Urban Residential Energy Demand Modeling in Developing Countries: A Nigerian Case Study.

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ABSTRACT

An econometric model is used to estimate urban residential electricity demand in Nigeria. The model uses residential energy demand data from 1975 to 2005. Shortcomings of the econometric model are highlighted, and system dynamics modeling is proposed as a complement to the econometric approach. It is suggested that this hybrid approach comprising econometric techniques and system dynamics may lead to better energy demand forecasting in developing countries.

(Keywords: energy demand, developing countries, econometric modeling, system dynamics, Nigeria)

INTRODUCTION

Having sufficient energy supply is vital for economic development. Energy forecasts aid energy planning which is not possible without a reasonable knowledge of the past and present energy consumption and likely future demands of a region [1]. The objectives of energy planning includes being able to determine the detailed energy needs of the economy in order to achieve growth and development targets, choosing the mix of energy sources to meet future energy requirements in the cheapest way possible, conserving energy resources and eliminating wasteful consumption.

The importance of energy demand forecast lies in the fact that timely and reliable energy supplies are important for the functioning of a modern economy and the fact that expansion of energy supply systems require many years as investments in such systems is capital intensive. Current energy models do not adequately address the energy related problems encountered in developing countries. This is mainly due to the lack of reliable data for the various parameters that affect the demand for energy.

In this study, the residential electricity energy sector in Nigeria is explored using an econometric model. The data used in this study is the Nigerian residential energy demand data from 1975 to 2005. Following an analysis of the econometric model, a system dynamic approach is proposed as a complementary tool to the econometric model.

REVIEW OF PREVIOUS WORK

There have been many studies on the residential demand of electricity both in developed and developing countries. Economic theory suggests that the demand for energy is based on a number of factors such as per capita income, economic production output, the supply and cost of available energy alternatives. Energy end-user behavior and preferences of energy form as well as the relative ease of substitution between the available energy forms is also important. However, such end-user characteristics can only be accounted for empirically. As yet, little is known about the conditions under which personal commitment, normative beliefs, convenience or other attitudes make an important difference in energy demand. Formal models based on the assumption of rational choice may not capture the appropriate variables for energy user responses to changing conditions and as a result, may be quite wrong about the level of short run response to changes in the energy environment.

However, it appears that formal models have advantages over informal judgements in that such models ensure that all parts of the energy economy are included in the analysis on the assumption that they are based on quantitative approaches. Different approaches have been used to analyze the determinants of residential demand for electricity. It was found that the number of customers, the price of electricity and the number of tourists correlate with annual electricity consumption [2]. Whilst price plays a major role in explaining conservation behaviour by electricity consumers, Ziramba [3] concluded in his studies on electricity demand for South Africa, that price increase alone will not discourage residential electricity consumption and that the increase in income does not induce a significant increase in residential electricity demand.

Some studies have expressed the demand for electricity as a function of own price, price of substitute and real income [4]. Beenstock et al. [5] model the household demand for electricity in Israel as a function of consumer spending; Holtedahl and Joutz [6] model the demand for residential electricity in Taiwan as a function of household disposable income, population growth, price of electricity and the degree of urbanisation. The use and interpretation of a measure like urbanisation in determining the level of consumption of electricity will be influenced by a country's institutions and history. According to [6] this measure may not prove useful in countries that have pursued policies aimed at electrifying rural areas and subsidising electricity to reduce urbanisation. Nevertheless, the level of urbanisation can capture aspects of economic development not explained by income alone.

Studies which have used micro-level survey data have included many more variables to capture household characteristics. It is generally considered that demand for electricity at household level is mainly determined by economic factors such as income and price of electricity. There are however few studies from developing countries that estimate electricity demand by making use of micro household data. Yoo et al. [7], employing survey data for Seoul, modelled the residential electricity demand as a function of family size, household income, price of electricity and a number of dummy variables reflecting electrical appliances possessed by the household. Filipini and Pachauri [8] modelled residential energy as a function of the price of the electricity, prices of LPG and kerosene, household income (approximated by total expenditure), size of the dwelling, size of the household and a number of dummy variables to capture household differences.

One conclusion arising out of all these studies is that the level of income of the household, the price of electricity and its substitutes influence the household's demand for electricity.

BACKGROUND

Development of the electricity utility industry in Nigeria started in 1896 when the first generation plant was installed. In 1950, the Electric Corporation Nigeria was established to coordinate and prioritise the development of the electricity sector for the whole country. The Niger Dam Authority was formed as a result of the anticipated growth in load demand as well as social development pressures. In 1972, the Electricity Corporation and the Niger Dam Authority merged to form the Nigerian Electricity Power Authority (NEPA). This was done with a view to generate, transmit and distribute electricity to consumers throughout Nigeria under a vertical management structure. This merger resulted in the substantial growth of the electricity sector in Nigeria over the next 20 years.

In the late 1990's the reliability and security of the Nigerian electricity industry became negatively impacted by technical, human and operational constraints and this consequently led to a crisis state. Although Nigeria is a net oil exporter, energy shortages marked by power interruption and fuel shortages are commonplace. This may be due to inadequate or out of date infrastructure, lack of spare parts, manpower shortage and inefficient management.

EMPIRICAL SPECIFICATION AND DATA

As seen in most of the literature reviewed, the demand for energy (electricity) has been modelled in variety of ways. The most common variable used includes, income, price of electricity and price of a substitute. The most common specification for electricity demand takes the form of a linear double-logarithm form. Data from the Power Holding Company of Nigeria (formerly the Nigerian Electricity Power Authority) were used for the period from 1975 to 2005.

The model adopted is in the form of: *lnREC f* (*lnEG, lnGDPC, lnPop, lnPe, lnPk*).

The model is specified as:

$$lnREC = -a_0 + a_1 lnEG + a_2 lnGDPC + a_3 lnP_e - a_4 lnP_k + u \quad (1)$$

where:

lnREC = natural log of total residential electricity consumption (MWh)
lnEG = natural log of total electricity generation (MWh)
lnY = natural log of per capita real disposable income (Million Naira).

LnPe = natural log of the price of electricity (Kobo)
lnP_K = natural log of the price of kerosene (Kobo)
u = stochastic error which is assumed to be white noise which is normally and identically distributed.
a_0 = constant
$a_1 – a_4$ = coefficients of the explanatory variables

RESULTS AND DISCUSSIONS

In order to find out the residential electricity consumption, Ordinary Least Squares (OLS) regression was carried out using Microfit 5.0®. The total residential electricity consumption was taken as the dependent variable while the amount of electricity generated, disposable income, price of electricity and the price of a substitute/complement (kerosene) were used as the explanatory variables.

Table 1 shows that about 89% of the variance of residential electricity consumption can be explained by the amount of electricity generated, gross domestic product per capital, price of electricity and the price of kerosene. This is in agreement with the findings by Subair and Oke [9] that indicated that electricity generation can be used to analyze and estimate electricity consumption.

With regard to the impact of the price of electricity and kerosene to electricity consumption, the size of the coefficients relative to standard error indicates that neither the price of electricity nor the price of kerosene is highly significant in determining the level of residential electricity consumption. This may be due to the fact that in the short to medium term, both supply and demand are inelastic to changes in fuel prices. A reason for this inelasticity is that consumers invest significantly in domestic appliances and supporting infrastructure tailor-made for the intended energy form. This places great constraints on the ability of consumers to switch from one energy form to another in the short to medium run. Moreover, electricity tariffs in Nigeria are generally low and are administratively determined, as opposed to being market driven. Consequently, electricity tariffs have not played any role in signaling the scarcity value of electricity to consumers.

Table1: Regression output for Nigerian Residential Energy Demand Data from 1975 to 2005.

Ordinary Least Squares Estimation
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Dependent variable is lnREC
Based on 28 observations from 1975 to 2005
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Regressor	Coefficient	Standard Error	T-Ratio [Prob]
A_0	-.47591	.92291	-.51566[.611]
lnEG	.84084	.14707	5.7172[.000]
lnY	.99071	1.9568	.50629[.617]
lnP_e	.022995	.066643	.34505[.733]
lnPk	-.059230	.058052	-1.0203[.318]

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R-Squared	.89252	
R-Bar-Squared	.87383	
S.E. of Regression	.16330	
Stat.	F (4, 23)	47.7478[.000]
Mean of Dependent Variable	5.9401	
S.D. of Dependent Variable	.45974	
Residual Sum of Squares	.61335	
Equation Log-likelihood	13.7640	
Akaike Info. Criterion	8.7640	
Schwarz Bayesian Criterion	5.4335	
DW-statistic	1.3924	

Diagnostic Tests
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Test Statistics	LM Version	F Version
A: Serial Correlation	CHSQ (1) = .80115[.371]	F (1, 22) = .64802[.429]
B: Functional Form	CHSQ (1) = 2.0228[.155]	F (1, 22) = 1.7131[.204]
C: Normality	CHSQ (2) = 1.0532[.591]	Not applicable
D: Heteroscedasticity	CHSQ(1) =.58821[.443]	F (1, 26) = .55792[.462]
E: Predictive Failure	CHSQ (3) = 6.6947[.082]	F (3, 23) = 2.2316[.112]

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A: Lagrange multiplier test of residual serial correlation
B: Ramsey's RESET test using the square of the fitted values
C: Based on a test of skewness and kurtosis of residuals
D:Based on the regression of squared residuals on squared fitted values
E: A test of adequacy of predictions (Chow's second test)

Table 2: Correlation between Residential Electricity Consumption and associated Variables based on 31 observations from 1975 to 2005.

	lnREC	A_0	lnEG	lnY	lnP_e	lnP_k
lnREC	1.0000	*NONE*	.94900	.84839	.85215	.77496
A_0	*NONE*	*NONE*	*NONE*	*NONE*	*NONE*	*NONE*
lnEG	.94900	*NONE*	1.0000	.88914	.89339	.82490
lnY	.84839	*NONE*	.88914	1.0000	.96579	.97558
lnP_e	.85215	*NONE*	.89339	.96579	1.0000	.94102
lnP_k	.77496	*NONE*	.82490	.97558	.94102	1.0000

As shown in Table 2, income is an important determinant for electricity consumption. This may be due to the fact that income directly affects living standards. According to Babatunde and Shuaibu [10], an improvement in living standards contributes significantly to an increase in residential electricity demand. Growth in real per capita income leads to an increase in the purchase of electrical equipment and appliances, thereby leading to an increase in electricity demand.

Increased electricity demand will spur electricity generation. As Table 2 shows, there is a high correlation between electricity demand and generation. This suggests that an increase in per capita income will lead to an increase in residential electricity demand, which in turn leads to higher electricity generation. Like any developing nation, Nigeria has a large informal sector, which means that determination of per capita income is not always accurate. Consequently, electricity generation may be a more accurate determinant of residential electricity demand than recorded per capita income. This may be the reason why the correlation of residential electricity demand to generation is higher than the correlation of per capita income to residential electricity demand in Table 2.

Adenikinju [11] observes that there is significant suppressed demand for residential electricity in Nigeria. According to Adenikinju, by the year 2005 only 34% of Nigeria's population had access to the public power supply, with consumed energy per capita being 161kWh, barely enough to light ten 40-watt bulbs for one hour each day of the year. In addition, the supply of electricity is unreliable, with the public power supplier reliability being estimated at less than 50% by time nationwide in 2005. Because of the inadequacy of a reliable grid electricity supply, auto generators are an important source of electricity in Nigeria, especially in the more affluent households. In addition, kerosene remains an important source of fuel for the poorer households.

The regression model we have utilized is a typical econometric model that uses aggregated economic data to examine interactions between the energy sector and other sectors of the economy. The basic assumption behind such models is that the historical trends in the aggregated data contain sufficient information to predict the future [12]. This is not practical for developing countries like Nigeria where the economic data available does not necessarily reflect the true economic activity in the country since a significant part of economic activity takes place in the informal sector. Also, developing economies are in a transition stage, which means that past data cannot be used as a basis to estimate future trends.

Energy models that capture all the available energy end-uses and technological options are preferable for developing countries [12]. Such models are usually combined with a descriptive method to provide practical estimates of the technology mix resulting from decisions that are based on factors such as end-user preferences, intangible costs, capital constraints, attitudes to risk, uncertainty, and market barriers [12]. This disaggregated approach to energy demand analysis enables better representation of specific features of developing countries. For instance such models can capture spatial differences in housing stocks, consumption behavior, technological choices as well as differences in demand by income class. In addition, they can also be used to capture the use of traditional energies as well as to track the transition of energy use due to policy and income-induced effects [13].

Energy systems are characterized by causal linkages between sub sectors within the energy sector as well as between the energy system and other economic sectors. For instance, in the Nigerian housing sector, changes in per capita income can lead to households making the transition from kerosene to the use of auto-generators, and increased access to reliable grid electricity can lead to the decline of auto-generators and kerosene as energy sources. Energy models that capture the interactions between the various energy subsystems as well as the interactions between the overall energy system and other socio-economic systems are essential. The system dynamics approach [14][15] is well suited to developing such models.

SYSTEM DYNAMICS

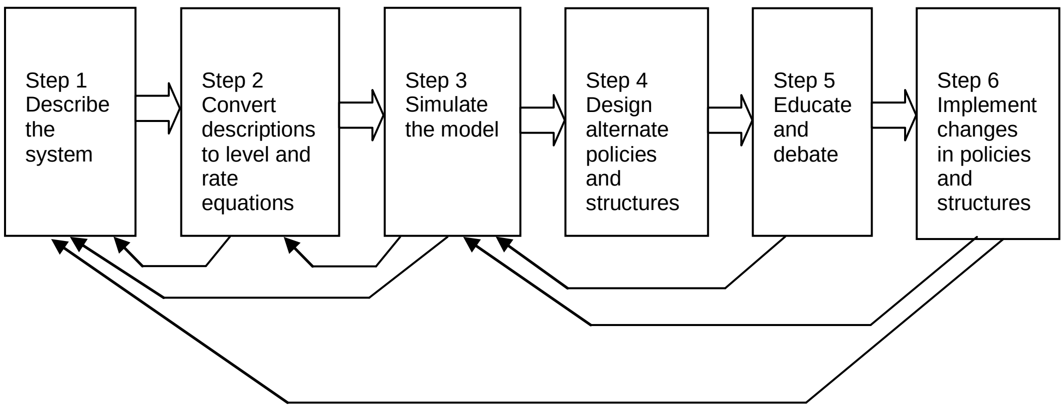

Figure 1: Steps in the System Dynamics Modeling Process [16].

System dynamics originally arose in the late 1950s out of Forrester's attempts to find methods to enable management and policy makers to study the effects of policy changes in industrial systems [14]. The field of system dynamics has now extended to analysing the behaviour of systems in such diverse fields as environmental change, politics, economics, medicine and engineering in addition to the field of management [15].

In system dynamics, computer simulations are used to enable the effects of policy changes on different parts of the system. In addition to physical quantitative data, system dynamics also offers the facility to use descriptive information. System dynamics comprises two stages, namely the quantitative and qualitative stages [17]. In the qualitative phase, cause and effect diagrams for exploring and analysing the system are developed. System actors collaborate in the development of these diagrams. In the quantitative phase, the relationships between all variables in the system diagrams are quantified, relevant parameters are calibrated, and the appropriate rate and level equations are developed. The process of creating a system dynamics model encourages active participation by all the system actors. This ensures that by the end of the modelling process all the actors involved will have a better shared understanding of the system.

The process of system dynamics comprises six stages as shown in Figure 1. In step 1 the relevant system is described. In step 2 the system description is translated into a set of level and rate equations. As indicated in figure 1, this is an iterative process, and goes on until the system actors are satisfied that both the system description and accompanying level and rate equations adequately represent the system being modelled. In step 3 the model is simulated. Again this is an iterative process in which both steps 1 and 2 are revisited until the simulation behaviour of the system adequately represents the behaviour of the real system. Step 4, in conjunction with step 3, identifies alternate policies and structures that may be implemented to modify the behaviour of the system in accordance with the objectives of the system actors.

Step 5 works towards a consensus for implementation of the changes identified in step 4. This may involve other stakeholders in addition to the system actors involved in steps 1 to 4. The discussions and debates arising may require the previous steps to be revisited and modified until consensus is reached. Step 6 is the final implementation of the changes proposed in the system, and success depends to a great deal on the quality of the previous steps. This is generally a lengthy step, and environmental conditions and policy objectives may change, requiring previous steps to be revisited.

As Figure 2 demonstrates, the causal loop diagram is an important tool to begin to understand the interactions between the supply and demand for the three fuels in the urban residential sector. Economic growth or decline, as seen through the rise and fall of household incomes, and the concomitant rise and fall in urban populations, is seen to have a direct impact on energy demand. Similarly political considerations, as implemented through government controlled pricing of both kerosene and electricity, have a significant impact on the dynamics of the urban residential energy sector.

Subsequent development of the causal loop diagram into a systems dynamics model of the urban residential energy sector will enable these causal relationships to be fully quantified. This, in turn, will enable the government, energy suppliers, and other stakeholders to develop an urban residential energy policy that is both measurable and controllable. This will ensure that the impact of such a policy can be measured and quantified even before the policy is implemented. This in turn, will enable the policy to be fine-tuned to suit the existing social, political and economic environment. In addition, even when the policy has been put in place, timely interventions can be instituted to ensure that the policy remains relevant and up-to-date despite changing requirements.

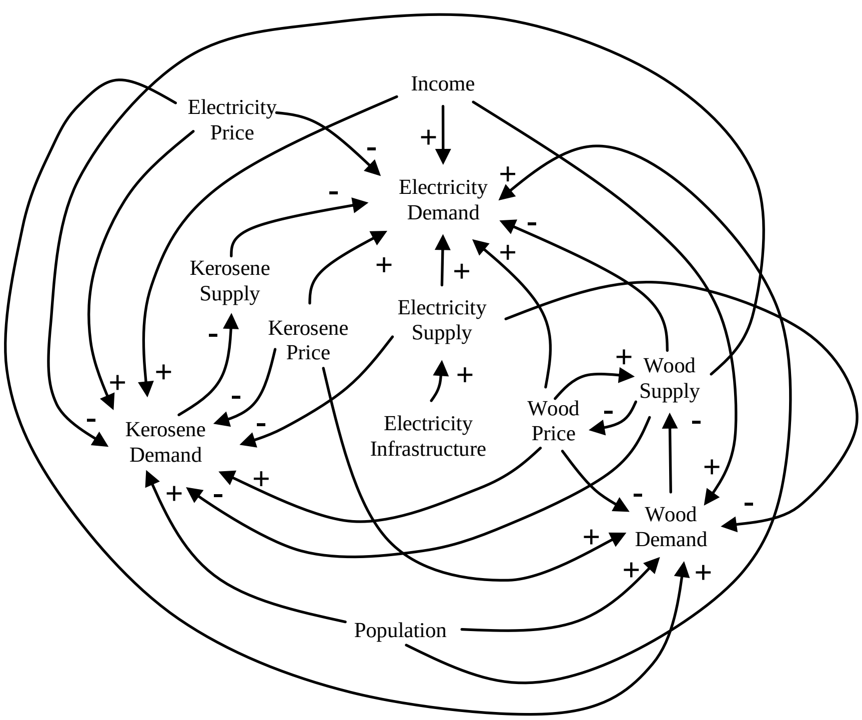

Figure 2: Causal Diagram Illustrating the Typical Dynamics of Urban Residential Energy Sector Demand in a Developing Country.

CONCLUSION

In this paper, multiple regressions were used to model residential electricity demand in Nigeria. The results show that residential household demand for electricity is affected mostly by the generation of electricity and real disposable income. A hybrid approach towards modelling urban residential electricity demand in developing countries is proposed. The proposed approach will comprise econometric modelling complemented by system dynamics modelling. It is anticipated that such a hybrid modelling approach will build on the capabilities of the two approaches, thereby leading to better energy forecasting.

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