HOUSEHOLD ENERGY DEMAND PREDICTION IN DEVELOPING COUNTRIES

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ABSTRACT

Studies show that energy demand in developing countries is expected to contribute a significant amount to the total energy demand in the near future. Although still currently small compared to demand in industrial countries, a prolonged energy demand surge poses a great threat to the environment and social development when not met adequately. Efficient energy planning and management through national and regional policies is the key in minimizing the impact of energy demand to the environment while providing a platform for optimal energy supply to meet social needs for development. Unfortunately, lack of record keeping, poor data management and detailed data availability pose a great threat in effective energy management and planning in these countries. Currently, energy policies in most developing countries are generic national policies concentrating on energy supply. There are yet no policies for the control of energy demand drivers due mainly to the lack of data.This paper introduces a new method to illicit household end-use information needed in energy consumption trend analysis and demand estimation by combining urban land use characteristics, satellite image analysis and a basic household energy survey. The methodology can then be used as a tool for energy planners and managers to establish policies on the household and regional level

INTRODUCTION

Energy demand in developing countries

Rapid population growth and urbanization in developing countries is the main cause of the rapid surge in energy demand. It is expected that out of the total energy demand in the world in the next 20 years, about 60 percent will be from these countries [IEA, 2010]. As a result to urbanization improvement to the standard of living in developing countries is also an important factor to the energy demand increase. Currently developing countries are facing a crisis on how to satisfy their energy demand. Abrupt changes in energy demand between urban and rural areas are part of the problem but unplanned energy supply and management systems contribute to the problem to a larger part.

There have been a massive number of studies showing the correlation between energy use and economic development [A. E. Akinlo, 2008; Perry Sadorsky, 2010]. Some researchers have even named energy as a prerequisite condition for economic growth and development [O.J. Ebohon, 1996]. Theoretically, energy has been shown to be equally important as other factors of production such as land, labor and capital because of its correlation with economic growth [J. Ikeme and O.J. Ebohon, 2005]. This relationship is found to be much stronger for electric energy than energy as a whole [Andrews-Speed P. and Dow S., 2000]. Since energy boots development and development boots energy demand – up to a certain point, developing countries are in a constant battle to maintain energy balance to support development and social advancements. Currently, however, the energy status in developing countries is very unstable with frequent power shortages and unsatisfactory services in other sources of energy such as petroleum products and semi-formalized traditional energy such as charcoal. Even traditional energy sources such as firewood are under strained conditions due to long dry spells, environmental degradation and deforestation.

Urbanization

Energy use in developing countries is still concentrated in urban populations [Stephen Karekezi and Lugard Majoro, 2002]. The urban population in Sub-Saharan Africa alone increased from 22 percent to 36 percent between 1980 and 2005 [The World Bank, 2011]. While the population in developed countries is seen to be larger in the urban centers already, developing countries are expected to experience large rural-urban shift in the near future. Sharp increase in the population in urban areas in the less developed areas is in sharp contrast to the population decline in the rural area. The rate of urbanization in developing countries is expected to remain high until from the year 2030 where it is expected to undergo a much slower growth. The urbanization rate in Sub-Saharan Africa is at an average of 5 percent followed by the East Asia and Pacific region [The World Bank, 2012]. While most developed countries reaches saturation points before year 2025, urbanization trend potential in developing countries seems to continue beyond year 2050. The United Nations projects that by 2030, 60 percent of the total world population will be in the cities [UN, 2011].

The International Energy Agency predicted that about two thirds of all energy consumed in the world is in cities around the world even though only around one half of the population lives in urban areas. By

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2030, increase in urbanization will drive up city energy to 73 percent of the worlds' energy use where 80 percent of this increase is expected to be in developing countries [IEA, 2010] . It is understood that due to better availability of energy services in the urban areas coupled with improvement in the standard of living, modern energy intensity per urban capita is higher than the national average. In China for an instance, the energy intensity per urban capita is 1.82 times the national average [IEA, 2010] whilst in Tanzania in 1993, the urban modern energy intensity was about 4.4 times the national average [R. Hosier,1993]. Hosier concluded that one rural person migration to the city results in a tripling of the economic costs for supplying that person's energy needs [R. Hosier, 1993]. In Tanzania, while the rate of electrification for the whole country is around 15 percent, only 2 percent is in the rural area whilst 39 percent is in the urban area. Out of all the energy consumed in Tanzania 50 percent is consumed in the largest commercial city, Dar es Salaam [Alex Kyaruzi et. al, 2012; Helio International, 2006]. Hence, understanding the energy use in the urban center in developing countries is important in understanding the total energy use trend.

Household sector

The household sector in developing countries makes up a large share of the total energy consumption. In Tanzania, 72.5 percent of the total energy consumption is in the residential sector, whilst being 80.63 percent in Kenya and 81.01 percent in Nigeria. Out of which, traditional biomass fuel is 97.2 percent in Tanzania, 94.7 percent and 98.2 percent in Kenya and Nigeria respectively [IEA, 2009]. Even though the most commonly used fuel in residential sector in developing countries is traditional biomass, residential sector has a strong impact to the modern fuel use especially in countries without a strong industrial sector. Twenty seven percent of the total electricity use in Kenya is in residential sector, 56.3 percent is used in Nigeria and 45.5 percent in Tanzania [IEA, 2009].

The energy demand pattern of the poor households largely evolve around household energy end-use of cooking and lighting while the wealthier households have more end-uses such as refrigeration, air cooling, information and entertainment, and domestic water heating. The effect of residential energy consumption is not only felt in the total national energy consumption but also in the daily peak demand. Energy required to meet residential end-use demand affects the amount of energy needed to be produced at the national level to meet that demand. The demand in residential area is locality specific and can have a higher intensity in one locality compared to another. Appliance ownership rate, which plays an important role in modern energy demand, especially electricity is also influenced by urbanization [Michael A. McNeil]. McNeil concluded that the rate of refrigerators ownership is not only affected by household income but also urbanization whereby households in areas with high rate of urbanization own more refrigerators than households with the same income level in less urbanized areas. This means that by understanding the energy demand drivers in developing countries' household sector in the urban centers can help in controlling to a large extent the energy demand in these countries

Data availability

While conducting a survey on the energy use pattern in slum dwellers in Nairobi – Kenya, Stephen Karekezi, et al. [2008] mentioned limited availability of secondary data and information sources for crosschecking the primary data for consistency and accuracy as a limitation for their survey. This limitation is consistent throughout energy studies in developing countries. For instance, models found in literatures mainly use national level data to simulate energy demand in developing countries even when simulating energy consumption trend in the household level. This is mainly caused by lack of grass root level data. Biswas [1990] states that data concerning energy infrastructure in developing countries is very limited. Moreover, poor or non-existent data management, inter-ministerial or inter-institutional rivalry, unnecessary classification of data as secret or confidential combined with official apathy often result in unavailability of the data that actually are collected. Moreover, when data is available, its reliability is not guaranteed.

The International Energy Agency [IEA, 2005] established a set of indicators to assess country's energy efficiency performance and benchmarking. When reviewed by The World Bank [Dian Phylipsen, 2010] for their application to formulate and evaluate progress of Energy Efficiency policies in developing countries, it was found that end-uses and activity data was lacking hence limiting indicators when available to the national and sectoral level. This limits the extent to which the indicators can be used for energy efficiency planning and monitoring. It was also noted that lower aggregation level data requires specific surveys and analysis and is not found on regular statistics. End-use data gathering procedure development and strengthening was proposed for efficient indicators use in policymaking and identification of available activity data and surveys for additional data collection was also recommended. It was also found that there is no clear understanding between efficiency indicators and policy implications in some developing countries. While compiling the energy access situation in developing countries, UNDP and World Health Organization [2009] stated that while data was sought it was not always found for all developing countries and estimations had to be made. Where data was available for two out of three – national, urban, rural levels – estimates were made for the third using the available information. Where data from some countries were missing, estimates of global and regional access for developing countries were produced using a simple extrapolation process where the extrapolation involved aggregating the data from countries were that particular data is available and assuming that the level of access is the same in the countries without that data.

Under the background of constrained data availability in developing countries, energy demand estimation model is proposed in this study to be used as a tool for energy planners and managers in controlling future energy demand.

METHODOLOGY

From the literature review and direct interviews with energy managers and policy makers, it was found that developing countries are facing a huge problem in energy management and appropriate policy mechanism due to a lack of detailed data on energy consumption. As a result, energy policies in these countries concentrate on the national or sectoral energy demand management and ignore locality based management and end-use planning. In developing countries where the household sector contributes a high percentage of the total energy demand, understanding the drivers in the household sector is important in making informative decisions on energy management and policy making. To overcome the lack of energy data limitation, a new methodology to estimate energy demand in developing countries is proposed.

<u>Hypothesis</u>

Firstly, a new method to collect regional/locality level data was introduced. The basic hypothesis behind this method is the assumption that households form or are segregated in zones of similar income and consequently similar energy consumption intensity since energy use is directly related to income.

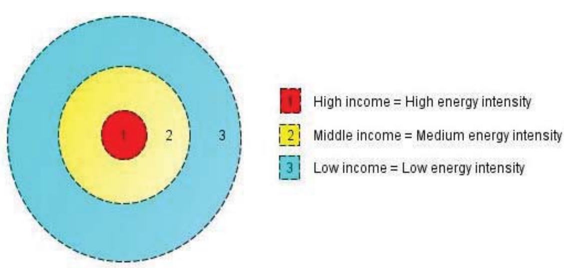

Figure 1: Hypothesis – Income Vs Energy

Using this hypothesis, total energy consumption intensity in each zone is aggregated to calculate the total energy consumption intensity of the whole area.

Since the hypothesis requires the establishment of energy consumption intensity zones, land use analysis involving regional planning and master plan analysis is proposed. From the land use analysis, zones having similar household income and consequently similar household energy demand are established. Housing density, housing type and social services availability are taken as indicators when analyzing the income distribution in an area. Low housing density in well planned neighbourhood with complete set of social services such as electricity, clean water, sanitory systems and security is taken as an indication of high income area. Satellite pictures taken from samples within these zones are analyzed and the total number of houses in each zone is computed.

From then onwards, a simple household energy use survey from a sample in each established zone is conducted in order to understand the appliances penetration level in each income zone, the number of hours they are used per day, and the quantity of appliances per household in each income zone. The survey also looks into the appliances energy consumption (power ratings) to understand the difference – if any – of appliances' efficiency in each income zone. This information together with the data collected by land-use analysis is then inputted in an end-use model to predict the future energy demand of that locality.

<u>Model simulation</u>

To analyze and test the model, Dar es Salaam city in Tanzania was chosen as a case study. This city is chosen because it is among the top ten rapidly expanding cities in the world and experiences acute energy shortages – especially electricity. Three master plans of 1954, 1969 and 1979 were analyzed together with current infrastructure and land use reports to establish the household zones per income. The housing density, housing type and avalibility of social services such as garbage collectors, clean water and electricity in a neighborhood indicated that the northern area of the central business district along the Indian Ocean coast is a prime housing area with plot values decreasing further from the coast. Satellite image analysis confirmed that the housing density is the lowest from the coastal area inwards establishing the zones for middle/high income households along the coastal area to the north and low-income households in the unplanned settlement areas in the hinterland [Figure 5].

Household energy use survey was then conducted via three different media; Word file though emails that got 48 responses, paper handouts that got 52 responses, and an online version that got 57 responses; 157 in total. The survey asks on the energy use for cooking and lighting together with the type of electrical appliances the household own. It also asks on the number of hours the appliances are in use together with their quantity. Another survey was conducted on site on 53 households to understand appliances power and efficiency. This information is inputted in an end-use model proposed to simulate the energy demand for Dar es Salaam for the year 2012.

The end-use model combines the aggregated energy in each household by calculating the total energy use by each appliance use as follows:

$$\text{Energy consumed by End Use}_i \text{ in House}_i \left(\frac{KWH}{Year}\right) = \text{Appliance Power (W)} \times \sum^{n} \text{Appliance} \times \sum^{24\,hours} \text{Time of Use} \times \sum^{366\,Days} \text{Days of Use}$$

$$\text{Energy consumed by all End Uses for Group}_i \left(\frac{KWH}{Year}\right) = \text{Electrification level} \times \sum^{n} (\text{End Use}_i \times \text{Appliance}_i \text{ Penetration level}) \times \sum^{N} \text{Houses}$$

When the results are compared with real consumption energy [Source: Tanzania Electricity Supply Company - TANESCO] they show a close similarity at 0.4 percent difference. To validate the model, Malaysia's appliances use characteristics [Malaysia Bureau of Statisctics, 1999] was used because of the geographical, climatic and cultural similarities between Malaysia and Dar es Salaam, Tanzania. The simulated results using Malaysia's information differs to when Dar es Salaam's information is used by 3.01 percent for year 2012 consumption.

The results indicate that the model hypothesis is sound and the energy use characteristics between the two income groups can be used in energy demand estimations forecasting in developing countries that lack detailed energy use data. Drivers behind the energy demand in the forecasted years can then be understood and appropriate actions can be then taken by energy planners for energy sources optimization.

<u>Model application</u>

The model was then used to forecast energy use for Dar es Salaam region for the year 2020 and year 2030. Under the forecasting conditions, household income group (middle/ high income households) was taken to expand with time and so does appliances penetration level. The rest of the parameters are taken to be at a fixed value rached in year 2012 illicited in the household energy use survey conducted for this study.

To observe the change in appliances penetration level and middle/high income group growth trend, historical data from national budget survey conducted in the national census is used. Information for the year 2001 and year 2007 are available for the case of Dar es Salaam and this data is coupled with the year 2012 data collected in this study to understand the energy demand estimates. The growth trend of the two factors – middle/high income household group expansion and appliances ownership level expansion – is taken to be under a polynomial function with an order k and constant c_i is used

$$y = c_0 + c_1 x + c_2 x^2 + \cdots + c_k x^k$$

Two functions for the appliances ownership growth were derived using historical data from the national budget survey - giving slow appliances ownership growth, and the historical data combined with data from the survey conducted in year 2012 – giving high appliances growth rate. The demand estimates for the two years are plotted together with the real consumption data for the years 2007 to 2012 given by Tanzania Electricity Supply Company – TANESCO. It should be noted that up to the year 2012, only 43 percent of the total households in Dar es Salaam were taken to have electricity whilst all households in the city were taken to have electricity in the estimated years of 2020 and 2030.

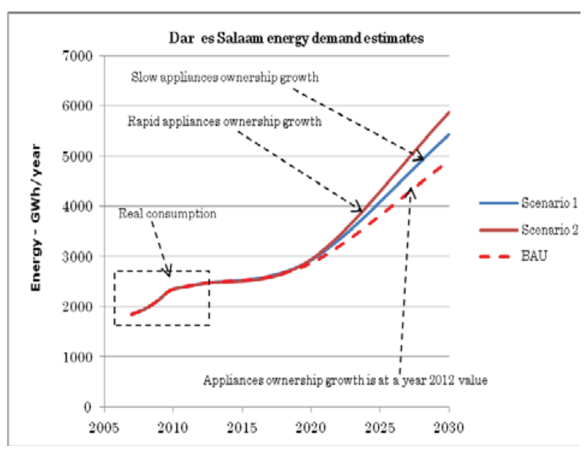

Figure 2: Hypothesis – Income Vs Energy

In the period of ten years between year 2020 and 2030, the total unconstrained demand is seen to increase by about 185 percent. The load share of appliances for the year 2020 and 2030 under slow appliances penetration level growth (Scenario 1) show a huge shift between the year 2020 to year 2030 where the biggest load share change is in lights – from 33 percent to 27 percent, followed by air conditioners – from 37 percent to 42 percent. The load share of washing machines changes from 3 percent to 5 percent from year 2020 to year 2030. The load share of refrigerators show a decrease from 10 percent to 8 percent within that change of time. The results show that lights being the most common appliance has the highest impact to the energy use but the effect of the expansion of the middle/high income household group favouring high ownership rates of comfort appliances such as air conditioners, washing machines and water heaters will have a greater impact with time to the total energy demand in the city of Dar es Salaam and consequently Tanzania as a whole.

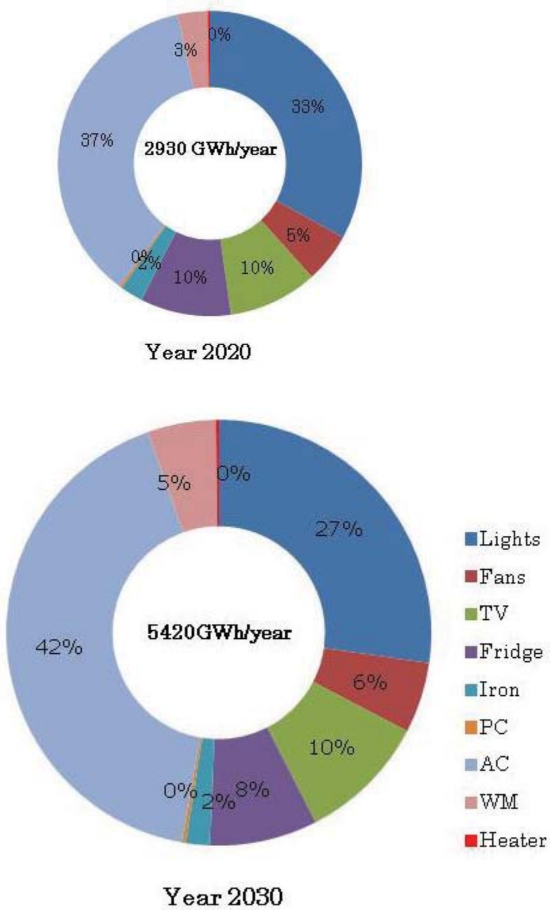

Figure3 : Appliances load share

CONCLUSION AND DISCUSSION

Although the method introduced in this paper is established under a very limited data availability condition, the results reached can be used to give basic explanations of expected energy demand growth in developing countries.

Using the methodology proposed in this study, the energy demand drivers in the household sector in developing countries lacking detailed energy consumption data can be understood. Policy makers can then use this methodology as a tool to plan and control demand for optimal resources utilization. For instance, by controlling the load share of energy used by lights in Tanzania in the low income households by the introduction of efficient light bulbs from the current 60W bulbs to 30W bulbs, a 25 percent change to the more efficient 30W bulbs in the low-income households alone can conserve about 108GWh/year while a hundred percent conversion can conserve 430GWh/year. Controlling the efficiency of air conditioners imported in the country through labelling and other incentives can also contribute greatly to the energy management in the country since the effect of the appliance is seen to be growing with the improvement to the standards of living.

Figure4 : Light power control in low-income households

Thus, this method can be used by energy planners to make informed decisions on energy policies in developing countries that focus on a smaller locality level compared to the current national level and on the end-use level compared to the current sectoral level.

Although this method can be used as an important step in a more detailed energy management in developing countries, energy use data recording is recommended in these countries for more precise results and consequently better and more poignant policies.

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Figure 5: Dar es Salaam Housing income zoning