2008; Mohammed et al., 2013; Ozturk & Bascetincelik, 2006). According to Saidur et al. (2011), biomass derived from crops and waste products is among the primitive sources of energy. Various biomass materials utilizable for energy production were elaborately described by Amigun et al. (2010), Brew-Hammond (2010) and Saidur et al. (2011). Locally available biomass which include agricultural residues accounted for more than 75% of energy used in West African countries (Ouedraogo, 2013). With an intensive system of agricultural production, up to 45% of global arable land can still be used for biomass production (Wolf et al., 2003). Conversion of biomass to enhance energy security in the West African rural and peri-urban areas where energy insufficiency still persists had already been reported by (Amigun et al., 2012; Bensah & Brew-Hammond, 2010; Brew-Hammond, 2010; Mohammed et al., 2013). However, only a few studies have examined factors affecting the use of agricultural biomass from stakeholders' perspectives. Stakeholders in this context refer to independent persons or groups with interest in using non-food agricultural biomass to generate renewable energy. These include government and public sectors, private sectors, university and research institutions, international funding organizations, farmers' organizations, and non-governmental organizations.

Due to combination of many factors, the benefits of agricultural biomass as a potential source of renewable energy is yet to be fully realized in the Member States of Economic Community of West African States (ECOWAS) such as The Gambia. Some reasons for this include insufficient mobilization of funding (Brew-Hammond, 2010), few policies to support energy production (Amigun et al., 2011), little awareness about alternative renewable energy (Arthur et al., 2011), and inadequate access to modern energy services (Ouedraogo, 2013). This understanding motivated ECOWAS and her partners to encourage Member States to develop national policy and favourable institutional framework for generation and sustainable utilization of renewable energy (EREP, 2012). Meanwhile, renewable energy based on agricultural biomass is among the options that could be explored in a bid to achieve goals of Sustainable Energy for All by 2030. Achieving such goal calls for engaging stakeholders in identifying factors and non-food agricultural biomass options which would enhance or otherwise limit sustainable production and utilization of renewable energy.

This study is exploratory in nature and it focuses on the possibility of using non-food agricultural biomass as a source of bioenergy. Non-food agricultural biomass such as post-harvest crop residues, forest products, energy crops, animal waste and manure that are used in bioenergy production were targeted. The general objective is to identify crucial factors and non-food agricultural biomass options that could be considered in designing projects and policies for renewable energy generation, using The Gambia as a case study. The country was chosen based on the increasing activities of the government to reduce dependence on imported fossil-based fuels. The Gambia Renewable Readiness Assessment (IRENA, 2013) and Gambian Renewable Energy Act (GREA, 2013) were among the key policy strategies taken by the country up to date.

2. Methodology

The research questions were answered through desk review, use of questionnaires and focus group discussions (Figure 1). Review of scientific articles, technical reports and relevant policy documents was used to acquire additional information on the subject matter of investigation. Opinions from stakeholders at the village levels were gathered through three Focus Group Discussions (FGDs) in the North Bank, Upper River and West Coast Regions of The Gambia. Each FGD also served as awareness creation on potential of renewable energy in the country. In designing the questionnaire, two prominent theories called Technology Acceptance Model (Venkatesh & Bala, 2008) and Theory of Planned Behaviour (Ajzen, 2002; Lindenberg & Steg, 2007) were systematically combined to form a composite model tagged as Bioenergy Acceptance Model (Figure 1). Based on this new model in Figure 2, six constructs namely Perceived Behavioural Control (A), Subjective Norms (B), Intention (C), Attitudes toward Behavior (D), Perceived Usefulness (E), and Cues to Action (F) were used. The six constructs tested are as described in Table 1. Altogether, the six constructs contained 52 items testing the Bioenergy Acceptance Model. Each item of the questionnaire was answered on a 5-point Likert scale by a minimum of 168 respondents.

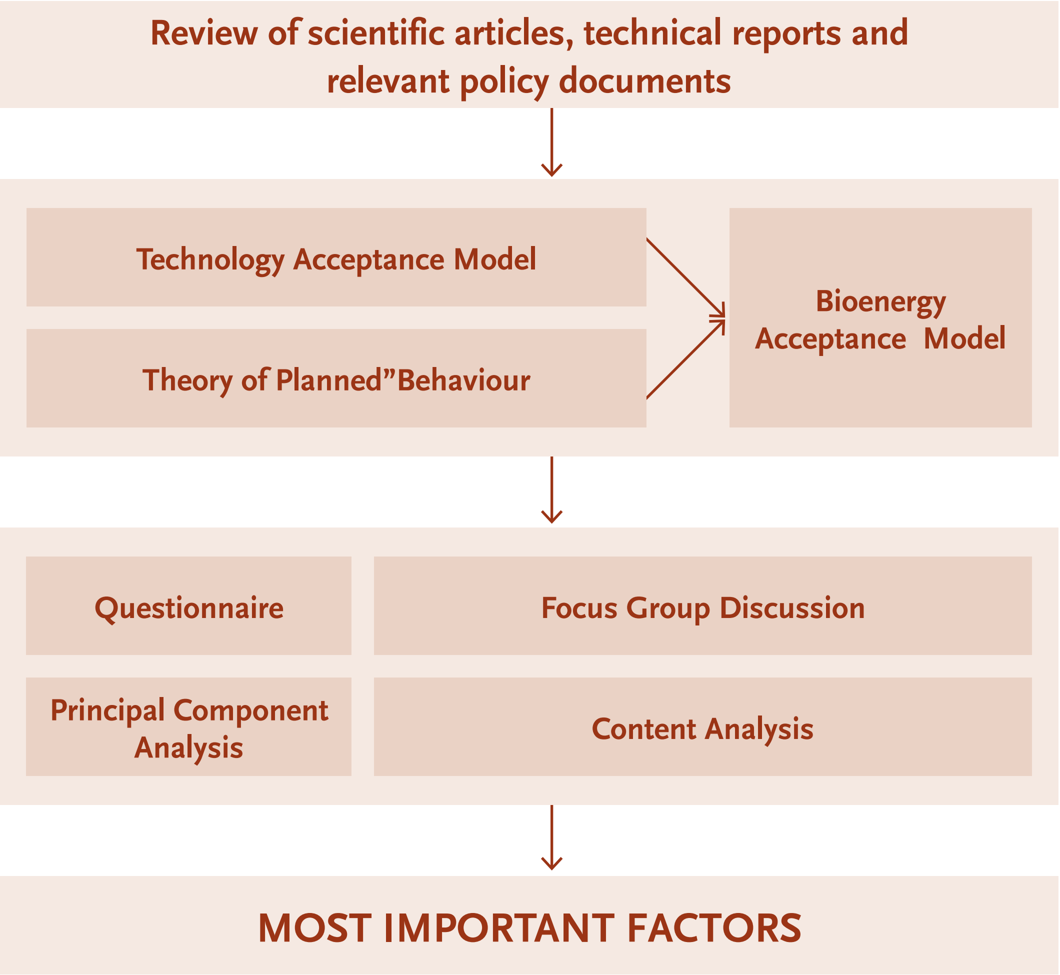

FIGURE 1: THE RESEARCH THEORETICAL FRAMEWORK AND FINAL OUTPUTS

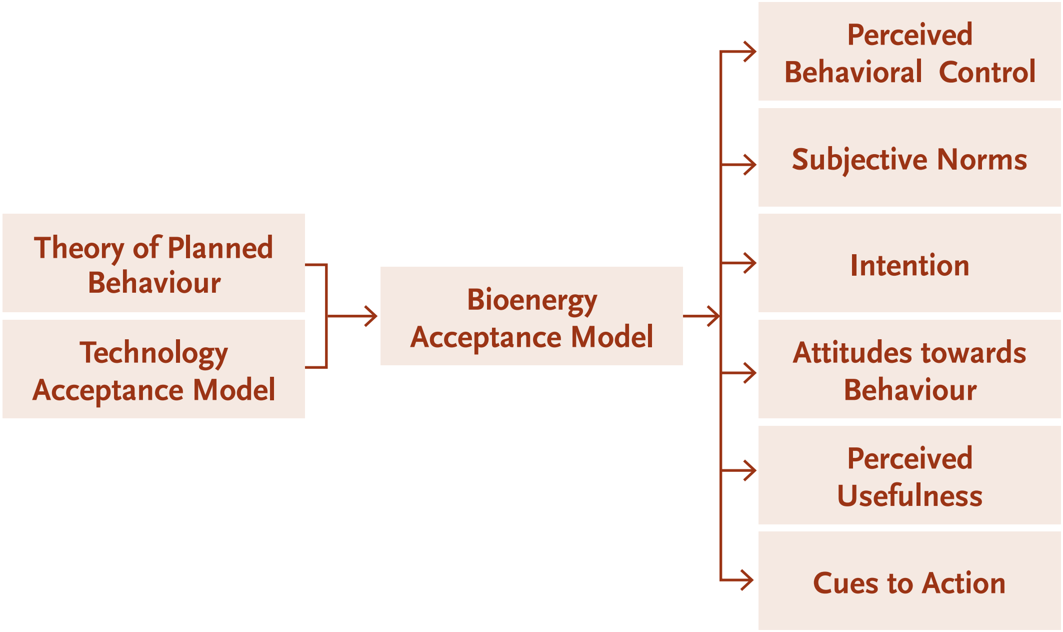

FIGURE 2: CONSTRUCTS OF THE BIOENERGY ACCEPTANCE MODEL

TABLE 1: DESCRIPTION OF THE CONSTRUCTS ASSESSED UNDER THE BIOENERGY ACCEPTANCE MODEL

Constructs	Labels	Definitions
Perceived Behavioral Control	A	Perceived ease or difficulties with regard to using agricultural biomass for production of renewable energy (RE).
Subjective Norms	B	Social influence in relation to the use of agricultural biomass to produce RE.
Intention	C	Indicators in relation to adoption or non-adoption of agricultural biomass to produce RE.
Attitudes towards Behaviour	D	Indicators of what can motivate energy consumers to use agricultural biomass to generate RE.
Perceived Usefulness	E	Energy consumers' activities which can be improved by using agricultural biomass to generate RE.
Cues to Action	F	Necessary actions by The Gambian government and other stakeholders that can promote utilization of agricultural biomass to generating RE.

Demographic information of the respondents such as age, gender, religion, level of education, and type of organization was assessed through descriptive analysis using frequency counts and percentages. Responses to the Likert-scale questionnaire were coded as 1, 2, 3, 4 and 5 to represent "I strongly disagree", I disagree", "neutral", "I agree", and "I strongly agree" respectively. Descriptive analysis of the respondents' demographic variables (age, gender, religion, institution, and number of years at work) was carried out using the Statistical Package for Social Sciences (SPSS - version 22). Cronbach's Alpha coefficient was used to determine internal consistence and reliability of each questionnaire constructs (Figure 2).

The Principal Component Analysis (PCA) approach was used to reduce the 52 items captured in the six constructs of the questionnaire (Table 2) to a minimum set of uncorrelated components without loss of information. Appropriateness of each construct for PCA was examined through ratio of sample size to variables (at least 6:1), at least 2 correlations with values >0.3 in the correlation matrix of the variables, Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy (>0.50) and Bartlett's test (p<0.05). Variance loadings within each component were maximized and Oblimin with Kaiser normalization was set as the rotation option. Latent root condition for number of components to be retained was based on Eigenvalue-one criterion (Tabachnick and Fidell, 2001). In each construct, a component was retained if its Eigenvalue is greater than 1. Within a construct, the amount of variance explained decreases from the first loading component to the last one.

Each extracted component was named based on the value of highest loading item in that construct. To complete the stakeholder analysis, relationships among the components extracted by PCA and the demographic variables such as age, gender, religion, education levels, and institutions of the respondents were assessed using Pearson's Chi-square. This approach was based on the hypothesis that each extracted component was dependent on demographic variables of stakeholders. 5% was set as the significance level.

3. Results

There are many key stakeholders in The Gambian energy sector. They were classified as government/public institutions; private sector; Non-Governmental Organizations; Universities and research institutions; and Farmers' groups. The stakeholders' categories differ in terms of their key roles in renewable energy generation. Depending on the context, some of them play multiple roles in policy formulation, regulation, finance, knowledge generation, advocacy, research and development.

Based on Cronbach's Alpha coefficient in Table 2, items captured in construct F measuring 'cues to action' were the most consistent with a total value of 87%. This was closely followed by the constructs labelled E, C, A in a decreasing order. The constructs B and D both had the same Cronbach's Alpha coefficient of 81%. All the constructs met the condition of Kaiser-Meyer-Olkin measure of sampling adequacy (minimum 0.50) and the Bartlett's test of sphericity (p<0.05). KMO for the measured constructs ranged from 0.77 (Attitudes towards behaviour) to 0.84 (cues to action). In Table 2, % variance explained indicating the amount of variability in the data that has been modelled by the extracted components varied from 54% (construct E and F) to 70% (construct D).

TABLE 2: QUESTIONNAIRE ITEMS AND CORRESPONDING COMPONENT LOADINGS

S/n	Constructs	Labels	No of items	Cronbach's Alpha	KMO	Extracted components	% Variance explained
1.	Perceived Behavioral Control	A	9	0.83	0.79	2	59
2.	Subjective Norms	B	9	0.81	0.79	2	55
3.	Intention	C	9	0.84	0.81	2	61
4.	Attitudes towards Behaviour	D	9	0.81	0.77	2	70
5.	Perceived Usefulness	E	8	0.86	0.79	2	54
6.	Cues to Action	F	8	0.87	0.84	1	54

Table 2 also indicates component loadings of the six constructs which were initially measured on a 5-point Likert-scale questionnaire. Based on Eigenvalue 1 criterion, two components each (10 altogether) were extracted by PCA from the items contained in constructs A to E. However, only one component was extracted from the 8 items in construct F (cues to action). Those 11 extracted components were the main factors influencing the use of agricultural biomass for generating renewable energy in The Gambia. In addition to the extracted factors, the column titled explanatory component in Table 2 summarizes the items which loaded together in the same component.

Evaluation of the extracted components (factors) by the stakeholder variables

The 11 components/factors extracted from the PCA were tagged with reference to the highest loading item in a particular component (Table 2). The result of Pearson's Chi-square involving the extracted factors and the stakeholders' demographic variables are presented in this section. Outputs presented in Table 3 indicate that there was a significant relationship ($p<0.05$) between stakeholders' gender and the social factors affecting use of agricultural biomass for renewable energy production in The Gambia. Such social factors include relationships at the individual, family and community levels (Table 3). Meanwhile technological, institutional, economic, production and supporting factors was not related to gender.

Significant relationship ($p<0.05$) was observed between stakeholders' age groups and factors such as technology and relativity but this was not the case for the other factors indicated in Table 4. The religious affiliation of the respondents was only related to the factors tagged as feedstock, indirect effects and specific national policy. There was no significant relationship ($p>0.05$) among all the extracted factors and stakeholders' institutions categorized as Government and public sectors, private sectors, university and research institutions, international organizations, non-governmental organizations, farmers and rural dwellers. Concerning the educational levels, significant difference ($p<0.05$) was only observed for the extracted component tagged as supporting factors.

Concerning the inducing factors (Table 5), stakeholders' age groups was not statistically related ($P>0.05$) to government supports and establishment of small production units. Stakeholders' gender and religions were only statistically ($P<0.05$) related to community-based organizations and national policy respectively. There was no statistical relationship ($p<0.05$) between inducing factor and variables such as stakeholders' level of education and type of institution where they were working.

TABLE 3: DESCRIPTION OF THE EXTRACTED FACTORS

Clusters	Variables	Highest loading items	Extracted components/ factors	Explanatory components
Perceived Behavioural Control	A1-A3	A2 (0.85)	Feedstock	Availability, collection, storage, productivity, easiness
	A4-A9	A6(0.79)	Technological	Conversion, adoption, home utilization
Subjective Norms	B1-B3	B3 (0.74)	Social	Family involvement; social relationships; community participation
	B4-B9	B6(0.88)	Institutional	Government policy and regulatory framework; stakeholder partnerships

Clusters	Variables	Highest loading items	Extracted components/ factors	Explanatory components
Intention	C1-C4	C2 (0.80)	Deciding	Availability; cost and benefit; external support; quality of RE produced
	C5-C9	C8 (0.86)	Motivating	Family capacity and need; access to information; technical and financial support; public or private support, reliability of inputs
Attitudes toward Behaviour	D1-D2, D6-D9	D8 (0.77)	Environmental	Ecosystem; behavioural change; disposal of biomass; farming systems compatibility
	D3-5	D5 (0.86)	Crosscutting	Food security; climate change adaptation; Rural development
Perceived Usefulness	E1-E5	E2 (0.86)	Comparative	Health Benefit, living standard of farmers; cleanness and safety; community facilities; industrial facilities
	E6-E8	E8 (0.89)	Economic	Job opportunities; powering of agricultural operations; quality of life
Cues to Action	F1-F8	-	Inducing	National policy; government's support; improved training; incentives to private and public sectors; establishing small production units; community-based organizations; awareness creation; research and development

TABLE 4: THE EXTRACTED FACTORS AND STAKEHOLDERS' DEMOGRAPHIC VARIABLES

Description	Age groups	Gender	Religion	Highest level of education	Institution
Feedstock	0.26	0.17	0.00**	0.12	0.74
Technological	0.00**	0.48	0.32	0.32	0.83
Social	0.82	0.02**	0.11	0.63	0.27
Institutional	0.15	0.54	0.57	0.09	0.62
Production	0.05	0.29	0.25	0.90	0.62
Supporting	0.47	0.65	0.02	0.01**	0.78
Environmental	0.08	0.20	0.13	0.33	0.46
Indirect effects	0.06	0.28	0.02**	0.33	0.69
Relativity	0.00**	0.82	0.58	0.68	0.88
Economic	0.98	0.05	0.65	0.68	0.81

** indicate significant difference at p=0.05

TABLE 5: RELATIONSHIP BETWEEN INDUCING FACTORS AND STAKEHOLDERS' DEMOGRAPHIC VARIABLES

Description	Age groups	Gender	Religion	Highest level of education	Institution
Specific national policy	0.00**	0.26	0.03**	0.41	0.87
Government support	0.10	0.06	0.16	0.67	0.77
Training of technicians	0.00**	0.29	0.21	0.24	0.87
Incentives to public/private sectors	0.00**	0.47	0.30	0.18	0.16
Small production units	0.18	0.21	0.12	0.32	0.82
Community-based organization	0.00**	0.00**	0.36	0.54	0.40
Mass media campaign	0.00**	0.17	0.12	0.84	0.37
Research and development	0.00**	0.32	0.16	0.27	0.79

** indicate significant difference at p=0.05

4. Discussion

An initial assessment in this case study of The Gambia indicated that many people are yet to be fully aware of the potential of renewable energy. Relatively low knowledge of biomass-based energy might have accounted for diverse opinions among the stakeholders concerning the use of agricultural biomass for renewable energy generation. There are also differences among countries concerning availability of non-food agricultural biomass. Besides, ECOWAS Member States vary with regard to demographic, environmental, social and political situations. However, certain clues and relevant data in this study will be relevant for similar West African countries in terms of information that could be used to formulate an evidence-based energy policy and projects.

Although there are many benefits from using non-food agricultural biomass for heating and warming purposes, there is however a challenge of collection and storage as found in this study. In addition to seasonal availability of biomass, there are also stakeholders' concerns with regard to large quantity of agricultural biomass needed for producing bioenergy. In modeling of biomass conversion to energy, Mafakheri & Nasiri (2014) and Nilsson & Hansson (2001) identified seasonality and variability in the energy supply chain as some of the challenges facing production of bioenergy. Seasonal availability of raw materials accounted for discontinuous use of bioenergy in many circumstances.

According to Singh et al. (2007) and Frombo et al. (2009), challenge of quantification and spatially scattered distribution of biomass can be overcome through the use of Geographical Information System. In that case, energy production can be concentrated to the areas with relatively high biomass availability in order to reduce transportation and labour cost. Such decision can be made based on nature of the biomass and available transportation options (Mafakheri & Nasiri, 2014). There are models concerning decisions on location and transportation (Eksioglu et al., 2010) and storage (Kanzian et al., 2009; Nilsson & Hansson, 2001) of biomass. The Bioenergy Acceptance Model proposed in this study will be relevant for accessing the interest, level of awareness and willingness to adopt bioenergy related technologies. Although this study focused on the use of non-food agricultural biomass for renewable energy production, the main concept of Biotechnology Acceptance Model can also be extended to other aspects of generating energy for rural and peri-urban dwellers in developing countries.

There is a social dimension to sustainability of using agricultural biomass for renewable energy production. The key social issues identified in this research are how to ensure participation of individuals, family and community members in bioenergy production activities. According to Thornley et al. (2008), bioenergy production can be related to creation of employment in the whole chain. The same view was also supported by Krajnc & Domac (2007) who mentioned integration and development as additional social benefits of producing biomass-based energy. On the other hand, Saidur et al. (2011) reported conflicts and social disintegration among some energy producing communities. However, with transparent communication and clear terms of engagement, some of the limiting social factors associated with the use of non-food agricultural biomass for energy production can be overcome. Stakeholders' gender because of its relationship with the social factors should be well incorporated at every stage of renewable production and consumption.

Stakeholders' gender is also an important factor in designing and operating an efficient bioenergy production system. According to Amigun, et al. (2011), gender should be considered during consultation and design of bioenergy projects. The dual roles of women in reproduction and production mentioned by Olaniyan (2016) is also important when assessing the entire supply and demand chains of bioenergy production. However, negative impacts of biomass-based production of energy on the health of women was reported by Bensah & Brew-Hammond (2010). The relativity factor mentioned in this study compares bioenergy with other forms of energy. For example, bioenergy production requires more energy and time from women when compared with fossil-based energy. However, extra time and effort utilized by women during transformation of non-food agricultural biomass to bioenergy can be compensated by health benefits they can derive from using such bioenergy. This relative advantage is expected to motivate women in deciding to produce and utilize bioenergy for cooking purposes especially in rural and peri-urban areas.

Initial investment and idleness of equipment due to lack or inadequate raw materials are some economic costs associated with use of non-food agricultural biomass for bioenergy generation. Meanwhile economic factor as identified in this study was not dependent on any of the stakeholders' variables such as age groups, gender, religion, and type of institution. According to Amigun et al. (2012), economics of biogas production and use rather depends upon a project situation. Relationship between feedstock factor and technology selection was described by Cameron et al. (2007). Bensah & Brew-Hammond (2010) focusing on Ghana indicated that women are mostly affected by high initial cost of bioenergy investment. They therefore proposed a business model involving a public-private partnership for solving such issues at the household level. Also, providing rural and peri-urban dwellers with financial and technical supports can enhance rate of adopting bioenergy for heating and cooking purposes. Other inducing factors identified in this study include establishment of small production units, research and development, and creation of community-based organizations. Careful combination of some of those suggested options can help in reducing the economic costs of bioenergy production in developing countries.

There are some institutional and policy factors affecting the use of non-food agricultural biomass for producing renewable energy in The Gambia. Although renewable energy technologies are relatively not new in this country, the level of awareness among the rural and peri-urban areas is still low as gathered from the FGDs. For Ghana, Bensah & Brew-Hammond (2010) proposed establishment of a specialized government agency that can create awareness about biogas production. Concerning institutional and policy-related challenges, ECOWAS and her partners encourage Member States to develop appropriate national policy and favourable institutional framework for generation and sustainable utilization of renewable energy (EREP, 2012). However, such policy tools should incorporate partnership among private and public sectors in order to enhance production, utilization and adoption of bioenergy. All the factors that can motivate and induce the stakeholders at their different institutional levels should be captured in governments' bioenergy policies.

To overcome some of the institutional challenges associated with renewable energy production, provision of grants, interest-free loans and mobilization of fund from local and international donors were suggested in The Gambia's National Energy Policy (NEN, 2005). The National Energy Policy which aimed at maximizing development and utilization of scarcely available energy was not isolated from other development strategies such as Vision 2020 and Poverty Reduction Strategy Paper. Involvement of private sectors in energy production, transmission, and distribution through a tariff model was recommended. As part of the policy, responsibility of the Public Utilities Regulatory Authority (PURA) as a government agency should include licensing and regulation of investment in the country's energy sector (REEP 2013). in addition, government agencies such as Departments of Agriculture, Department of Community Development, National Environmental Agency, and Ministry of Energy should be grossly involved in awareness creation and capacity building at both community and household levels.

Discussion on technological issues affecting production of renewable energy from biological sources also exists in the scientific literature. To derive optimal benefits from the use of agricultural biomass for renewable energy generation, it is required to use appropriate technologies concerning biomass production, collection, storage, transportation, transformation and distribution to final consumers. Examining the biomass supply chains, Mafakheri & Nasiri (2014) identified resource efficiency and productivity as part of the technological issues. Apart from low technical knowledge, Saidur et al. (2011) indicated there is also a challenge of proper maintenance of production facilities. However, Amigun et al. (2012) mentioned that energy production technology for African countries should be relatively simple and adaptable to the local conditions.

5. Conclusion

Knowing the factors and furthermore, the realistic agricultural biomass options for generation and utilization of bioenergy in The Gambia will help in meeting the objectives of ECOWAS Regional Renewable Energy Policy. The 11 key factors identified in this study can be relevant for achieving Sustainable Development Goals and Sustainable Energy for All targets. There are crosscutting impacts of generating renewable energy from agricultural biomass. These include its impacts on food security, ecosystem, climate change mitigation, and rural development. However, production and provision of non-fossil based fuels through sustainable approaches are the policy targets of many governments. With the price fluctuations and other effects of relying on fossil fuels, the use of agricultural biomass to produce energy is expected to be among the fore front agendas of developing countries.

The growing population of West African developing countries will not only necessitate an increase in food production, there would also be high demand for clean and safe energy from non-food agricultural biomass. Given that mechanised agricultural production is also energy intensive, the task of balancing food security with energy production is expected to remain a challenge for many developing countries. However, inclusion of energy production in agriculture and rural development strategies, establishment of specialized agencies, awareness creation and training on renewable energy can increase its adoption. Doing this in accordance with Agenda 21 of the United Nations will help to improve productivity of rural and peri-urban dwellers.

Bioenergy Acceptance Model tested in this study can also be applied to other forms of renewable energy production. The participatory approach of this study through stakeholders' involvement can enrich availability of policy-relevant data at the national level. Because the research objectives were in synergy with the agenda of The Gambia's Ministry of Energy, the output is expected to inform decision making and policies on renewable energy and energy efficiency. To overcome some of the challenges associated with renewable energy production, government and other stakeholders should pay attention to awareness creation, gender-related issues, provision of financial and technical resources, private and public partnership, research and development.

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Feasibility Study of Solar Photovoltaic Systems for Energy in Residential Homes: A Case Study of Metropolitan Lagos, Nigeria[1]

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Abstract

This report presents the feasibility of solar photovoltaic (PV) systems in meeting the energy demand (as a stand-alone or back-up for grid energy), greenhouse gas (GHG) emission reduction potential and the economic benefits that may be derived from its integration compared to the use of back-up diesel generators in residential buildings in Lagos metropolis. Data was collected from 5 different categories of dwellings (duplex, single family bungalow, traditional court yard, flat/apartment dwelling and '*face-me-I-face-you*[1]') in 5 Local Government Areas (LGAs) in Lagos metropolis. Structured questionnaires were used to collect both quantitative and qualitative data from 250 residents (10 residents each from the 5 different building types obtained across the 5 LGAs. Data collected includes building characteristics, energy demand, and policies that may influence adoption/integration of solar photovoltaics on residential buildings in the study locations. Respondents do not have knowledge on the policies of solar PV systems. However, to a very large extent they perceive the following policies may influence adoption/integration of solar photovoltaics on residential buildings in the study locations: reduced taxes on solar PV systems; grants and subsidies from local government to cut down cost of solar PV systems; awareness raising and public leadership programmes by local governments on solar PV systems

KEYWORD: ENERGY; PHOTOVOLTAIC; NIGERIA; RENEWABLE ENERGY; RESIDENTIAL BUILDINGS

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This dwelling type consist of a block of single or double rooms mainly built in two rows with a walkway in between which leads to the back of the house where shared facilities like kitchen, toilet and bathroom for the tenants are located. The term 'face- me –I- face -you' is derived from the building design which shows row of rooms to the left and right with their entrances facing each other.

1. Introduction

1.1 Background

Globally, energy security is a concern due to burgeoning human population, unprecedented depletion of natural resources and a concomitant increase in the demand of energy to drive national economies. Energy conservation through the use of innovative and cost-efficient technologies is critical in the sustainable use of natural resources (Otene et al., 2016). Furthermore, the sustainable use of natural resources is necessitated by climate change and variability as well as adverse effects of climate change on the human population and environment. The built environment is recognised for its high energy use. Energy inefficiency in buildings can be related to the use of poor building materials with high energy consumption and the use of conventional fuel associated with greenhouse gas (GHG) emissions that drives global climate change.

Energy use in buildings constitutes a large part of energy demand at the global and regional levels (Ürge-Vorsatz, 2015) contributing a major share to global environmental problems (Ürge-Vorsatz, 2013). The Intergovernmental Panel on Climate Change (IPCC) reported that in 2010, the global building sector accounted for about 32 % of final energy use, and 19 % energy-related emissions (9.18 GtCO$_2$ eq GHG emissions) (Pachauri et al., 2014). The energy demand from this sector is projected to double by mid-century with environmental impacts and implications on energy security. Nigeria's Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC) reported that energy-related activities contributed the largest (155.34 MtCO$_{2e}$) to the total greenhouse gas (GHG) emissions, accounting for about 70.4% of the country's total emissions (214.21 MtCO$_2$ eq) in 2000 (Federal Ministry of Environment Abuja-Nigeria, 2014). Nigeria is committed to adaptation and mitigation measures to climate change and variability. In 1994, the country became a Party to the United Nations Framework Convention on Climate Change, ratified its Kyoto Protocol in 2004 and submitted First and Second National Communication in 2003 and 2014 respectively. Further commitment is reflected in the country's Intended Nationally Determined Contribution (INDC) at the Paris climate summit (COP 21) in December 2015 (Federal Government of Nigeria – FGN, 2015). In addition to promoting low-carbon to build a climate resilient society, the policies and measures included in Nigeria's INDC aims to promote sustainable economic development. As reported in the INDC, about 900 million tonnes of GHG (CO$_2$, N$_2$O, CH$_4$) emissions (equivalent to 3.4 tonnes per person) is projected for Nigeria in 2030 under business as usual (BAU) scenario (assuming strong economic growth of 5 % per year, population growth of 2.5 %, and electricity access for all Nigerians both on-grid and off-grid). Targeted emission reduction below the BAU projected for 2030 is 20 % (unconditional contribution in line with current development trends and government policy priorities) and 45 % (conditional contribution with international support such as capacity building, finance and investment, and technology). Also pointed out in the INDC is potential GHG reduction of 31, 26 and 179 million tonnes per year in 2030 by key mitigation measures such as renewable energy, reduced transmission losses and economy-wide energy efficiency respectively.

The Vision 20:2020 of the Nigerian Government is to grow the country's economy from 31st position (2010 IMF's ranking of countries of the world by GDP on Purchasing Power Parity – PPP basis) to be among the 20 most developed countries of the world in 2020 by GDP ranking (FGN, 2010; Energy commission of Nigeria - ECN, 2014). This requires growing Nigeria's economy from the present annual growth rate of 6 % to 13.8 % per annum which implies increase in the country's GDP to about 900 billion USD and per capita income of 4 000 USD. Access to sustainable electricity generation is essential to achieving Vision 20:2020 of the Nigerian Government (Aliyu et al., 2013; ECN, 2014). The energy implication for Vision 20:2020 is restructuring and expanding the installed electricity capacity of the country from 4 000 MW in 2007 to 35 000 MW and petroleum refining capacity from 445 000 b/d to 750 000 barrel/day in 2015 and 1 500 000 barrel/day by 2020 (ECN, 2014). Strategies being developed to increase the presently installed capacity to the required target is the refurbishment of existing power generation units, investment in new hydro and adoption of electric thermal plants (Sonibare, 2010; Ejiogu, 2013). Independent Power Producers (IPPs) are expected to play prominent roles (Ibitoye & Adenikinju, 2007; Ejiogu, 2013). Limitations to the implementation of the policy issues of sustainable energy development of the vision 20:2020 of the federal government of Nigeria include weak government motivation, lack of economic incentives, multiple taxations, non-existent favourable customs and excise duty act to promote renewable energy technologies (Ajayi & Ajayi, 2013). Another limiting factor is the potential capacity of the Government to stimulate and regulate a sustainable future electricity system considering environmental and social imperatives (Gujba et al., 2011). Nigeria is Africa's most populous country, one fifth of the sub-Saharan African population and the largest economy in sub-Sahara Africa in 2014 with GDP per capita of about 2 950 USD (FGN, 2015). Energy commission of Nigeria (ECN, 2014) reported the following as Nigeria's energy resources: Crude oil = 36.2 billion barrels, Natural gas = 187 trillions of standard cubic feet, Coal and Lignite = 2.7 billion tonnes, Tar sands = 31 billion barrels of oil equivalent, Wind = 2 to 4 m/s (annual average) at 10 m in height, Solar radiation = 3.5 to 7.0 kWh/m^2/day with annual average of daily sunshine hours of 4-9 hr/day, Biomass (fuelwood = 11 million hectares of forest and woodland, animal waste = 245 million assorted animals, energy crops and agricultural residue = 72 million hectares of agricultural land and all waste lands, and Hydro power (large scale = 11 250 MW, small scale = 3 500 MW). As highlighted, the country is endowed with large and diverse energy resources. However, there is a significant gap between energy supply and demand such that energy supply do not meet energy demand in the country. Thermal electricity generation primarily from gas accounts for 64% of electricity generation in Nigeria while 36 % is from hydro (ECN, 2012). The country has an installed capacity of 8 425 Megawatts (MW), operational capacity of 4 125 MW which represents 50 % of the installed capacity (Adenikinju, 2003; Nnaji, 2012). The estimated peak load demand is between 22 000 MW and 25 000 MW (Udeme, 2012).

Access to reliable and clean supply of energy is a major challenge for both urban and rural dwellers in Nigeria due to low and inadequate generation and distribution capacity (Adaramola, Oyewola & Paul, 2012). Since operational capacity cannot meet the growing energy demand, private power supply for households, commercial and industrial sectors include petrol or diesel generators and traditional biomass (Ajayi & Ajayi, 2013; Ejiogu, 2013). Previous studies (Obadote, 2009; Okafor & Joe, 2010) reported that only 40% of Nigeria's population is connected to the national electricity grid with frequent power cuts (Obadote, 2009; Okafor & Joe, 2010). Majority (about 60 %) of the rural dwellers and urban poor depend on traditional fuels which accounts for 55 % of the total energy consumption in the country (ECN, 2014).

The increasing challenges of the energy sector of Lagos State and Nigeria at large include low electricity transmission and distribution network, high cost and limited access of energy by poor communities, unfavourable legal and regulatory framework for investment in grid power system, poor energy infrastructure such that undeveloped domestic market for low carbon energy options and high reliance on lowly-priced fossil oils for electricity generation which is vulnerable to climate change impacts (Building Nigeria's Response to Climate Change-BNRCC, 2012, FGN, 2015; Organisation for Economic Cooperation and Development- OECD, 2015). Similarly, Ejiogu (2013) highlighted that underinvestment over a long period of years and neglect of the sector are major factors contributing to energy crises in the country.

The inability of the national power utility to supply sufficient power to meet demand has significant impact on the country's socio-economic and technological developments (Obadote, 2009; Sambo et al., 2010). Otene et al. (2016) attributed the energy crises in the country to lack of diversification and utilization of renewable energy resources. Diversification of energy sources is economically important for sustainable development with the realities of population growth, urbanization and industrialisation (Droege, 2004). Future policy initiatives in the electricity sector should include the introduction of more renewables into the electricity mix as they have the potential to reduce considerably the life cycle environmental impacts (Gujba et al., 2011).

1.2 Report objectives

The expected increase in the population of Nigeria will require the building sector in the country to expand so as to cater for the population growth. The increase in housing will put pressure on the country's energy infrastructure which is currently inadequate in meeting the nation's electricity demand. The deployment and integration of renewable energy technologies into buildings and the existing energy infrastructure can lessen the adverse effects of climate change as well reduction in GHG emissions. With a good solar resource that ranges from 3.5-7 kWh/m^2/day (ECN, 2005), there exist potential for the generation of electricity from solar photovoltaics in Nigeria. So far, efforts to assess the solar photovoltaic renewable energy potential in Nigeria has been more focussed on grid-connected applications with limited studies conducted on the feasibility of this technology at the residential or dwelling level. The research therefore seeks to provide knowledge on the application of the solar PV technology in residential buildings in Nigeria using Lagos Metropolis as a case study. This is hinged on Lagos State being the most populous city in the country and in Africa. The aim of this study is to conduct the technical, environmental and economic feasibility of PV systems in residential buildings in Lagos State, Nigeria. This study seeks to answer the following research questions:

a) What is the technical feasibility for the use of solar PV systems in meeting the energy demand (as a stand-alone or back-up for grid energy) of residential buildings in Lagos?
b) What is the economic benefit for the integration of a solar PV in buildings in Lagos compared to the use of back-up diesel generators.
c) What are the possible impacts of government policies on photovoltaics adoption/integration in buildings?
d) To what extend will energy use from solar PV in buildings reduce greenhouse gas emissions in Nigeria?

The objectives of this study include to:

a) determine the technical feasibility for the use of a solar PV as an energy source to residential buildings in Lagos State as a stand-alone system or back-up for grid energy.
b) conduct an economic analysis for the integration of solar PV in residential buildings in Lagos State.
c) assess the possible impacts of government policies (sensitivity analysis) on the integration of solar PV in buildings.
d) conduct an environmental analysis to determine the greenhouse gas emission reduction associated with the integration of solar PV in buildings in the study area.

2. Solar Energy in Nigeria

2.1 Solar energy in Nigeria

Nigeria's energy resources, population, economy, and politics place the nation in a very vital position in sub-Saharan Africa (Diemuodeke et al., 2017). Despite this spectacular profile in sub-Saharan Africa, the energy sector in the country has been under-performing. The country's abundant renewable energy resources is yet to translate to sustainable, reliable, and affordable energy supply. Focusing on solar energy, Nigeria has good solar resource that ranges from 3.5 kWh/m^2/day in the coastal region to 7 kWh/m^2/day in the far North (ECN, 2005). Based on an average solar radiation of 5.3 kWh/m^2/day in a year, about 1770 thousand TWh/year of solar energy can fall on Nigeria's total land area of 923 768 km^2 (ECN, 2003, 2005; Ohunakin et al., 2014). Solar energy can be a source of sustainable energy to alleviate energy crisis and also contribute to sustainable socio-economic development in Nigeria. The abundance of this energy source in the country provides opportunity for solar energy applications in form of stand-alone units, off-grid decentralized systems, and large-scale grid-connected applications (Ohunakin et al., 2015; Anjorin, 2014; Njoku, 2014 & Chineke et al., 2009). Sambo (2009) reported that based on 5.3 kWh/m^2/day in a year with efficient commercial solar-electric generators, about 1850 x 103 GWh of solar electricity per year can be generated from covering 923 768 km^2 of total land area (1 %) with solar collectors or modules. Habib et al. (2012), Okafor and Joe-Uzuegbu (2010) highlighted that an average solar radiation of 5.535 kWh/m^2/day on Nigeria's total land area can generate 1.804 x 1015 kWh of incident solar energy annually. Habib et al. (2012) argued that this annual solar energy insolation value is approximately 27 times the nation's total conventional energy resources and above the electric power generation in the country by 117 000 times. Furthermore, Habib et al (2012) referring to Okafor and Joe-Uzuegbu (2010) pointed out that only about 3.7 % of the Nigeria's total land area is required to generate energy from the sun that is equal to the country's conventional energy reserve.

Habib et al. (2012) reported that solar PV of 1 % area of from twenty selected States in Nigeria has a total potential of about 1189321.65 MWh. Nonetheless, solar PV installations in Nigeria is still limited especially in the rural communities (Akorede et al., 2017). Although a gradual increase of up to 1MW in Nigeria was reported (Sambo 2010), the majority (i.e 80%) of the solar PV installations belongs to the government agencies for water pumping, street lighting, vaccine refrigerators, and community lighting whereas the domestic application is yet to be made known (Akorede et al., 2017). This is however, hampered by many factors involving but not limited to unfavorable and unsupportive government policies and incentives; lack of awareness in terms of the types, benefits and technical know-how of solar PV system; poor grid system incapable of meeting up to the conventional electricity generation technologies; design and/ or wrong sizing of the solar energy system; high operating and maintenance cost; land disputes, susceptibility to theft; and the diurnal and the site-specific nature of solar energy resource, which in Nigeria, varies from one part of the country to another (Dike et al. 2017; Akorede et al. 2017; Giwa et al., 2017).

2. 2 Economic factors of solar power generation in Nigeria

A sustainable, reliable and affordable energy supply is the driving force for any country economic development (Mohammed et al., 2017). Significant access to modern energy can help foster economic development and reduce poverty (Mohammed et al., 2017). An efficient application of decentralized energy economy that relies on locally available clean energy sources drives sustainable development in any progressive economy (Mohammed et al., 2017). Nigeria's energy generation mix is not adequately diverse despite the abundance of both renewable and non-renewable energy source (Mohammed et al., 2017). Factors that stimulate solar energy developments in Nigeria include: (a) environmental benefits such as CO_2 reduction potential; (b) growing electricity demand; (c) opportunity for reaching out to rural communities that have overtime been disconnected from the national grid system; (d) unlimited source of solar energy readily available; and; (e) opportunities for job creation (Giwa et al. 2017). Factors that limit the adoption of solar PV in Nigeria is the competitiveness between the high cost solar electricity and the subsidized imported fossil fuel products (Giwa et al., 2017). The current economic challenges with fossil fuels products as well as volatility in the global price of petroleum (Siddig et al., 2014) suggests that solar power generation can be viable in the country. Adurodija et al. (1998) examination of PV market viability in Nigeria reported a positive PV market outlook for Nigeria. In addition, the authors recommended approaches that will accelerate massive adoption of PV technology in Nigeria and they include: (a) appropriate financial plan and incentives by the government; (b) financial system adjustment to accommodate rural customers; (c) local production of PV system to support affordability; (d) employing low profit organisations in installing PV system; (f) awarding subsidies that could be gradually withdrawn as the PV system price falls; and (g) promoting Research and Development institutions in the country.

2. 3 Policies and incentives for solar energy in Nigeria

There is significant gap in government policies that could encourage solar energy use in Nigeria. No specific policy or programme with precise targets have been designed for solar PV development in Nigeria (Oparaku, 2002). The current programme and policies have only been geared towards broad goals on renewable energy development, with no specific mention of the desired contribution from PV systems (Oparaku, 2002). The existing policies are directed towards environmental conservation; energy efficiency, job creation and development of technical expertise; public enlightenment and creation of resource database; establishment of regulatory and institutional capacities for policy monitoring; promotion of private sector and incentive creation (Oparaku, 2002). Previous studies (Ohunakin et al., 2014; Okoro & Madueme, 2004) proposed the following policies to promote solar energy adoption in Nigeria: (a) provision of economic incentives like tariff waivers and subsidies; (b) creation of favorable long-term policies on solar activities to curb the fear of potential investors on instability; (c) awareness campaign for the public solar applications sensitization; (d) repayments for citizen whose lands may be used for solar development; (e) guaranteeing that a quality standards of solar power equipment are used; (f) adequate funding of a cutting edge research to ensure reliability of meteorological data; (g) training and development of personnel in solar technology and sufficient funding for research on solar application devices; (h)standardising the practice and execution of energy related projects; and (i) consistent monitoring of the progress of energy centres.

3. Solar Photovoltaic Systems

3.1 Types of PV system

Different types of PV systems exist based on their characteristics. Using system configuration, Zeman (2012) made a distinction of three basic types of PV systems including: grid connected, stand-alone, and hybrid system. The stand-alone PV system rely solely on solar power and can be connected directly to a load or can include batteries for the storage of the energy generated during the day to be used at night or during moments of poor weather conditions. Regarding the grid connected systems, they have a similar concept like power stations since the power generated is sent to the grid through grid-connected capable inverters and no battery is required for storage. Hybrid systems comprises the combination of PV panel and another means of electricity generation including but not limited to gas, wind or diesel generator and often require a more sophisticated charge control system compared to the stand-alone PV systems.

3.1.1 Stand-alone PV systems

In such a system, excess energy produced during periods with little or no load demand is stored in the battery for use subsequently during periods of low solar radiation. As a result of the variable nature of solar energy, an important and expensive aspect of stand-alone PV systems is its autonomy, required to provide reliable power supply to meet the load during unfavourable conditions which are usually moments of low radiation values and adverse weather conditions (Sick & Erge, 1996). Figure 3.1 represents components of a stand-alone PV system.

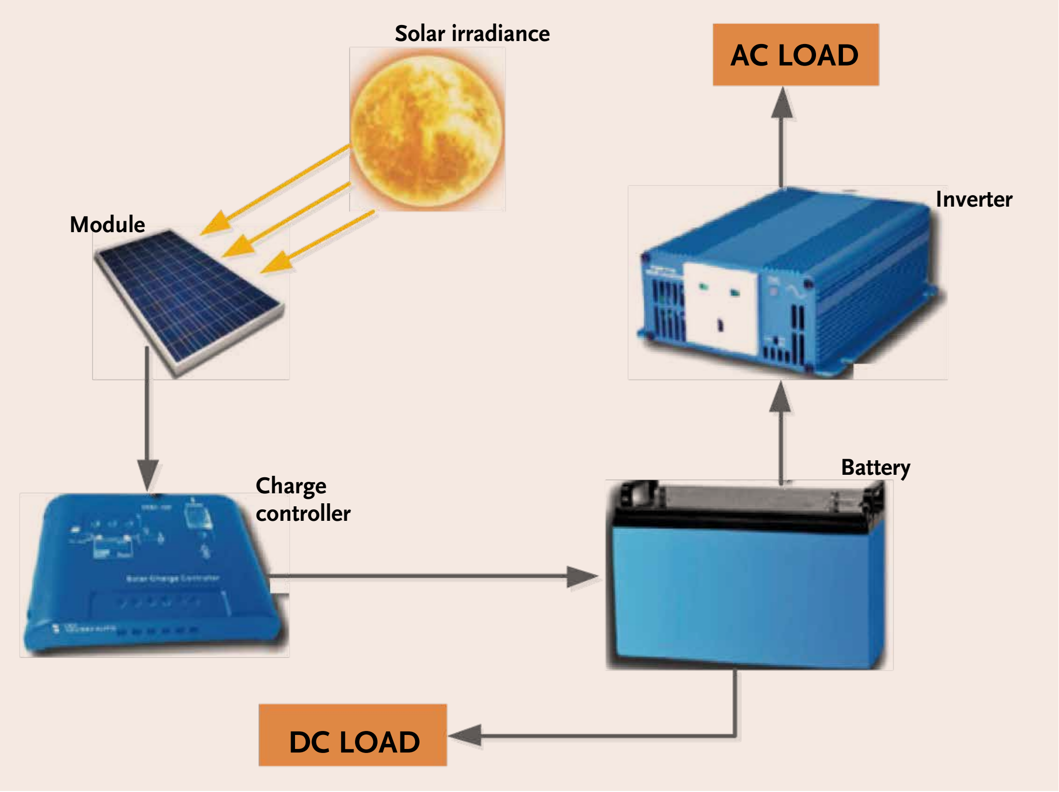

FIGURE 3.1: COMPONENTS OF A STAND-ALONE PV SYSTEMS

(Source: adapted from Abdul & Anjum, 2015).

3.1.2 Grid Connected Systems

These are PV systems that are connected directly to the public grid. Such systems are cost-effective when the utility load is well matched to the solar resource profile of the location (Sick & Erge, 1996). For instance, a grid connected system will perform well in a location with high air conditioning load peaks that coincides with peak sunshine hours of a summer day.

3.1.3 Hybrid PV system

In the case of a hybrid system, electrical energy is generated from two or more systems. According to Domenech et al. (2015), the combination of individual systems is proven to be adequate in the generation of power. A hybrid system is advantageous in that both technologies employed in the generation of energy complements and culminates in an increase in the reliability of the system.

3.2 Economic and Environmental benefits of PV systems

3.2.1 Economic benefits

An economic analysis is often conducted in order to determine the economic potential of PV systems. Different economic analysis methods have been employed in literature for determining the economic potential of PV systems: Darras et al. (2015) and Bernal-Agustin & Dufo-Lopez (2006) used the net present value (NPV) economic analysis model; Abdul & Anjum (2015) and Abanda et al. (2016) employed the life cycle cost analysis; Koberle et al. (2015) used the levelized cost of electricity (LCOE) to demonstrate the economic potential of PV systems; Ghosh et al. (2015), Ayompe and Duffy (2014), Ma et al. (2015) and Mbaka et al. (2010) made use of the HOMER software to determine the LCOE of PV systems; while Lang et al. (2016) used an economic model that entails cash flow dynamics for determining the economic performance of a PV system.

3.2.2. Environmental benefits of PV systems

Life Cycle Assessment (LCA) is the tool often used to determine the environmental footprint of a product. LCA is a methodology used in quantifying the environmental burdens and impacts associated to the life cycle of a product or service (Treyer & Bauer, 2015). LCA permits the identification of environmental hotspots and enables an unbiased comparison of product or services which meets the same needs as is the case of comparison of the environmental footprints of a kWh of electricity generated from different sources. Scholars have had a controversial view over the environmental benefits of renewable energy technologies; while some scholars consider these technologies as carbon free, some others do not share this view. Nugent and Sovacool (2014) conducted life cycle GHG assessment for some renewable energy technologies; wind and solar photovoltaics (PV) and their assessment revealed the renewable energy technologies to be unfree from emissions since both wind and solar PV were associated with an average emission of 34.11 gCO_2-eq/kWh and 49.81 gCO_2-eq/kWh respectively. However, their emissions are found to be relatively low when compared to diesel (778 gCO_2-eq/kWh) and coal (960 gCO_2-eq/kWh). The use of electricity generated from renewable sources therefore have a positive impact on the environment in terms of GHG emission reduction (Sapkota et al., 2014) as they are lower in carbon compared to conventional fuel employed in electricity generation. The manufacturing process of photovoltaics is associated with high metal use such as iron ore, nickel, copper and silver (Treyer & Bauer, 2015). Generation of electricity from PV systems is associated with the release of toxic substances to the environment during the mining process of the metals. The life cycle emission of PV system depends on the the solar cell material since energy requirements for manufacture vary among materials. Sherwani et al. (2010) estimated the life cycle emissions for amorphous, monocrystalline and polycrystalline solar PV systems to range from 15.6-50 gCO_2eq/kWh, 44-280 gCO_2eq/kWh and 9.4-104 gCO_2eq/kWh respectively.

3.3 Case study analysis of solar PV projects in West African Countries

A number of ongoing and proposed solar PV projects exists in West Africa with the envisaged Nzema project in Ghana to constitute Africa's largest photovoltaic power plant (Blue Energy, 2015). This Nzema plant will increase by 6% Ghana's current generating capacity. The project's cost is estimated at 350 USD million and it is envisaged to go fully operational in 2017 with a 20 years operational life. Table 3.1 presents the list of top 20 solar PV projects in West Africa.

TABLE 3.1: TOP 20 SOLAR PHOTOVOLTAIC PV PROJECTS IN WEST AFRICA

No	Name of Project	Current capacity	Location	Developer	Status
1	**Nzema Solar PV Park**	155 MW	Awaso, Ghana	Blue Energy	Proposed
2	**Tenergie Senegal PV Projects**	50 MW	Taif, Darou Mousty and Merina Dakhar, Senegal	Tenergie Senegal	Proposed
3	**Ivory Coast Scatec Solar PV Park**	45 MW	North Ivory Coast	Scatec Solar	Preferred bidders
4	**Akuo Energy Mali Solar Projects**	41 MW	Kita, Kangaba, Mali	Akuo Energy	Proposed
5	**Mali Scatec Solar PV Park**	33 MW	South Mali	Scatec Solar	Contracting
6	**Zagtouli Plant**	22 MW	Ouagadougou, Burkina Faso	T.B.D	Proposed
7	**Cameroon '51 villages' project**	21 MW	Konye, Cameroon	"Group of organisations"	Breaking ground
8	**Kona dept. Solar PV plant**	20 MW	Kona dept., Burkina Faso	Helios Energie	Financially closing down
9	**Burkina Scatec Solar PV Park**	20 MW	Center Burkina	Scatec Solar	Preferred bidders
10	**Senegal Scatec Solar PV Park**	20 MW	Coastal Senegal	Scatec Solar	Proposed
11	**Scatec solar Ghana PV project**	20 MW	Coastal Ghana	Scatec Solar	Under development
12	**Gambia Solar PV project**	20 MW	Birkama, The Gambia	CAMAC	Financially closing down
13	**Sheikh Zayed Solar Power Plant**	15 MW	Nouakchott, Mauritania	Masdar	Commissioned

No	Name of Project	Current capacity	Location	Developer	Status
14	**Prosolia Solar PV projects**	13 MW	Ndiare Wakhy, Coki and Barale, Senegal	Prosolia Energie Solaire	Proposed
15	**Benin Solar Power Plant 1**	6 MW	Kandi, Benin	Helios Energie	Commissioned
16	**Mulk Solar PV Project**	6 MW	Freetown, Sierra Leone	Masdar	Financially closed
17	**5 MW Solar PV Project**	5 MW	Djogou, Benin	CEB	Proposed
18	**Mali '30 villages' Project**	3 MW	Mali	T.B.D	Proposed
19	**Zouerate 3 MW PV projects**	3 MW	Zouerate, Mauritania	Power Electronics	Commissioned
20	**Kolda Solar PV Project**	1.5 MW	Kolda, Senegal	Isofoton	Breaking ground

(Source: Competitive Solar Solutions West Africa, n.d)

4. Research Methods

4.1 Description of study location

Lagos State is located in south-western region of Nigeria (Latitude 6°27'14" N and Longitude: 3°23'40" E), with total land area of 3 577 km^2. It experiences a tropical wet and dry climate (average annual rainfall is 1693 mm and average temperature is 27 °C). There are two rainy seasons (high rainfall periods: April to July, low rainfall periods: September to December). Highest amount of rainfall occurs in June (average of 386 mm), lowest rainfall occurs in December (about 21 mm), highest temperatures are in March (average of 28.6 °C), and lowest average temperature of 25.2 °C occurs in August (see https://en.climate-data.org/location/552/). Lagos is divided into five Administrative Divisions (Lagos, Epe, Badagry, Ikorodu and Ikeja) which are further divided into 20 Local Government Areas (LGAs) and 37 Local Council Development Areas (LCDAs). The "Lagos Metropolitan Area" also known as Metropolitan Lagos contains about 85% of the population of Lagos State, and includes semi-rural areas. We used purposive sampling technique to select five largest LGAs (Alimosho, Ajeromi-Ifelodun, Kosofe, Mushin and Oshodi-Isolo)[2] out of the 16 LGAs in Metropolitan Lagos (Figure 4.1).

Lagos State GDP of N12.091 trillion (80.61 billion USD) contributed 35.6% to National GDP of N33.985 trillion (226.5 billion USD) in 2010 (Lagos Bureau of Statistics - LBS, 2012). About 70 % of Nigeria's industries and financial services including headquarters of most companies and 90 % of foreign trade flows are located in Lagos due to the diverse and thriving economy of the State (Lagos State Government, 2012). Based on attractiveness of business environments, Lagos city is 108 out 178 economies in the world (World Bank, 2008). The diversified and thriving business environment has impact on the energy consumption – Lagos State accounts for 60 % of energy consumption in Nigeria (Lagos State Government, 2012). Economic growth and development of Lagos State may be commendable with the increasing population but development efforts to promote environmental sustainability is not performing spectacularly. Environmental challenges in Lagos State include air and noise pollution from the transport sector, poor sanitation and waste management especially for the urban poor, pollution of surface and ground water resources from domestic, loss of ecosystems and biodiversity, flood events (BNRCC, 2012; Change & Cities, 2013; Owolabi, 2016); energy supply for buildings, commercial and industrial activities is mainly from combustion of fossil fuel leading to high GHG emissions (Olugbenga & Adekemi, 2013; Ezema et al., 2016); fragmented and insufficient policies on reduction of risks, adaptation and mitigation to climate change and variability (Ajibade et al., 2016).

4.2 Data collection and analysis

A multidisciplinary approach composed of principles from engineering, economic and environmental disciplines were employed in this study. The following 5 types of building: duplex, single family bungalow, traditional court yard, flat/apartment dwelling and *'face-me-I-face-you'* in Nigeria as reported in previous study (Jiboye, 2014) were considered for the study. Ten of each of the afore-mentioned building types were selected from the 5 LGAs considered for the study (Table 4.1). The number of local governments and buildings selected were based on the available financial resources for data collection. Quantitative and qualitative instruments were used for data collection. This includes cross-sectional data collection tools such as questionnaires (Appendix A), field observations, and review of literature.

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[2] Data from 2006 population census (National Population commission Nigeria, 2010)

TABLE 4.1: SELECTION OF NUMBER OF BUILDINGS IN LOCAL GOVERNMENT AREAS

Building type	LGA1	LGA2	LGA3	LGA4	LGA5	Total
Duplex	10	10	10	10	10	50
Simple family bungalow	10	10	10	10	10	50
Traditional court yard	10	10	10	10	10	50
Flat/apartment	10	10	10	10	10	50
'Face-me-I-face-you'	10	10	10	10	10	50
Total	50	50	50	50	50	250

LGA: Local Government Area

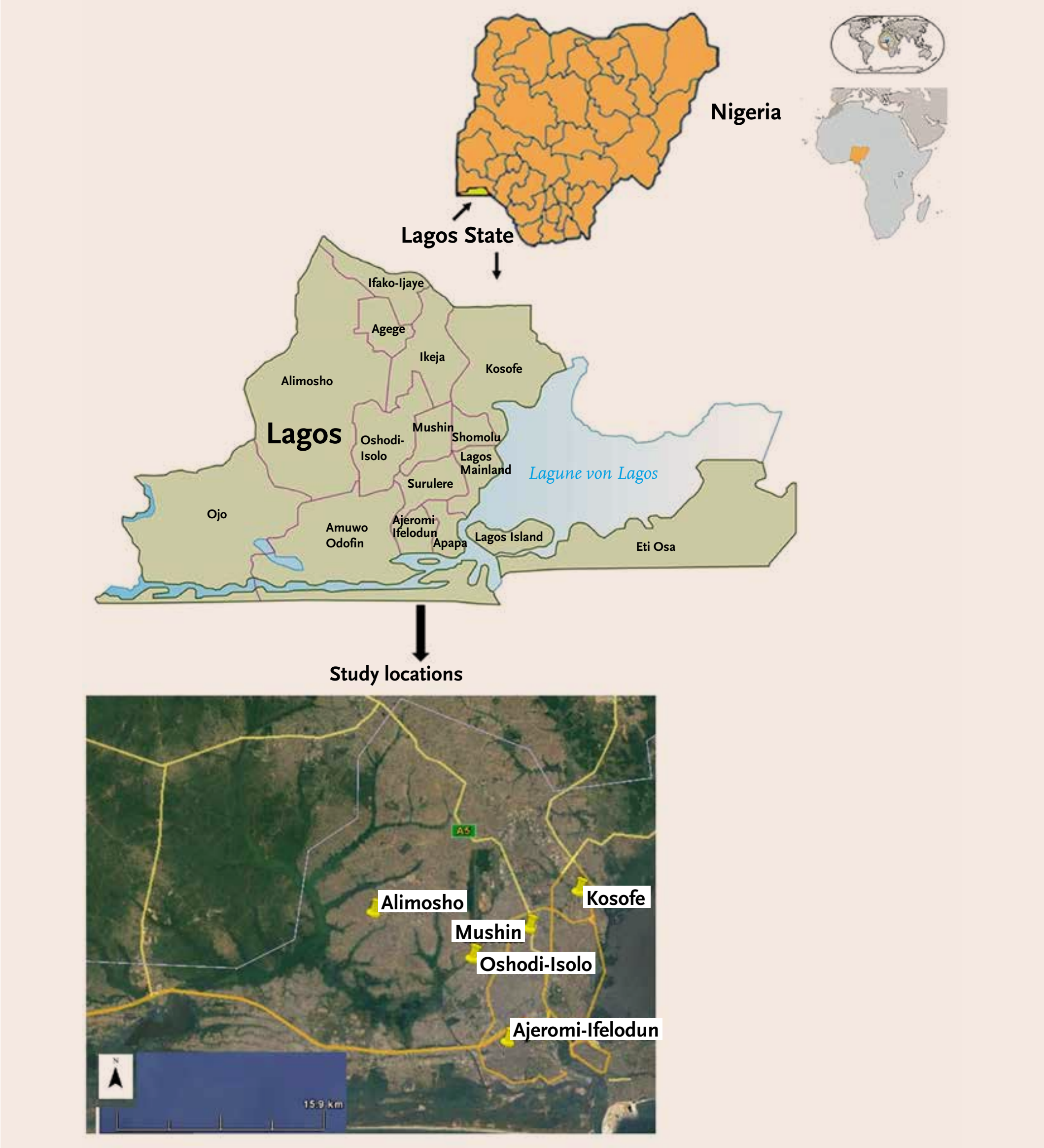


FIGURE: 4.1: STUDY LOCATIONS

(Source: Globe, Africa, Nigeria, and Lagos State maps were adapted from Group B - Collaborative Climate Adaption Project: https://fluswikien.hfwu.de/index.php?title=Group_B__Collaborative_Climate_Adaption_Project; Study locations- *Google Earth Image – 29 June 2017*).

4.2.1 Questionnaire design and response rate

A questionnaire was designed based on the information that was intended to be collected. The first draft of the questionnaire was finalized and was reviewed by the entire research team. Based on comments received, the questionnaire was adjusted and a second draft was obtained. This second draft was shared with members of the research team for further review and few comments were received at this stage. The comments were addressed and the third draft was shared electronically with the team of research assistants (for pre-test) who were to use the tool for collecting the required data. No negative feedback was received at this stage and consequently, the third draft of the questionnaire was then adopted by the research team as the final questionnaire to be employed in the data collection process (Appendix A).

The questionnaire was structured principally to collect information on the electrical load from all electrical appliances in the households. The questionnaire was structured into four different sections. Section one of the questionnaire was designed to capture socio-economic data of the surveyed household while section two was designed to obtain data on the characteristics of the dwellings under survey. The third section of the questionnaire was designed to collect information on the electrical appliances used in the dwellings. This section captured information on the different types, number and power ratings of appliances in the surveyed building. The power ratings of the different appliances were read directly from them. The final section of the questionnaire was designed as a time of use diary to collect information on the daily duration of use of the different appliances in the surveyed dwelling and the section was designed to obtain data for a week (Monday to Sunday) after which the questionnaires were retrieved from the respondents. Questionnaires were administered in December, 2016. Altogether, 246 questionnaires were filled by respondents and were retrieved out of 250 that were administered (survey response rate = 98.4 %). The high questionnaire response rate could be attributed to the approach employed by the researchers – the research assistants made prior appointments with residents and met them at their homes, handing questionnaires to those who could answer and assisted others with their responses by ticking for them.

4.2.2 Data analysis using SPSS

The quantitative data generated were analysed using simple descriptive statistical tools of Statistical Package for Social Science (SPSS, Version-22, SPSS Inc. New York, NY, USA) software.

4.2.3 HOMER Software and analysis

The acronym HOMER stands for Hybrid Optimization Model for Electric Renewable. Developed in 1993 by Dr Peter Lilienthal of the United States National Renewable Energy Laboratory (NREL). HOMER is one of the most widely used tools in the simulation, optimization and performance of sensitivity analysis of both grid-connected and off-grid renewable energy systems (Baghdadi et al., 2015). In the simulation process, HOMER models the behaviour of the system configuration each hour of the year to determine its technical feasibility and life cycle cost (Lambert et al., 2006). Optimizations entails the simulation of many different system configurations by the software in order to search for the one that satisfies the technical constraints at the lowest life cycle cost. Pertaining to sensitivity analysis, the HOMER software performs multiple optimizations using a range of input assumptions to determine the effects of uncertainty or changes in the input of the model. Figure 4.2 presents relationship that exists between simulation, optimization and sensitivity analysis.

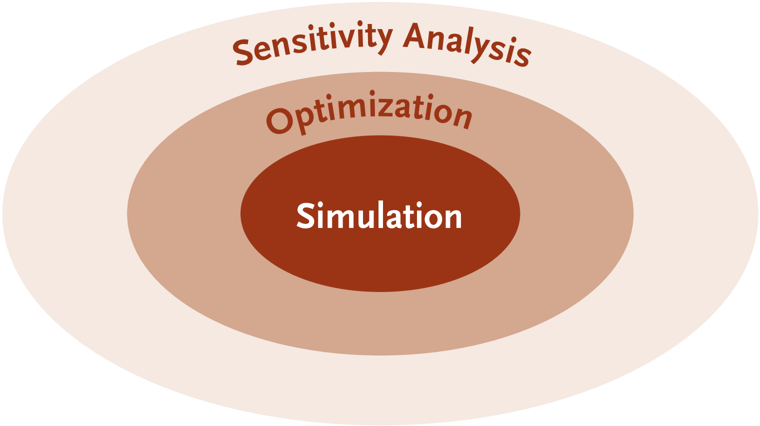


FIGURE 4.2: CONCEPTUAL RELATIONSHIP BETWEEN SIMULATION, OPTIMIZATION AND SENSITIVITY ANALYSIS IN HOMER PRO.

(Source: adapted from Lambert et al. (2006))

HOMER legacy is the original HOMER software version that was created at the NREL. The HOMER Pro software is the global standard employed in the optimization of micro grid design in all sectors. It was developed at the NREL but enhanced and distributed by HOMER energy.

4.2.3.1 Load profile computation

The energy load profile for the appliances for all the buildings surveyed was computed using Excel spreadsheet. The hourly energy load (in watts) for each building was obtained by summing up the power rating of all the appliances used at each of the 24 hours of the day. The daily load profile for each dwelling was obtained as an average of the load profile for the seven days of the week. The computed daily load profile for the different buildings is presented in Appendix F. This includes characteristics of appliances in some selected buildings (including extreme case buildings with very high loads).

4.2.3.2 PV system Modelling

System design

A stand-alone (See Figure 3.1) PV system was designed to meet the minimum and maximum load profile for each building type per LGA (Table 4.1). A total of 50 PV systems were therefore designed. The schematic of the designed PV system is presented in Figure 4.3.

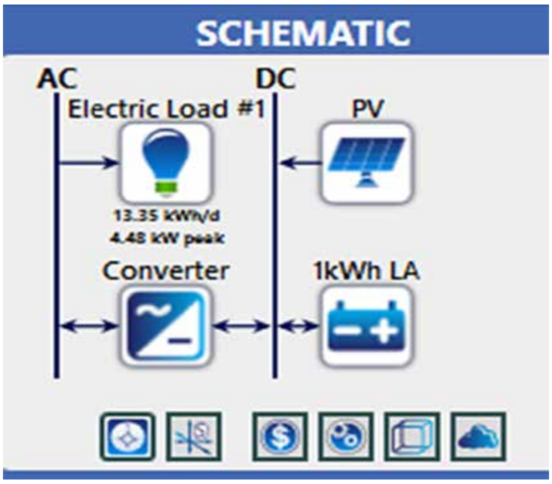
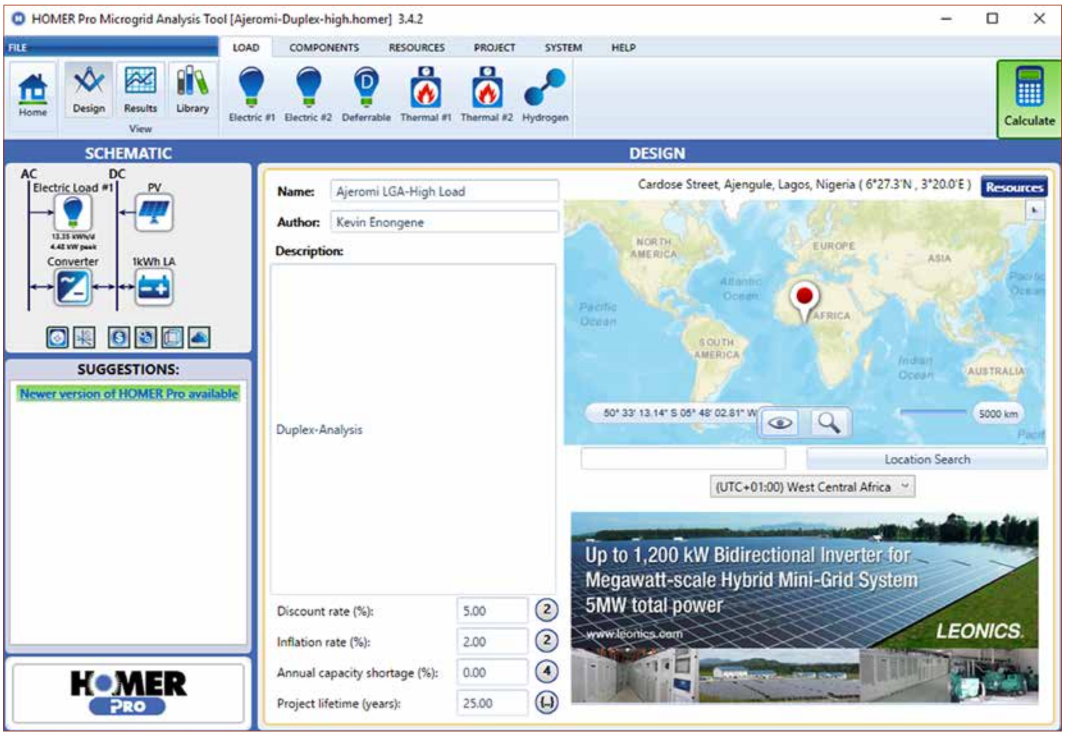


FIGURE 4.3: SCHEMATIC OF THE DESIGNED PV SYSTEM

Step 1: Specification of site

Site specification is an important aspect in the design of renewable energy systems using the HOMER Pro software. The home page of the software has the world map with a search box (Figure 4.4). To begin, details of the project such as the name and author were provided on the home page and the location of the study area was searched. Each of the five LGA from which load data information was obtained was typed in the search box and searched. Each time a location was typed in the search box, the software searched the specified location on the map and displayed its geographical coordinates.



HOMER Pro Microgrid Analysis Tool [Ajeromi-Duplex-high.homer] 3.4.2

Name: Ajeromi LGA-High Load

Author: Kevin Enongene

Description: Duplex-Analysis

Cardose Street, Ajengule, Lagos, Nigeria (6°27.3'N , 3°20.0'E)

(UTC+01:00) West Central Africa

Discount rate (%): 5.00

Inflation rate (%): 2.00

Annual capacity shortage (%): 0.00

Project lifetime (years): 25.00

FIGURE 4.4: HOME PAGE OF THE HOMER PRO SOFTWARE

Step 2: Load profile and system components specification

The minimum and maximum electric load profiles for each building type of selected LGA (see Appendix F) were introduced into the HOMER Pro software under the load tab (Figure 4.5).

HOMER Pro Microgrid Analysis Tool [Ajeromi-Duplex-high.homer] 3.4.2

Name: Electric Load #1

January Profile

Hour	Load (kW)
0	0.123
1	0.000
2	0.000
3	0.000
4	0.000
5	0.000
6	0.000
7	0.250
8	0.250
9	0.250

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 10

Timestep (%): 20

Metric	Baseline	Scaled
Average (kWh/d)	13.35	13.35
Average (kW)	.56	.56
Peak (kW)	4.48	4.48
Load Factor	.12	.12

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost ($): 0

Lifetime (yr): 10

Scaled Annual Average (kWh/d): 13.35

FIGURE 4.5: LOAD TAB OF THE HOMER PRO SOFTWARE

The different PV system components (battery, PV array and converter) technical and cost details were specified under the component tab of the software. The solar resource data (Global Horizontal Irradiation-GHI) for the study locations (LGAs) were imported directly into the software under the resource tab from the National Aeronautics and Space Administration (NASA) Langley Research Centre Atmospheric Science Data centre. The average daily solar radiation per month for one of the LGAs obtained from the HOMER Pro software is presented in Figure 4.6.

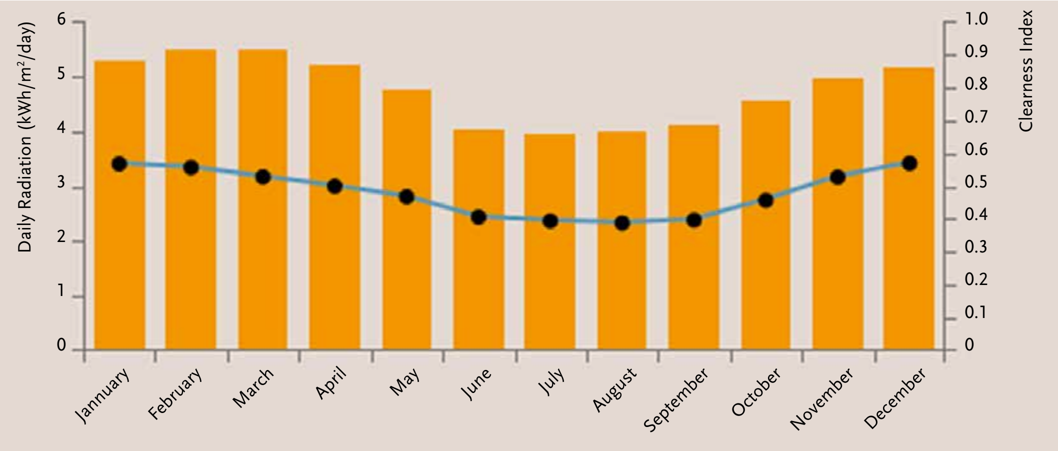


FIGURE 4.6: AVERAGE DAILY SOLAR RADIATION FOR THE KOSOFE LGA OBTAINED FROM THE HOMER PRO SOFTWARE

Step 3: Calculation

HOMER Pro was used to conduct the simulation process by modelling the behaviour of the system configuration each hour of the year in order to determine the system's technical feasibility and life cycle cost. This includes the optimization of the system by simulating different system configurations with the objective of searching for the system that satisfies the technical constraints at the lowest life cycle cost. The base case scenario calculation was performed based on the following; a minimum battery State of Charge (SOC) of 40%, 0% maximum annual capacity shortage, 5% discount rate, 2% inflation rate and a PV lifetime of 25 years.

PV system modelling

HOMER Pro was used to perform sensitivity analysis based on five different variables: maximum annual capacity shortage, PV lifetime, minimum battery SOC, inflation and discount rate in order to determine their effect on the system's LCOE. Table 4.2 presents the sensitivity parameters used.

TABLE 4.2: SENSITIVITY PARAMETERS EMPLOYED IN THE HOMER MODELLING.

Sensitivity variable	Base case	Sensitivity case(s)
Maximum annual capacity shortage	0%	5%, 10% and 15%
Discount rate	5%	10%
PV lifetime	25 years	20 years and 30 years
Inflation rate	2%	5%
Minimum battery SOC	40%	30%

Computation of PV array area

The size (area) of the PV array for the different buildings was computed using equation 1 as purported by Birajdar et al. (2013).

$$A_{pv} = \frac{L_{el}}{H_{avg}\ x\ n_{pv}\ x\ n_b\ x\ n_i\ x\ T_{FC}} \qquad (1)$$

Where A_{PV} represents the required PV array area in m^2, L_{el} is the required daily electric load of the building in kWh/day, H_{avg} is the location's average daily solar irradiation in $kWhm^{-2}d^{-1}$, η_{pv} represent the PV panel efficiency in %, η_i is the efficiency of the inverter in % while T_{CF} stands for the temperature correction factor. The battery and inverter efficiency were adopted from Abdul and Anjum (2015) as 85% and 90% respectively while the T_{CF} was adopted from Caisheng and Nehrir () as 80%. It is important for the PV area to be adjusted to take into consideration variation of the PV system output over its lifetime as a result of degradation. This adjustment is effected by dividing the PV area by the module derate factor which accounts for PV output reduction due to the accumulation of dust and degradation over time. A module derate factor of 0.9 was adopted from Sandia National Laboratories (1995). See Table 5.3 for required PV array area (in m^2) computed for the different buildings.

4.2.3.3 Economic analysis of the PV systems

Using HOMER Pro we conducted the economic analysis with the available data (Table 4.3). We determined the net present cost (NPC) and the levelized cost of electricity generated by the system using 2% inflation rate and 5% discount rate. The operation and maintenance cost was considered as 2% of the initial PV module cost while the installation cost of the system was considered as 10% of the initial PV module cost.

TABLE 4.3: COST OF SOLAR PV COMPONENTS (OBTAINED FROM A LOCAL SUPPLIER)

System component	Cost (USD)[3]
Module (100W monocrystalline)	158
Charge controller (60 AMP)	190
Battery (Deep acid lead, 83.3Ah)	160
Inverter (1 kW)	158
Total	666

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[3] Converted from Naira to USD based on an exchange rate of 1USD = 315 Naira (exchange rate on the 20th June, 2017)

4.2.3.4. Environmental analysis of PV systems

In order to estimate the environmental benefits or potentials of the PV systems employed in this study, there is the need of LCA data for electricity generated from PV systems in Nigeria. Since such information is scarce, the average LCA data of 162 gCO_2eq/kWh of electricity generated from monocrystalline modules obtained by Sherwani et al. (2010) was adopted. From Brander et al. (2011), the emission associated with a kWh of electricity from the grid stands at 440 gCO_2eq. The emission saving (Es) associated with the use of a kWh of electricity generated by the PV systems employed in this study was computed using the same approach employed by Abanda et al. (2016):

$$Es = EG – EPV = 440\ gCO_2eq - 162\ gCO_2eq = 278\ gCO_2eq$$

Where EG represents emissions associated with a kWh of grid electricity while EPV represents emissions of a kWh of PV generated electricity. The emission saving of 278 gCO_2eq constitutes a 63.2% emission reduction compared to the business-as-usual scenario (use of grid electricity). The daily emission saving that would result from the use of electricity from the PV systems by the buildings was computed by simply multiplying the daily load of the buildings in kWh by 278 gCO_2eq.

5 Results

5.1 Background information of respondents and building characteristics

5.1.1 Household size, occupation of household heads and construction material of building

Majority (53.71 %) of the houses in the study locations have 4 – 6 persons living in them (Appendix B). Most (60 %) of the household heads are business men and women. The buildings in the study locations are mainly constructed with brick and concrete (74.8 %) followed by those built with concrete only, and brick only (7.2 % and 6.8 % respectively).

5.1.2 Room composition of building types

The room composition (number of bedrooms, kitchens, dining rooms, lounge and toilets) of the building types considered in the study are presented in Appendix C. The prevalent number of bedrooms for Duplex = 4, Single family bungalow = 3, Flat dwelling = 2 or 3, Traditional court yard and *'Face-me-I-face-you'* = 1. All the building types mostly contain 1 kitchen, 1 dining room, 1 lounge. Apart from Duplex and Traditional court yard with 4 and 1 toilet(s) respectively, other building types contain 2 toilets.

5.2 Sources of energy and fuel consumption

The main source of energy for all the building types in the study locations is Diesel generators and Rechargeable lanterns - charged either by the diesel generators or grid power supply, when available, accounting for 48.4 % of the total source energy available in the area (Appendix D). Based on frequency of use of the available energy sources, diesel generators are used in duplex buildings, Diesel generators and Rechargeable lanterns are used in Flat dwellings, Rechargeable lanterns are used in Single family bungalow, Traditional court, and *'Face-me-I-face-you'*. Furthermore, Rechargeable lanterns are mostly used in the study locations during grid outage.

Heating, lighting, leisure and air condition accounts for the highest (24.8 %) of energy consumption in the study locations. The average weekly consumption of diesel, kerosene, and candles in study locations is about 28 litres, 1 litre and 7 sticks respectively[4] (Appendix D). In some cases, consumption differs with building types and utility. The average weekly consumption of diesel for Traditional court buildings = 12 litres, Duplex and *'Face-me-I-face-you'*= 14 litres, Single family bungalow and Flat dwellings = 28 litres. It was observed that Traditional court buildings use more kerosene (average of 7 litres per week) followed by duplex (average of 5 litres per week) compared to 1 litre used in Single family bungalow and Flat buildings. Highest number of candles (average of 20 sticks per week) was recorded from Flat buildings. Power consumption in the study locations are greatly increased during dry seasons and festive periods. To a very large extent (44.8 %), respondents agree that dry season affects their level of power consumption. Similarly, festive seasons like Christmas, Ramadan (fasting periods) and New Year have effect on power consumption to a very large extent (33.6 %, 37.6 % and 34.4 % respectively) in study locations.

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[4] Respondents provided the average quantity of each fuel type consumed weekly and values reported represent average weekly consumption with highest frequency.

5.3 Policies

5.3.1 Knowledge of policies

The results of the analysis of knowledge of policies (Appendix E) revealed that respondents do not have knowledge of policies on:

- incentives for promoting installation of solar PV systems (52.8% have no knowledge at all)
- use of taxation, reduce taxes on solar PV systems (54% have no knowledge at all)
- grants and subsidies from local government to cut down cost of solar PV systems (54%
- awareness raising and information campaigns about solar PV systems (45.6% of respondents have no knowledge at all) and
- public leadership programmes by local governments demonstrating solar PV systems (61.6% of respondents have no knowledge at all)

5.3.2 Effects of policies

Although respondents do not have knowledge of the policies considered in this study, they perceive that to a very large extent the following policies may influence adoption/integration of solar photovoltaics on residential buildings in the study locations:

- Policies on use of taxation, reduce taxes on solar PV systems (very large extent - 31.2% of respondents)
- Policies on grants and subsidies from local government to cut down cost of solar PV systems (very large extent – 36.4% of respondents)
- Policies on awareness raising and information campaigns about solar PV systems (very large extent – 38% of respondents) and
- Policies on public leadership programmes by local governments demonstrating solar PV systems (very large extent – 34.8% of respondents).

5.4 PV System design

5.4.1 Technical specifications for system components

The results of the HOMER simulations performed as part of the process for designing solar PV systems for meeting the minimum and maximum loads (Appendix E) of each building type per LGA is presented in Table 5.1. The technical specifications presented in Table 5.1 is for the base case scenario: 0% capacity shortage, 40% battery minimum state of charge, 25 years PV lifetime, 5% discount rate and 2% inflation rate.

PV design for maximum load of buildings

The largest size of PV array (215 kW) will be required for Duplex building type in Mushin LGA with 380 kWh lead acid battery, 16.8 kW converter, and highest PV power output of 300 577 kWh/year. On the other hand, Traditional court buildings in Kosofe LGA will require the smallest size of PV array (0.6 kW) with 4 kWh lead acid battery, and lowest converter and PV power output (0.6 kW and 839 kWh/year respectively). It is important to highlight that Single Family Bungalow and Duplex building types in Mushin will require the largest lead acid battery and converter (440 kWh and 16.8 kW respectively).

PV design for minimum load of buildings

The largest size of PV array, lead acid battery, converter, and highest PV power output (46 kW, 195 kWh, 5.6 kW, and 64 310 kWh/year respectively) will be required for Duplex in Mushin LGA. Conversely, 'Face -me –I- face -you' in Kosofe LGA will require the smallest size of PV array, lead acid battery, converter, and lowest PV power output (0.2 kW, 2 kWh, 0.1 kW, and 280 kWh/year respectively).

The findings on the PV design for maximum and minimum load of buildings in the study locations can be related to the number of bedrooms in the types of building considered. Prevalent number of bedrooms for Duplex = 4, Single family bungalow = 3, Flat dwelling = 2 or 3, Traditional court yard and 'Face-me-I-face-you' = 1. Hence, it is expected that Duplex with 4 bedrooms will require larger size of PV array, acid battery, and converter while 'Face-me-I-face-you' will require less. Equally important is the type of appliances used in the locations, for example the largest lead acid battery and converter and highest PV power output for Mushin LGA can be attributed to the use of low energy efficient appliances or low energy efficient culture that may be practiced in the location.

TABLE 5.1: TECHNICAL SPECIFICATIONS FOR SYSTEM COMPONENTS

Building type	LGA	PV Array (kW)	1 kWh Lead acid battery	Converter (kW)	PV power output (kWh/year)
PV DESIGN FOR MAXIMUM LOAD OF BUILDINGS					
Single Family Bungalow	Mushin	120	440	16	167 764
	Kosofe	3	30	1.6	4 194
	Oshodi	24	125	6.4	33 552
	Alimosho	15	108	7.5	20 972
	Ajeromi	22	98	5	30 751
Duplex	Mushin	215	380	16.8	300 577
	Kosofe	6	32	2	8 389
	Oshodi	30	130	7.2	41 940
	Alimosho	40	132	9	55 929
	Ajeromi	15	40	4.8	20 966
'Face-me-I-face-you'	Mushin	36	94	6	50 329
	Kosofe	1.6	16	1.6	2 237
	Oshodi	6	36	5.8	8 388
	Alimosho	78	176	20	109 055
	Ajeromi	20	66	5.8	27 955
Traditional court	Mushin	28	112	2.8	39 145
	Kosofe	0.6	4	0.6	839
	Oshodi	6	30	2.8	8 388
	Alimosho	16	68	3.4	22 370
	Ajeromi	13	48	4.6	18 171

Building type	LGA	PV Array (kW)	1 kWh Lead acid battery	Converter (kW)	PV power output (kWh/year)
Flat Apartment	Mushin	52	134	5.2	72 698
	Kosofe	3	18	2.8	4 194
	Oshodi	16	88	6.8	22 368
	Alimosho	42	76	13.2	58 772
	Ajeromi	24	38	7	33 546
PV DESIGN FOR MINIMUM LOAD OF BUILDINGS					
Single family bungalow	Mushin	24	128	3.6	33 553
	Kosofe	0.6	3	0.4	839
	Oshodi	4.5	19	1.2	6 291
	Alimosho	7	28	2.5	9 787
	Ajeromi	0.8	7	0.4	1 118
Duplex	Mushin	46	195	5.6	64 310
	Kosofe	0.8	9	0.6	1 118
	Oshodi	3	12	2.6	4 194
	Alimosho	22	80	4.6	30 795
	Ajeromi	1	10	0.8	1 398
'Face -me - I face –you'	Mushin	2.8	15	0.6	3 914
	Kosofe	0.2	2	0.1	280
	Oshodi	2.5	22	0.7	3 495
	Alimosho	7	42	5.4	9 787
	Ajeromi	0.4	3	0.3	559
Tradition court	Mushin	0.8	7	0.6	1 118
	Kosofe	0.3	2	0.4	419
	Oshodi	0.6	4	0.6	839
	Alimosho	1	8	0.4	1 398
	Ajeromi	0.5	4	0.4	699
Flat Apartment	Mushin	14	42	2.4	19 572
	Kosofe	0.7	3	0.6	979
	Oshodi	0.7	6	0.4	979
	Alimosho	5	22	1.4	6 991
	Ajeromi	2	12	0.6	2 796

Sensitivity analysis for technical specifications for system components

Sensitivity analysis was conducted on the annual capacity shortage (5%, 10% and 15%) and the minimum battery state of charge (30%) considering the technical specifications for the system components (Table 5.2). Results presented in Table 5.2 is the effect of varying annual capacity shortage and minimum battery state of charge on the technical specifications of the systems designed for the minimum loads of the single-family building type. See Appendix G for other types of buildings. An overview of the results of the sensitivity analysis shows that increase in maximum annual capacity shortage (from 0 – 15 %) will lead to decrease in the size of PV array, lead acid battery and PV power output. However, the case is different for lead acid battery in Alimosho (increase between 5- 10 % and subsequent decrease at 15 %) and Ajeromi (increase between 10 – 15 %).

For minimum battery state of charge (at sensitivity value of 30 %), results reveal that Mushin will require the largest size of PV array, lead acid battery and PV power output (20 kW, 128 kWh, and 27 961 kWh/year respectively). In contrast, Kosofe will require the smallest size of PV array (0.5 kW), lead acid battery (3 kWh), and PV power output (699 kWh/year).

TABLE 5.2: EFFECTS OF MINIMUM BATTERY STATE OF CHARGE AND CAPACITY SHORTAGE ON SYSTEM COMPONENTS (FOR MINIMUM LOADS OF SINGLE FAMILY BUNGALOW BUILDING TYPE)

LGA	Sensitivity value (%)	PV array (kW)	1 kWh Lead acid battery	PV power output (kWh/year)
SENSITIVITY VARIABLE: MAXIMUM ANNUAL CAPACITY SHORTAGE				
Mushin	0	24	128	33 553
	5	12	108	16 776
	10	10	112	13 980
	15	10	68	13 980
Kosofe	0	0.6	3	839
	5	0.3	3	419
	10	0.3	2	419
	15	0.3	2	419
Oshodi	0	4.5	19	6 291
	5	2.5	12	3 495
	10	2	12	2 796
	15	2	8	2 796
Alimosho	0	7	28	9 787
	5	4	20	5 593
	10	3	22	4 194
	15	3	14	4 194
Ajeromi	0	0.8	7	1 118
	5	0.6	4	839
	10	0.6	3	839
	15	0.4	4	559
SENSITIVITY VARIABLE: MINIMUM BATTERY STATE OF CHARGE				
Mushin	30%	20	128	27 961
Kosofe	30%	0.5	3	699
Oshodi	30%	4	19	5 592
Alimosho	30%	7	24	9 787
Ajeromi	30%	0.8	6	1 118

PV array area

The computed required PV array area for the different buildings is presented in Table 5.3. From literature (Eruola et al., 2010; Fagbemi, 2011), the rooftop area of typical buildings in Southwest Nigeria are as follows: single family bungalow (332.12 m²); duplex (218.3 m²); *Face-me-I-face-you'* (156.78 m²); traditional court (282.24 m²); and flat apartment (280.72 m²).

TABLE 5.3: REQUIRED PV ARRAY AREA FOR THE DIFFERENT BUILDINGS

Building type	LGA	PV Array area (in m²)-low loads	PV Array area (in m²)-High loads	Roof area (m²) of building
Single Family Bungalow	Mushin	73.97	330.93	332.12
	Kosofe	1.69	12.44	
	Oshodi	13.30	76.15	
	Alimosho	20.71	50.38	
	Ajeromi	2.96	52.88	
Duplex	Mushin	132.50	437.54**	218.3
	Kosofe	3.32	17.57	
	Oshodi	8.73	98.87	
	Alimosho	53.24	93.69	
	Ajeromi	4.21	34.09	
'Face-me-I-face-you'	Mushin	8.35	67.41	156.78
	Kosofe	0.79	6.41	
	Oshodi	9.63	16.85	
	Alimosho	26.35	187.63	
	Ajeromi	1.35	59.27	
Traditional court	Mushin	3.45	79.08	282.24
	Kosofe	0.89	1.94	
	Oshodi	2.37	18.84	
	Alimosho	4.37	46.19	
	Ajeromi	1.81	34.24	
Flat Apartment	Mushin	31.79	119.58	280.72
	Kosofe	2.12	9.32	
	Oshodi	2.50	47.50	
	Alimosho	14.78	65.83	
	Ajeromi	5.85	40.86	

** denotes a building whose required PV array area exceeds the available rooftop area.

5.4.2 Economic analysis

The economic analysis results of the PV systems in terms of the LCOE and net present value (for base case scenario) is presented in Table 5.4.

TABLE 5.4: ECONOMIC ANALYSIS OF THE PV SYSTEMS

LGA	Initial capital (USD)	LCOE (USD/kWh)	NPC (USD)	LGA	Initial capital (USD)	LCOE (USD/kWh)	NPC (USD)
For maximum loads				For minimum loads			
BUILDING TYPE: DUPLEX							
Mushin	437,554	0.496	542,774	**Mushin**	112,125	0.447	148,359
Kosofe	15,876	0.497	21,872	**Kosofe**	2,927	0.552	4,598
Oshodi	74,138	0.398	98,546	**Oshodi**	7,614	0.459	10,051
Alimosho	92,142	0.411	137,557	**Alimosho**	51,807	0.502	66,915
Ajeromi	33,258	0.509	43,462	**Ajeromi**	3,466	0.505	5,335
BUILDING TYPE: SINGLE FAMILY BUNGALOW							
Mushin	281,728	0.439	364,085	**Mushin**	33,553	0.467	86,457
Kosofe	10,273	0.508	15,818	**Kosofe**	1,587	0.529	2,215
Oshodi	62,771	0.452	86,098	**Oshodi**	11,060	0.439	14,641
Alimosho	44,565	0.513	64,750	**Alimosho**	17,055	0.432	22,396
Ajeromi	54,750	0.589	78,016	**Ajeromi**	2,575	0.523	3,873
BUILDING TYPE: ‘FACE -ME -I -FACE -YOU’							
Mushin	78,628	0.645	108,928	**Mushin**	7,367	0.486	10,160
Kosofe	5,597	0.538	8,612	**Kosofe**	683	0.531	1,053
Oshodi	17,116	0.571	24,119	**Oshodi**	7,981	0.498	12,017
Alimosho	167,040	0.429	201,658	**Alimosho**	19,753	0.422	27,818
Ajeromi	46,276	0.397	58,933	**Ajeromi**	1,223	0.533	1,791
BUILDING TYPE: TRADITIONAL COURT							
Mushin	67,082	0.444	87,895	**Mushin**	2,607	0.455	3,920
Kosofe	1,779	0.54	2,615	**Kosofe**	905	0.575	1,301
Oshodi	15,682	0.453	21,383	**Oshodi**	1,779	0.43	2,552
Alimosho	39,257	0.45	52,003	**Alimosho**	3,083	0.417	4,564
Ajeromi	31,027	0.484	41,507	**Ajeromi**	1,573	0.515	2,332
BUILDING TYPE: FLAT APPARTMENT							
Mushin	112,805	0.48	143,672	**Mushin**	24,360	0.533	42,394
Kosofe	5,220	0.547	12,674	**Kosofe**	1,218	0.449	2,390
Oshodi	42,994	0.501	59,574	**Oshodi**	2,241	0.533	3,359
Alimosho	87,326	0.743	122,521	**Alimosho**	12,441	0.488	16,584
Ajeromi	41,760	0.62	63,413	**Ajeromi**	5,495	0.527	7,727

The effect of the inflation rate and discount rate on the LCOE is presented in Figure 5.1 (Duplex building type). Increasing the maximum annual capacity shortage of the system implies a reduction of the proportion of the building’s load to be met by the system. At 0% capacity shortage, 100% of the building load would be met by the system and at 5% capacity shortage, 95% of the building's load would be met by the system. An increase in the discount rate from 5 to 10% increases the LCOE while an increase in the inflation rate from 2 to 5% reduces the LCOE. Using the Duplex building type (maximum load) for the Mushin LGA as an example, an increase in the inflation rate from 5 to 10% increases the LCOE from 0.496 USD/kWh to 0.712 USD/kWh. The same trend was observed for the other building types for the different LGA (Appendix H).

An increase in the maximum annual capacity shortage decreases the LCOE of the systems. The LCOE for the flat apartment building type (maximum load) for Mushin decreased from 0.48 USD/kWh (0% capacity shortage) to 0.28 USD/kWh (15% capacity shortage) as can be verified from Figure 5.2. The effect of capacity shortage for the other building types for the different LGAs is presented in Appendix G. It is observed that there is a marked difference between the LCOE at 0% capacity shortage and 5% capacity shortage. Using Mushin as an example (Figure 5.2), the LCOE (USD/kWh) at 0% and 5% capacity shortage is 0.48 and 0.322 respectively amounting to a difference of 0.158. This difference is large compared to the difference in the LCOE between 5% and 15% capacity shortage (0.322 – 0.28 = 0.042). Increase in the maximum annual capacity shortage from 5% to 15% did not result to any change in the LCOE of the system as is the case with Ajeromi whereby the LCOE for 5%, 10% and 15% capacity shortage is 0.4.

Pertaining to the effect on the PV lifetime on the LCOE, the PV lifetime is inversely proportional to the LCOE of the system. An increase in the PV lifetime from 25 to 30 years reduces the LCOE of the PV systems while the reverse is true for a decrease in the PV lifetime from 25 to 20 years as can be verified from Figure 5.1 (Traditional Courthouse). Details for the other buildings types is available in Appendix H.

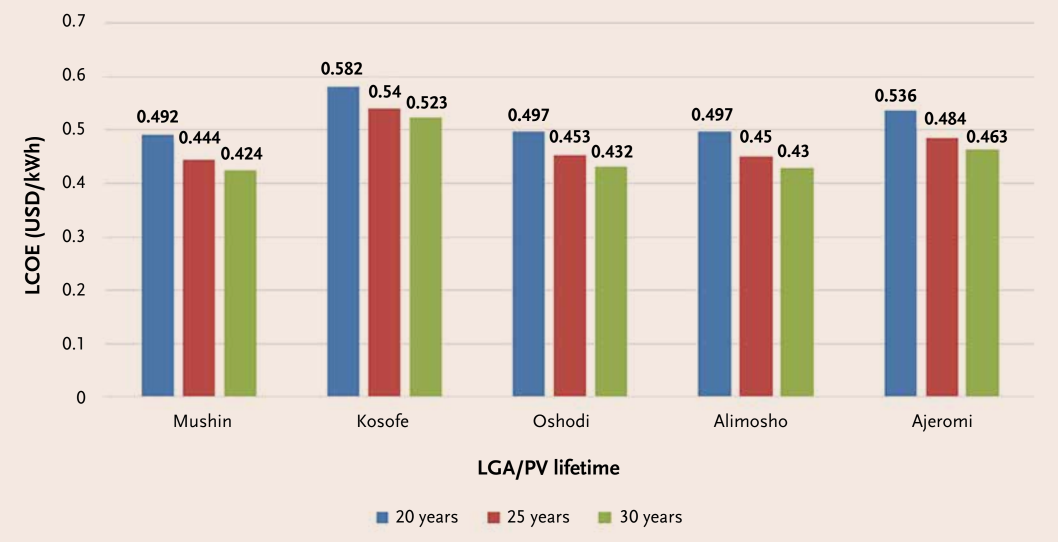

FIGURE 5.1: EFFECT OF PV LIFETIME ON THE LCOE FOR THE SYSTEM DESIGNED FOR THE MAXIMUM LOAD FOR TRADITIONAL COURT YARD BUILDING TYPE

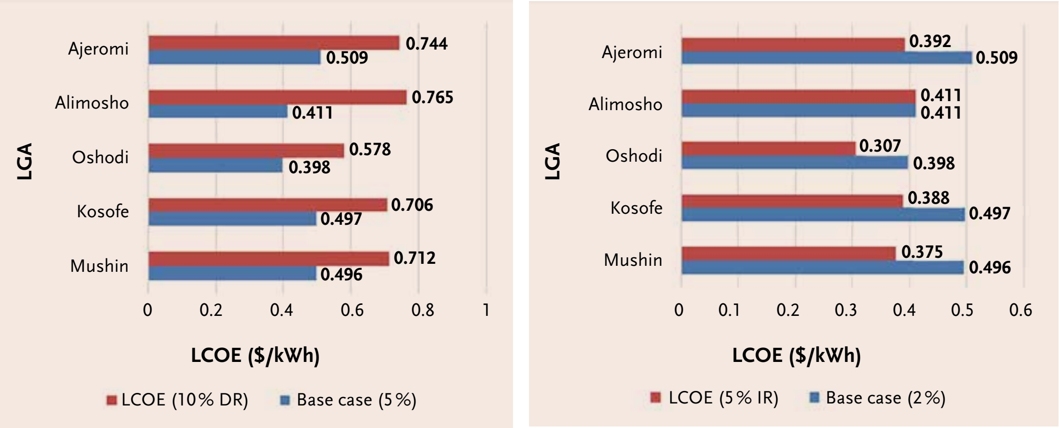

FIGURE 5.2: EFFECT OF DISCOUNT RATE (LEFT) AND INFLATION RATE (RIGHT) ON THE LCOE FOR THE SYSTEM DESIGNED FOR THE MAXIMUM LOAD FOR THE DUPLEX BUILDING TYPE.

Note: $ = USD

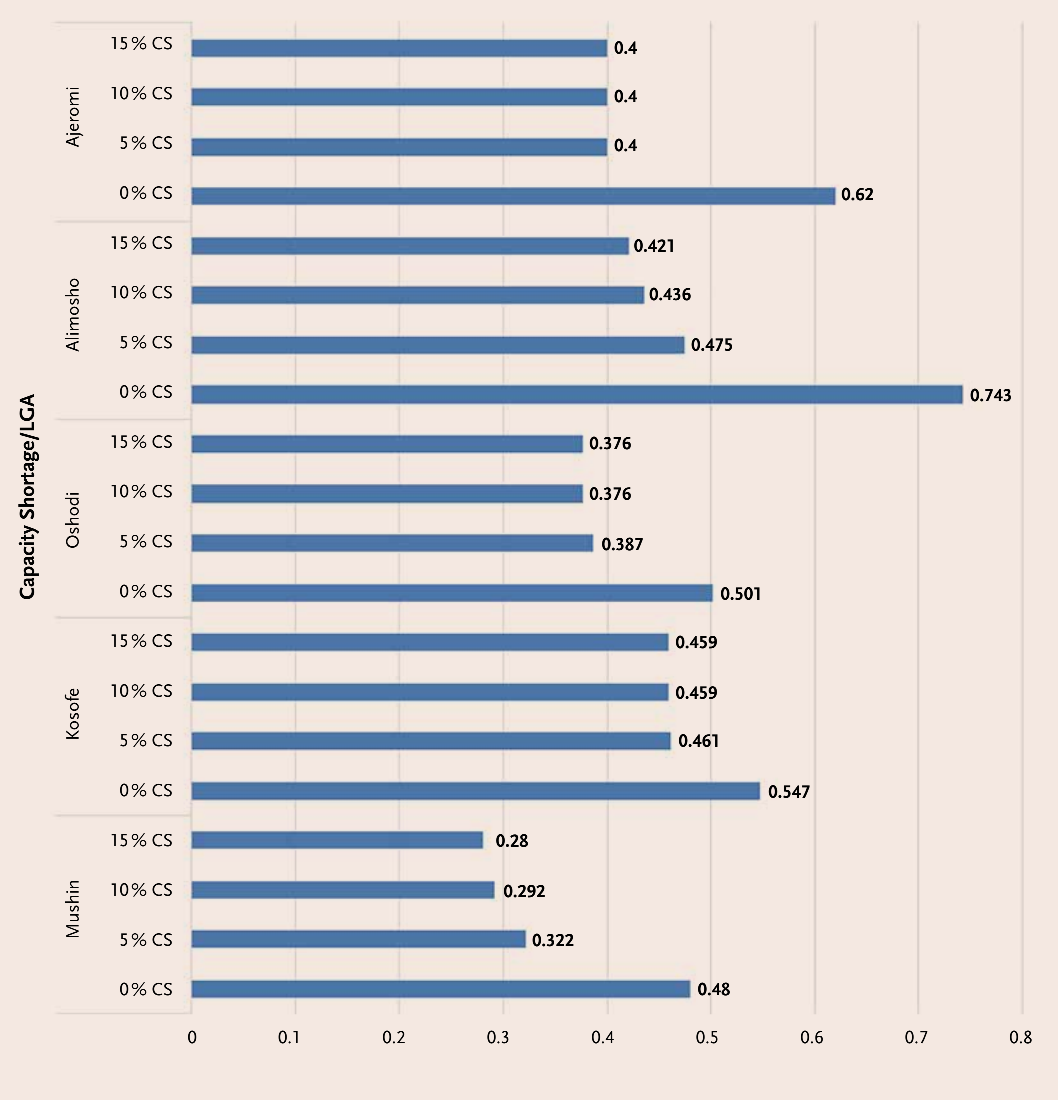

FIGURE 5.3: EFFECTS OF CAPACITY SHORTAGE ON LCOE FOR THE MAXIMUM LOAD OF FLAT APARTMENTS FOR THE DIFFERENT LGAS.

Note: $ = USD

5.4.3 Environmental Analysis

The environmental analysis associated with the use of solar PV generated electricity for meeting the entire load of the buildings (0% capacity shortage) is presented in Table 5.5. The emission reduction associated with the use of electricity from the PV system varies from building to building. For the high loads, the annual emission reduction varies from 76.90 (Traditional Court, Kosofe) to 17387 kgCO$_2$eq (Duplex, Mushin) while for the low loads, the emission reduction varies from 35.95 (Traditional Court, Kosofe) to 2985.44 kgCO$_2$eq (Single Family Bungalow, Mushin). This variation is due to the fact that there exist differences in the daily loads of the buildings. In a nutshell, the use of PV system generated electricity in each building reduces annual emissions by 63.2% compared to the business-as-usual scenario whereby the buildings would rely solely on the grid to meet their respective energy loads.

TABLE 5.5: ANNUAL EMISSION REDUCTIONS (KGCO2EQ) ASSOCIATED WITH THE USE OF PV GENERATED ELECTRICITY IN BUILDINGS

Building types	Mushin	Kosofe	Oshodi	Alimosho	Ajeromi
HIGH LOADS					
Single Family Bungalow	13 150.95	493.56	3025.76	2001.86	2122.16
Flat Apartment	4795.54	370.58	1887.20	2615.87	1623.66
'Face- me –I- face –you'	2678.30	254.56	3673.65	7456.44	2457.27
Duplex	17 387.00	697.97	3930.15	3723.08	1377.49
Traditional Court	3132.18	76.90	748.85	1830.43	1360.13
LOW LOADS					
Single Family Bungalow	2985.44	66.46	528.95	822.69	127.52
Flat Apartment	1263.82	84.29	99.95	587.58	233.00
'Face -me –I- face- you	331.89	31.24	382.61	1394.63	53.27
Duplex	5265.64	132.49	347.39	2115.95	167.43
Traditional Court	136.98	35.95	71.32	173.88	71.67

6 Discussions

6.1 State-of-the-art solar photovoltaic systems in Nigeria

The use of solar energy ranges from thermal energy for drying agricultural products and materials in the industry to generating electrical energy that can be used in residential homes and public/commercial buildings. However, in Nigeria the productive use of solar energy is limited (See the review of Ohunakin et al (2014) for solar energy applications and development in Nigeria). Some studies (e.g. Oji et al., 2012; Ohijeagbon & Ajayi; 2015; Okoye, 2016) have reported the economic and environmental benefits that can be derived from the use of distributed generations of solar energy (Solar PV systems) in strategic cities in Nigeria. Oji et al (2012) concluded that the installation and use of solar PV system for residential buildings apartment has a long term economic benefit compared to diesel generators. In 40 meteorological sites in Nigeria, the assessment of Ohijeagbon and Ajayi (2015) on the potential and economic feasibility of solar PV standalone systems for embedded generation in relation to small off-grid rural communities are promising. Their results revealed that potential investors can gain 0.01 USD/kWh to 0.17 USD/kWh from 29 locations out of the 40 considered in the study. The results from Okoye et al (2016) showed that the unit cost of electricity from standalone PV systems in the study is lower compared to major diesel generators used in the country (case studies were in Onitsha, Kano and Lagos).

6.1.1 Policy strategies for the adoption of PV-systems in Nigeria

Despite the prospects of solar energy to provide clean, reliable and cost-efficient energy in the country, several factors underpin its adoption as well as sustainability. Policies that respondents in the study locations perceive may influence adoption/integration of solar photovoltaics on residential buildings are reduction of taxes on solar PV systems, provision of grants and subsidies by local government to cut down cost of solar PV systems, awareness raising on solar PV systems and public leadership programmes by local governments demonstrating solar PV systems. Similarly, such policies and factors have been reported in literature (Uzoma et al., 2011; Newman, 2012; Oji et al., 2012; Ohunakin et al., 2014; Dike et al., 2017) of studies carried out in Nigeria. They are (a) economic factors: high initial cost and installation; (b) technical factors: low quality/design of products, poor installation problems, maintenance problems due to limited access to trained technicians; (c) social and political factors: limited awareness/knowledge of solar PV systems, social acceptance, and inadequate policies to support solar PV systems at National, State and Local levels. Examples of government policies that can support solar PV systems are reduction of import duties/waive tariffs, effective quality control measures on materials/equipment, improving public private partnership, providing incentives such as part payment plans for consumers who wish to compliment the sub-optimal national grid with solar PV systems, supporting local manpower development/socioeconomic development on the technology (training at different levels on the installation and maintenance and developing infrastructure for community participation in solar energy projects).

6.2 The potential of solar photovoltaic systems in Nigeria

6.2.1 Technical

The technical specifications of the components for the different PV system designed varies and this is not unexpected since there is a variation in the load. While the PV systems are able to meet the load of the buildings, some LGAs have buildings with very high loads that requires a large capacity of PV array and battery bank for energy storage. Using the Mushin LGA as an example, meeting the entire load (maximum) of the Duplex building type requires 215 kW PV array and a battery bank of 380 kWh lead acid battery. This could be problematic as the roof of the building is smaller and will not accommodate the PV modules and there may also be issues related to the lack of space for the battery bank. An increase in the maximum annual capacity shortage decreases the size of the PV array and/or battery bank of the systems. This is explained as a result that, increasing the capacity shortage increases the acceptable amount of the load that can be unmet by the system implying that lesser energy is required from the system to meet the load. Conversely, a decrease in the minimum battery state of charge reduces the size of the PV array and/or battery. This effect of decreasing minimum battery state of charge on the system components can be explained by the fact that more energy from the battery bank is made available for use as the minimum battery state of charge decreases. The rooftop areas adopted for the different categories of buildings in this study is enough to accommodate the PV array except for one building (Duplex – Mushin) with an exceptionally high electric load which translates into a high PV array capacity and area. For this building, meeting the entire load of the building with electricity generated from PV systems is not technically feasible since the rooftop area of the building is smaller than the required area for the PV array. A PV hybrid system would be a more feasible option for such a building whereby electricity from the PV system is complemented by electricity from the grid.

6.2.2 Economic

The LCOE of electricity of the designed systems (50 systems) for the base case scenario ranges from 0.397 USD/kWh (Ajeromi, maximum load for '*Face -me –I- face -you'* building) to 0.743 USD/kWh (Alimosho, maximum load for flat apartment). This wide variation in the LCOE could be accounted by the fact that there exists a difference in the nature of the loads of the buildings. There exists some buildings with very high loads that occurs after sunshine hours and such buildings require a large battery bank for energy storage to meet the high loads that exists at night and this culminates in higher LCOE. The values of the LCOE obtained in this study are higher compared to 0.098/kWh (N30.93/kWh based on an exchange rate of 1USD = 315 Naira) cost of electricity from the grid power system in some locations in Nigeria. The range obtained from this study is higher compared to that (0.206 USD/kWh to 0.502 USD/kWh) obtained by Okoye et al. (2016) for selected cities (Onitsha, Kano and Lagos) in Nigeria. Studies by Ohijeagbon & Ajayi (2014) estimated the unit cost of electricity generated from diesel generators in Nigeria at 0.62 USD/kWh. Only two of the fifty systems designed had a unit cost of electricity that was superior to 0.62 USD/kWh. Hence, PV systems are more economically viable for use as stand-alone systems compared to diesel generators. The unit cost of electricity from PV systems obtained from this study could be lowered if the Nigerian government ensures an enabling condition that will bolster the adoption of the technology.

6.2.3 Environmental

The annual GHG emission saving associated with the integration and use of PV systems in the dwellings studied ranges from 35.95 to 17387 kgCO_2eq. This emission savings is associated to the fact that electricity generation from solar PV systems yields no GHG emissions during the operation phase of the system as opposed to conventional electricity generation modes.

7 Conclusions, Limitations and Recommendations

7.1 Conclusions

The insights from our study further confirms the results from previous studies that solar energy can be a source of sustainable energy to alleviate energy crisis and also contribute to sustainable socio-economic development in Nigeria. We have been able to provide:

a. The technical feasibility for the use of solar PV systems in meeting the energy demand (as a stand-alone or back-up for grid energy) of residential buildings in metropolitan Lagos, Nigeria. While PV systems are able to meet the load of the buildings, some LGAs have buildings with very high loads that requires a large capacity of PV array and battery bank for energy storage. Using Mushin LGA as an example, meeting the entire load (maximum) of the Duplex building type requires 215 kW PV array and a battery bank of 380 1kWh lead acid battery. This could be problematic as the roof of the building is smaller and will not accommodate the PV modules and there may also be issues related to the lack of space for the battery bank.

b. The economic benefit for the integration of a solar PV in buildings in Lagos is greater compared to the use of back-up diesel generators. The unit cost of 0.397 USD/kWh of electricity from PV systems (stand-alone systems) in some of our locations in this study is economically viable for use compared to use of diesel generators in Nigeria with unit cost of 0.62 USD/kWh reported in previous studies (Ohijeagbon & Ajayi, 2014). For buildings with LCOE as high as 0.743 USD/kWh, using PV generated electricity could still be cost effective compared to diesel generators provided some of their high loads that occurs at night is deferred since such loads is a factor that accounts for high LCOE of the systems. Outside the economics of the systems, use of PV systems in buildings is not associated with disturbing noise unlike diesel generators that produces noise and smoke which keeps household members uncomfortable. It is important to highlight, that the LCOE values obtained in this study are higher compared to 0.098 USD/kWh cost of electricity from the grid power system. The unit cost of electricity from PV systems obtained from this study could be lowered if the Nigerian government ensures an enabling condition that will bolster the adoption of the technology.

c. Environmental benefits (GHG reduction potential) of solar PV systems in buildings compared to the use of diesel generators in study locations. The annual GHG emission saving associated with the integration and use of PV systems in the dwellings studied ranges from 35.95 to 17 387 kgCO2eq. This emission savings is associated to the fact that electricity generation from solar PV systems yields no GHG emissions during the operation phase of the system as opposed to conventional electricity generation modes.

d. The possible impacts of government policies on photovoltaics adoption/integration in buildings. Although respondents do not have knowledge on the policies of solar PV systems, they perceive that to a very large extent the following policies may influence adoption/integration of solar photovoltaics on residential buildings in the study locations: reduced taxes on solar PV systems; grants and subsidies from local government to cut down cost of solar PV systems; awareness raising and public leadership programmes by local governments on solar PV systems.

7.2 Limitations of the Study

The limitations of this study includes:

a. Limited resources: Although a fixed grant was provided for this study, the design and sampling were based on limited resources. Nigeria was at the heart of inflation at the time of data collection (November 2015 and May 2016) for this study. The Limited resources translated into limited time accorded for the field work and the method employed in the collection of data. Hence, purposive sampling was used to select five largest LGAs out of the 16 LGAs in Metropolitan Lagos. While the use of electrical meters could generate more accurate hourly load data, again financial constraints made this impossible and it is for this reason that the study relied on the use of a time of use diary for the collection of load data. One week data was used for energy load profile computation (energy load profile computation of the appliances of each dwelling type was obtained as an average of the load profile for seven days). This may not be sufficient to account for monthly or seasonal variations that may exist in the load.

b. Security challenges: in the course of collecting the data, the team encountered a lot of refusals from security conscious residents. In some situations, the residents were totally uncooperative due to fear of being defrauded by strangers.

7.3 Recommendations

The following recommendations are made based on the limitations encountered during this study:

a. Sufficient time is recommended for subsequent studies. More insights can be generated in future study by collecting data on energy load profile over different periods and/or seasons of the year. This will also enable the residents to understand the study instrument and provide more reliable feedbacks.

b. For similar studies in the future, a collaboration with the public power supply personnel for data collection is recommended. This can actually help alleviate the fears of the residents.

c

. Future research should investigate periods during the day which power outages occur and based on this information, explore the possibility of designing a solar PV-grid connected hybrid system for the residential buildings.

. It is important that similar studies in the future should increase the population of the study to cover the 16 LGAs in Metropolitan Lagos so as to reflect the dynamic energy profile/use that may exist in the different LGAs.

e. This study focused on providing solar PV generated electricity to buildings from a stand-alone system. Information pertaining to areas where grid is available more than 50% of the time and the hours of the day during which power outage occurs is scarce and this constitutes and important aspect for the design of a solar PV-grid connected system. However, our study conducted a sensitivity analysis on the capacity shortage of the system, permitting the system to leave some of the load of the building unmet and such unmet load could be met by power from the grid. An important area which may constitute future research is the option of a solar PV system without battery especially in areas where the grid is available for at least more than 50% of the time.

f. The team propose that resources for subsequent studies be made flexible enough to accommodate changes that will come from peculiar circumstances associated with the study area.

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