Drivers of Energy Efficiency among Households using Grid Electricity in Kampala, Uganda

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Abstract

The study aimed at examining the drivers of energy efficiency among households that use grid electricity. Specifically to assess: the effect of awareness, Government incentive, and ICT investments on energy efficiency. A stochastic frontier analysis was carried out using cross-sectional survey data. Most households were found to be aware of energy efficiency. Households that had knowledge of energy efficiency labels, and apply any form of energy saving measure were relatively less inefficient. Likewise, households that; received the Government incentive of free energy saving bulbs; invested in ICT to change from post-paid to prepaid meters; and those using individual/unshared meters were also less inefficient. Further, inefficiency was lower for households residing in planned estates and/or rented homes, and relatively higher for households with backup energy resources. Therefore, implementing and popularizing appliance energy efficiency labels and codes may potentially increase energy efficiency levels in Uganda. The study also recommends increased investment in; energy efficient appliances, individual prepay meters, and incentivizing households with the opportunity to test energy saving technologies free of charge. All-inclusive awareness programmes capturing type of residence and publicity for individual meter use for tenants are pertinent.

Key Words: Energy Efficiency, Government Incentives, Household, Awareness, ICT Investment, Grid Electricity.

Introduction

The overall consumption of energy worldwide is continuously increasing and expected to increase by 53% in 2035 (EIA, 2012). This will negatively affect the environment and primary energy needed to produce output such as electricity, hence increasing the respective prices. Nevertheless, approximately 789 million people globally still lack access to electricity thus compromising social welfare (SEforALL, 2020). Most of this population is poor and has no access to grid-based energy. According to Foley et al., (2021), sustainable development goals target universal access to

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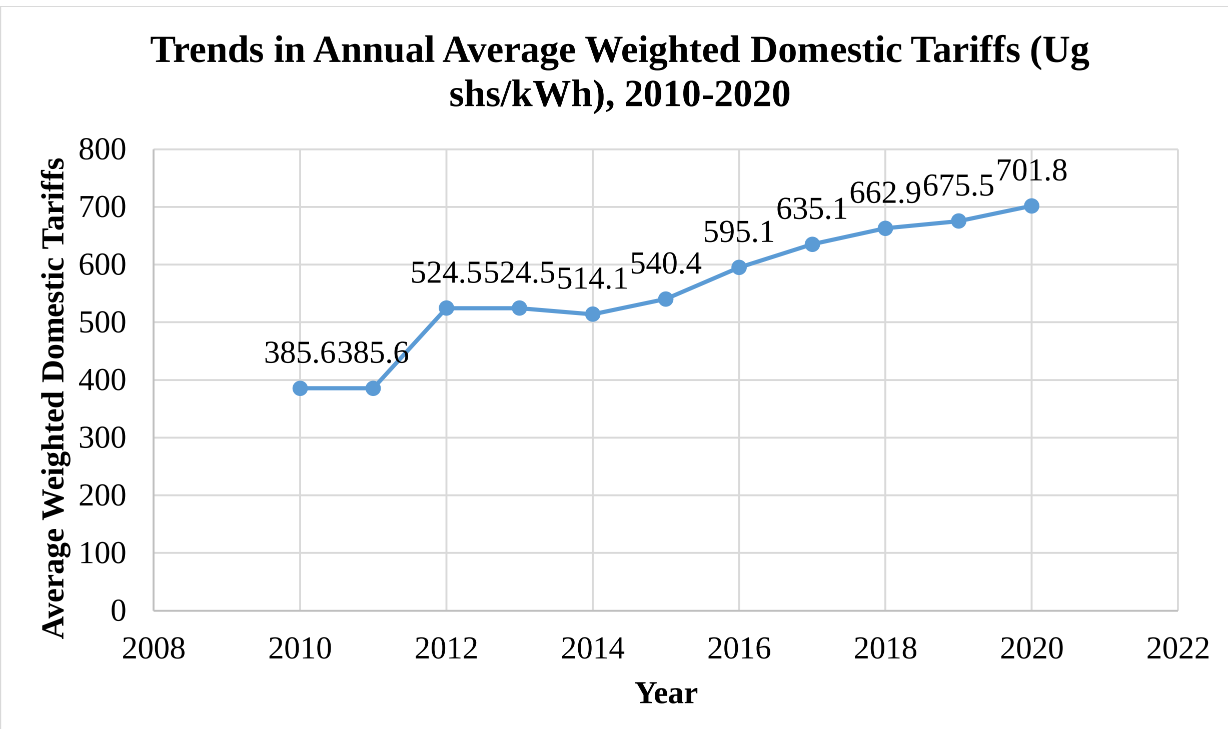
electricity by 2030 but this may not be met. This is because currently, an estimated 620 million people, 85% of whom are situated in Sub-Saharan Africa, would still lack access to electricity if the annual rate of electrification remains at 0.87%.

Uganda is not unique to this situation as it has one of the lowest electrification rates in Africa with a current access rate of 28%, way below the SSA average of 48% (IEA, 2019; Ministry of Energy and Mineral Development, 2017). In Uganda, households are among the fastest growth markets for electrical connections, growing at annual rate of approximately 13% with 26.7% of households having access to electricity of which 18% are in rural areas (UBOS and ICF, 2018). Over the NDP II Plan period, Government focus was on increasing the percent of the population with access to electricity from 14 percent to 30 percent (National Planning Authority, 2015). Electricity is consumed by residential (55%), commercial (24%) and industrial (20%) sectors and for street lighting (1%). Recognizing the need and importance of accelerating access to rural areas, new Rural Electrification Strategy covering the period 2013-2022 was adopted and implemented (Ministry of Energy and Mineral Development, 2012). Half the urban households use electricity for lighting (using inefficient incandescent lamps) whereas the majority of rural households use kerosene, which is more expensive (Lee, 2013). This could be attributed to the high and highly fluctuating domestic unit price of grid electricity as indicated in Graph 1.



Graph1: Trends in Average Domestic Unit Prices of grid electricity in Uganda (2010-2020)
Source: Weighted Average Domestic Tariffs (Ush/Kwh) (2021)

High grid electricity prices are expected to inversely affect its household demand. Unlike normal goods where supply response is applied to meet any possible increase in demand. In the case of energy the market demand response is employed to reduce the increase in demand. Hence, better optimization improves energy use and efficiency and also reduces energy consumption during peak time at high price (Zheng & Heshmati, 2020). Households may be forced to mitigate upon efficient measures to control grid electricity usage, and or reduce usage per unit of household output via energy efficiency use. Likewise, the government of Uganda partnered with Umeme, the power distributor, to distribute light emitting diode (LED) bulbs to some parts of the country as a demand suppressing strategy for electricity consumption. This initiative was rolled out in 2007 targeting 840,000 households in the country. Households in Kampala were among those who benefited from the initiative. The initiative was rolled out for the third time in 2016. A drop in electricity consumption by 30MW was attributed to the initiative (Bungane, 2016).

To advance the initiative of electricity demand management, the government of Uganda together with different stakeholders designed the Roadmap that prioritizes recommendations for implementing energy efficiency and maximizing benefits to meet the goals and priorities established in Uganda's 2015 SEforALL. To achieve this, there was need to create and increase demand for efficiency through long-term enabling policies and financial incentives combined with development of technical expertise in the labor force to allow for the promotion of new business models (du Can et al., 2018; Pudleiner, David et al., 2017). The power distributor, Umeme also rolled out the use of prepaid meters/ billing system (*Yaka*) program that had two fold objectives. This initiative aimed at management and reduction in power losses for the company and electricity demand management for the users, more so households (Umeme Limited, 2013). This was introduced in 2011 and over 97 per cent of the users are currently on *Yaka* prepaid metering (Babungi, 2021). Currently, payments are also done online through mobile telephone and bank services.

Motivation of the study

Electricity Regulatory Authority (ERA), Umeme in conjunction with the government of Uganda rolled out advocacy programs to encourage energy efficiency among households in the country (du Can et al., 2018; Pudleiner, David et al., 2017). Some households in Kampala were among the pilot group. These programs aimed at activating the demand side responses, by converting passive to active consumers who can respond to price signals. The mechanisms mainly focused on grid electricity users. The mechanisms include, offering free light emitting diode (LED) bulbs encouraging use of prepaid meters, time-of -use meters, information via different media and restrictions on importation of second hand/used electronic appliances. Most of these mechanisms have been implemented in urban centres and more so in Kampala. Worldwide the energy response programs play a fundamental role in ensuring sustainable energy efficiency. According to National Action Plan for Energy Efficiency vision 2025, programs that integrate energy efficiency, cross-sectional energy-efficiency measures and demand response can reduce barriers and yield multiple benefits (Trianni & Cagno, 2012; Wohlfarth et al., 2018; Wohlfarth et al., 2019). The National Action Plan for Energy Efficiency creates a sustainable, aggressive national commitment to energy efficiency through the collaborative efforts of utility regulators, and other partner organizations. Despite these benefits, few of such programs currently exist to offer customer oriented experience, energy savings and demand response, greater grid flexibility, and efficient administration (Schlomann et al., 2015). However, studies that examine the response towards these programs by households in developing world context are still scanty. Therefore, this study intends to fill the gap by establishing the significant drivers of energy efficiency among households using grid electricity in Kampala.

Objectives of the Study

The purpose of this study investigate the effect of awareness, government incentives, and ICT investments on energy efficiency among households that use grid electricity.

Specific objectives

- Examine the effect of awareness on energy efficiency among households that use grid electricity.
- Assess the effect of Government incentives on energy efficiency among households that use grid electricity.
- Examine the effect of ICT investments on energy efficiency among households that use grid electricity.

Theoretical Background and Review of Literature

According to Sweeney, (2016), energy efficiency refers to significant reductions in energy use. This is in relation to energy end use efficiency defined as the proportion of the amount of energy used for satisfaction of personal needs. Energy efficiency is considered as the most cost-effective approach towards addressing energy-related issues (IEA, 2014). According to Nehler & Rasmussen, (2016) as well as Nehler, (2018), firms are driven by increased global competition which calls for improved efficiency that can be achieved by efficient use of energy. Energy in form of grid electricity is the most commonly used by urban households in Uganda including Kampala. Thus efficient use of grid electricity by these household is paramount. Electricity demand is an input demand function derived from household production theory (Baker et al., 1989; Lancaster, 1966). These are inputs into the production of composite commodities which form elements of the household's utility function i.e. purchased goods and services.

Theoretical Model

Household's demand for electricity is derived from the need to run their appliances which provide energy related services. The services include cooking, refrigeration, entertainment –radio, television, and gaming, water heating, mobile phone charging, house cooling, computing, and lighting. Following Lancaster, (1966), electricity demand can be expressed as an input demand function derived from household production theory. In which case, purchased goods and services are inputs into the production of composite commodities which form elements of the household's utility function. For this study, it is assumed thata household's utility function depends on two composite commodities. Where, the first aggregates all services produced using electricity and second compounds all other goods and services produced using purchased non-electricity inputs. Focusing on electricity demand, ahouseholds is viewed as "prosumers" that is to say, as both consumers and producers of electricity. Household in Uganda use electricity from the national grid (E_g) and generate some electricity using roof-top solar, fuel powered generators, rechargeable batteries and inverters (E_h). However, households are constrained from selling electricity. Therefore, a household uses electricity from both sources to run its stock of appliances (K) , which produces a desired level of energy services (Z). The production function of Z is an increasing function in energy inputs and appliance stock. The distributor (UMEME), regulator (ERA) and government have been promoting household-level electricity conservation using both price and non-price interventions. Some non-price interventions (R) include distributing free energy saving equipment's (LED bulbs) and change to pre-paid meters (known as YAKA). Participating in such interventions directly affects the household's demand for electricity and indirectly affects the desired appliance stock. Hence *R* enters the production function for *Z*. Following Filippini, (1999) and Willett and Naghshpour, (1987) the household faces a two-level optimization problem; the cost minimization alongside the utility maximization. The first objective is to minimize the cost of producing a desired level of *Z* by solving the following problem:

$$\min_{\{P_g, E_g, K\}} \left(P_g E_g + P_h E_h + P_k K\right), \text{ subject to Z = z}(E_g, E_h, K; R) \tag{1}$$

Where, P_g is the regulated electricity price, P_h is the price for household-generated electricity, and P_k is the price of appliance stock. The solution to equation (1) gives a cost minimizing function(C) in equation (2).

$$C \quad = \quad c\left(P_g, P_h, P_k, Z; R\right) \tag{2}$$

It is assumed that C satisfies the homogeneity and curvature properties required for the cost function to have a microeconomics interpretation. Thus, first order derivatives with respect to input prices in equations (3-5) are the corresponding input demand function relative to any Z.

$$E_g \ = \ C_g'(\cdot) = e_g(P_g, P_h, P_k, Z; R) \tag{3}$$
$$E_h \ = \ C_h'(\cdot) = e_h(P_g, P_h, P_k, Z; R) \tag{4}$$
$$K \ = \ C_k'(\cdot) = k(P_g, P_h, P_k, Z; R) \tag{5}$$

The optimal level of Z is obtained by solving the household's utility maximizing problem. For simplicity, it is assumed that the household's utility function depends on two composite commodities; the composite energy commodity (Z) and the non-energy composite commodity (X). The household's utility is represented with a concave function that is twice differentiable in both Z and X. Therefore, as a consumer, the second optimization problem is to maximize utility subject to the budget that exhausts the household's money income (Y) as follows;

$$Max\ U = u(Z, X, D, G), subject\ to\ Y - C\left(P_g, P_h, P_k, Z; R\right) - \ P_x \text{X} \tag{6}$$

Where, P_x is the price for X, which is normalised to a numeraire for computational simplicity (Filippini, 1999). Vectors D and G respectively represent the demographic characteristics and geographical conditions, which affect the household's preferences. The Lagrangian optimization solution to problem (6) gives the household's optimal income demand function for Z^* and X^*as

$$Z^* \ = z^*(P_g, P_h, P_k, Y; D, G, R) \tag{7}$$
$$X^* \ = x^*(P_g, P_h, P_k, Y; D, G, R) \tag{8}$$

Substituting equation (7) into equations (3), (4), and (5), gives the household's input demand function at simultaneous equilibrium. Thus, the equilibrium household's demand for grid supplied electricity, self-supply, and electricity appliances are given by;

$$E_g \ = e_g(P_g, P_h, P_k, Y; D, G, R) \tag{9}$$
$$E_h \ = e_h(P_g, P_h, P_k, Y; D, G, R) \tag{10}$$

$$K = k(P_g, P_h, P_k, Y; D, G, R) \tag{11}$$

This model indicates that at equilibrium a household may adjust both the amount of electricity used and the rate of utilizing electricity appliances depending on energy prices and income.

Empirical Literature

The literature review section addresses the missing links between awareness, government incentive, ICT investments and Energy Efficiency among Households using grid electricity in a developing world setting.

Awareness and Energy Efficiency

Contextually, awareness in regard to energy efficiency involves the use of energy labels, energy standards, energy saving measures and sensitization manuals to optimize energy efficiency among the households in both rural and urban communities (Jairaj et al., 2013). Critically, energy efficiency among households involves the households using less energy to produce the same amount or the level of service or useful output, efficient energy storage and access among households (Butler, 2018; IEA, 2014). More so, energy efficiency involves energy conservation and energy consumption in terms of heating, lighting, use of energy efficient appliances, energy storage technologies, use of innovative fluorescent lamps the respond to climate changes and other energy services in commercial buildings (Byrne, 2013; Chung et al., 2006; Díaz-González et al., 2012). As such, creating awareness enables households using the grid electricity to adapt to climatic changes, new technologies of energy efficiency, energy financing strategies, enhancing economic and social developments in the new world of economies (Holtermann & Nandalal, 2015; Hordeski, 2021; IEA, 2014; Sarkar & Singh, 2010).

Further, the current increase in the levels of global warming, depleting sources of fossil fuels and increasing energy costs among households have created detrimental effect on the developing economies. Though extant efforts are being made to try and increase energy efficiency worldwide, one of the major troubles is unnecessary and excessive energy utilisation among household (Hassan et al., 2009). Awareness among households saves adverse effects of the future climatic changes, energy efficiency and energy saving. Though adoption of modern energy technologies seems to take the lead in the current digital era, implementation of programs to raise energy awareness among the rural and urban communities remain superficial. Thus, according one may argue that most households lack adequate knowledge about the effectiveness of awareness programs in spearheading energy efficiency and consumptions pattern (Pudleiner, et al., 2017). Accordingly, the study asserts and claims that increasing energy awareness, improves energy efficiency among household in Uganda’s developing economy. Thus, the hypothesisethat:

H_1: Awareness positively affects energy efficiency among households that use grid electricity.

Government incentives and Energy Efficiency

The taken for granted assumption that the impact of government incentives yields improvement in energy efficiency is another central concern in this paper. Although the Uganda Electricity Regulatory Authority has aimed at optimizing energy efficiency by bringing down electricity energy loss to less than 15% since 2005, the rate stagnated above 20%. This indeed raises a great concern on how such the energy efficiency variation can be handled. On perspective in this matter is appreciating the role of government incentives in driving the energy efficiency among the household using grid electricity. This involves giving free led bulbs, advocacy campaigns for energy efficiency use and use of energy efficient equipment to boost energy efficiency among the households in the developing world context. Extant scholars, explain that grid electricity power losses result from social-economic factors like electricity tariffs leading to inefficient electricity generation (Jamil & Ahmad, 2010; Pudleiner et al., 2017).

Surprisingly, economic energy and state renewable electricity policies tend to ignore such incentives that would yield significant energy efficiency results and meeting the growing energy demand (Carley, 2009; Gillingham et al., 2009; Gillingham & Palmer, 2020). More so, the governments in the context of developing economies focus on tax revenue growth of an emerging economy (Amoh & Adom, 2017), instead of providing incentives such as; free led bulbs, advocacy campaigns for energy efficiency use and use of energy efficient equipment to the poor household yet such incentives improve energy efficiency among the disadvantaged households in urban and rural communities. To some extent, such inadequate incentives result into electricity power losses and deteriorating pricing costs of electricity and consumption (Jamil & Ahmad, 2010; Kwakwa, 2018). The consistent empirical gap in the link between government incentives and energy efficiency among household using grid electricity, this further created another hypothetical insight to be tested in this study. Hence, the hypothesis that:

> *H_2: Government incentives positively affect energy efficiency among households that use grid electricity.*

ICT Investments and Energy Efficiency

Globally Investment in energy efficiency was reported at USD 221 billion in 2015 up by 6% from 2014 and Energy Service Companies (ESCOs) recorded a turnover of USD 24 billion (Birol & Motherway, 2016; IEA, 2014). Increasing energy efficiency requires the adoption and implementation of energy efficiency measures however decision making concerning energy efficiency measures is not always straightforward. An increase in energy efficiency can be achieved through technical organizational institutional and structural changes. Some of the changes that can be used in attaining energy efficiency include; thermal insulation of the buildings, use of energy saving cars and refrigerator (Barrett et al., 2008; Höfele et al., 2010; Moore et al., 2013). Factors like tight environment regulations, increasing energy prices, energy end-use efficiency policy programs have been highlighted as some the key factors that have contributed to the need for reduced energy consumption (Bertoldi, 2020; Schulze et al., 2016). Economically, the long-run ICT elasticities are smaller than the income growth elasticities but because ICT growth rates are so much higher than income growth rates, the impact of ICT on energy demand is greater that the impact of income on energy demand. Increasing ICT lowers energy intensity and increase or decrease in overall energy consumption depends on which trend is stronger. It was therefore concluded that more energy would be conserved by promoting ICT through use of energy efficient technologies (Coroama & Hilty, 2009; Gelenbe, 2011; Hilty et al., 2009).

Empirical studies have emphasized the potential of ICT to significantly increase energy efficiency in the household sector. The study of the role of ICT in energy efficiency management in the European household sector found out that ICT plays a major role in initiating and enabling the EU to reach its energy and environmental targets. Estimates vary from 50% to 125% of the total 20%

greenhouse gas reduction required by 2020 (Council, 2018). ICT energy investment is a critical enabler of economic productivity and economic growth (World Development Report, 2010). Although, ICT investment scholars have widely focused on ICT application and ICT investment returns from developed world context, in developing world context, Uganda in particular, various policy makers are appreciating the relevance of ICT investments in spurring energy efficiency among the household, and maximize renewable energy access in Africa (Hafner et al., 2018).

Accordingly, policy makers in developing economies are instituting various interventions like the digitization of the electricity billing system and other ICT investment solutions to enhance energy efficiency among households (Harris & Liu, 1993; Hordeski, 2021; Mazzoni, 2019; Tjong et al., 2020). ICT solutions in terms of smart logistics, smart grid or smart metering and smart buildings are emerging climate smart future in developing economies (Ahmad, 2011; Barai et al., 2015; Islam et al., 2014; Lawrence et al., 2016; World Bank, 2009). Indeed, in context of this study, ICT energy investments broadly concerns changing from post-paid to prepaid meters, use of energy efficient equipment, smart logistics, smart grid or smart metering and smart building to optimize energy efficiency among households using grid electricity. Grid electricity supply is a significant contributor to the growth and economic development process of any economy because it complements capital, labour and technology (Kwakwa, 2018; Mastelic & Brandic, 2015). Therefore, governments across the developing world always make conscious efforts to avail sufficient electricity and incentives to citizens for residential and non-residential purposes. In Africa, particularly, Uganda, it is important to identify technical and non-technical grid electricity challenges and devise appropriate ICT Energy investment solutions, boost energy efficiency and access, renewable energy resources, overcome energy poverty and other future energy challenges (Grueneich, 2015; Hafner et al., 2018; Joubert, 2016). As such, ICT investments catalyses energy efficiency among households in developing economies. Thus, the hypothesis that:

H_3: ICT investments positively influence energy efficiency among households that use grid Electricity

Energy efficiency gap

Attaining energy efficiency is an ideal situation but how realistic is it? (Hirst & Brown, 1990; Jaffe & Stavins, 1994; Nguyen et al., 2019; Stavins, 2013) refer to the situation as energy efficiency gap (a gap between actual level of energy efficiency and what theoretically could be reached given that cost effective technologies are implemented. In addition to this gap is the fact that this gap can be extended to include energy management (Backlund et al., 2012). The key issues that arise out of this situation are the non-implementation or at least slow rate of adoption of technically available energy efficient technologies (Nunayon et al., 2021; Schulze et al., 2016). In addition to the slow rate of adoption of the technically available technologies, implementation if adopted is a challenge (Hafner et al., 2018).

Research Methodology

Research design, population, and sample

This study adopted cross sectional research design and quantitative approaches. The justifications for choice of the design and quantitative methods is based on structured realities of energy efficiency among households in Uganda. Energy efficiency was objectively explored by key drivers using descriptive and correlational statistical measures as detailed in the study. Primary data was used in this study. Primary data was obtained through a household survey conducted in Kampala using a structured questionnaire. Using Krejcie and Morgan (1970) table, a sample size of 389 households was determined from a population of 418,787 households in Kampala. Proportional systematic sampling technique was employed in determining the sample size per division and selection of the households into the sample as indicated in Table 1. All types of dwellings were indiscriminately selected into the sample.

Table 1: Sample Distribution by Division

Division	Frequency	Percent
Central	78	20.05
Kawempe	83	21.34
Makindye	75	19.28
Nakawa	71	18.25
Rubaga	82	21.08
Total	389	100.00

Source: Secondary data-Own calculations from UBOS 2014 National Census Mapping Data.

Unit of Inquiry and Analysis

The household head was the respondent and thus the unit of inquiry since it is incumbent upon him/her to provide the basic needs of a household including energy for use. However, a household has been used as the unit of analysis in this study since energy consumption is at a household level and no specific member of the household can be deprived from consuming it.

Measurement and Model Estimation of the study Variables

Measurement of variables is the process of observing and recording the observations as per study variables. In this study, the measurement and model estimation of study variables was made based on previous research instruments used by the earlier scholars of measurement models and theory testing approaches (Babin & Svensson, 2012). The concepts used in this study were picked from theories and literature relating to energy efficiency among households using grid electricity (Ahmad, 2011; Baker et al., 1989; Barai et al., 2015; Chung et al., 2006; Filippini, 1999; Filippini & Sánchez, 2014; Gillingham & Palmer, 2020; Hafner et al., 2018; IEA, 2014; Joubert, 2016). Questions or measurement items were adopted, modified for each of the dimensions of the study variables.

Dependent Variable

The dependent variable in this study is energy efficiency. Energy efficiency involves energy conservation and energy consumption that respond to climate changes (Byrne, 2013; Chung et al., 2006; Filippini & Hunt, 2011; Gillingham et al., 2009; Zheng & Heshmati, 2020). There is no single indicator in measuring energy efficiency since various stakeholders have differing interests regarding energy efficiency. (Zhang et al., 2016), defines energy efficiency as a level at which a firm is able to allocate energy input efficiently during production process. While (Irrek & Thomas, 2008) defines energy efficiency as the ratio between the benefit gained and the energy used. In terms of demand, energy efficiency is the significant reductions in energy use considering the proportion of the amount of energy used for satisfaction of personal needs (Sweeney, 2016). However, in this study energy efficiency being a latent variable has been measured by benchmarking to obtain the best practice use of grid electricity among households living under different forms of city dwellings.

Independent variables
The independent variables include; government incentive, ICT investments, and awareness. In addition, a number of household characteristics were considered as control variables.

Government Incentive
Among the government incentives was free LED bulbs given out to some households in Kampala.

Free LED bulbs.
Some households received free led bulbs for efficient energy use. It was captured as dummy (1, if a household received free LED bulbs, 0 if not)

ICT Investments
Umeme rolled out digital prepaid meters (*YAKA*) that were used parallel to postpaid meters. AT the beginning it was made optional for consumers of grid electricity to choose the type of meter and pay for it.

Change of meter
Prepaid meters (*YAKA*) was introduced to phase out post-paid meters in a bid to improve energy consumption and efficiency. It was also captured as a dummy (1 if the household changed from a post-paid to a prepaid meter (*YAKA*), 0 otherwise).

Awareness
This was measured in terms of Knowledge about energy efficiency and energy saving and; knowledge about efficiency labels.

*Knowledge about efficiency labels*It is expected that having knowledge about energy efficiency labels would reduce the level of energy inefficiency since energy saving appliances would be purchased. It has been used as a dummy variable (1 if the household knows the meaning of energy efficiency labels; 0 if not).

Knowledge about energy efficiency and saving
This is expected to influence the level of inefficiency in energy use. This was captured as a dummy (1 if the household has knowledge about energy efficiency and energy saving; 0 if not).

Energy saving practices
Energy saving practices by a household reduces inefficiencies in energy use. An index of energy saving practices by households was constructed by considering the number of households that agreed to apply any energy saving practice. A natural logarithm of this index was used in model estimation.

Household Geographic Characteristics
Household geographic characteristics may have a bearing on the energy consumption behaviour of the households especially those in the urban centers. Thus this study includes household characteristics in the model estimation as control variables.

Renting
Household stay in a rented house is also expected to affect the level of energy consumption and efficiency depending on the art and management of bills in this household. It was used as a dummy in estimations (1 if a household stays in a rented house, 0 if not rented).
Some of these demographic profiles of household respondents were used as proxy measures of the predictor variables to explain energy efficiency.

Use of individual meter
It is expected that, households that use shared meters consume more and are likely to be more inefficient compared to those with individual meters. A natural logarithm of this variable was used.

Type of residence
Type of residence is expected to have an influence on energy consumption. This was considered as a dummy variable (1 if household stays in a planned estate; 0 if unplanned estate).

Back up energy source
It is expected that households with alternative sources of energy consume less grid electricity and may be less inefficient. This was used as a dummy variable (1 if household has a backup source of electricity; 0 if not).

A constant term was also estimated to capture the average prices since all households face similar grid electricity prices.

Limitations
Household monthly energy consumption was collected for the last three months (Quarter) and the responses might have suffered from memory lapse especially in cases that had no copies of the monthly bills and for households using the prepaid meters with no maintained records. Nevertheless, in such cases, respondents provided an estimated average consumption expenditure.

Descriptive statistics
Descriptive and summary statistics give an overall picture of the sampled households that have been used as the unit of analysis in this study. There are two types of residences in Kampala that include planned and unplanned estates. Whereas approximately 34 per cent of the selected households are in planned estates, approximately 66 per cent are in unplanned estates. Most of these households (31 per cent) lived in semi-detached houses; approximately 23 and 22 per cent lived in separate and compound houses respectively. A few (approximately 13 per cent) lived in Flats/ Apartments and only 11 percent lived where there are several low price buildings for example slums. In addition approximately 70 per cent of these households have more than two (2) rooms that imply more need for lighting and a higher chance of having a bigger number of residents. 71 per cent of the sampled households have monthly earnings of over Ushs.450,000 on

average and majority of these stay in semi-detached houses. Households with a monthly income above Ushs.1 million are the majority occupants of compound houses and flats/apartments while the majority occupants of dwellings with several buildings are households earning UShs.335,000 - 450,000.

In reference to Table 2, results show that the average number of members in a household is 4 with an average of 1 child and 3 adults. This is in line with the national average for urban areas (UBOS and ICF, 2018). The household head being the unit of inquiry had an average of 35 years old with the youngest and oldest being 16 years and 84 years respectively. In addition, households generally spend on average Ushs.465,053 per month, with an average quarterly expenditure of Ushs.58,269.6 on electricity consumption. Household average quarterly grid electricity consumption is approximately 46 Kwh (Units). Some households have adult members who stay home fully and this might have an effect on the monthly household electricity consumption.

Table 2: Summary Statistics for the Count and Continuous Study Variables

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
Number of Children	389	1.5	1.33	0	6
Number of Adults	389	2.8	1.33	1	9
Household size	389	4.2	2.16	0	12
Age	389	35.3	10.46	16	84
Average household monthly expenditure	389	465053	404306	20000	6500000
Average number of people who stay home all day	389	0.9	0.986835	0	9
Average Quarterly electricity consumption	389	45.98	16.56	7	127
Average Quarterly electricity expenditure	389	58269.6	98856.78	3667	160000

In this study, 77 per cent of the interviewed households were male headed with only 23 per cent of being female headed. However, 64 per cent have attained tertiary education and approximately 29 per cent have attained secondary/vocational education. Approximately 6 per cent of the household heads have attained primary education and only 1 percent are illiterate a true characteristic of urban dwellers. (UBOS and ICF, 2018) demographic and household survey reports indicate that there are very low illiterate rates in urban areas as compared to the rural areas.

Table 3: Energy Efficiency driven by Awareness

Knowledge of energy efficiency	**Frequency**	**Percent**
Yes	348	89.46
No	41	10.54
Total	389	100
Source of Information	**Frequency**	**Percent**
Television	146	42.2
Radio	32	9.25

Friends	130	37.57
Posters	6	1.73
Workshop	14	4.05

Results in Table 3 show that, approximately 89.5 per cent of the sampled households are aware of energy efficiency and its implications. Majority (42 and 38 per cent) of the households got information about energy efficiency through television and friends respectively. However, approximately 88 per cent of these households acknowledge having introduced some energy saving measures in the previous 12 months. Some of these energy saving measures include; Use of energy saving bulbs, turning off the lights, turning off other electricity consuming appliances before going to bed, buying only energy saving appliances, using alternative cheaper sources of cooking and using solar and battery storage to save electricity. However, most households use more than one energy saving measure as indicated by results in Table 4.

Table 4: Distribution of Energy Efficiency Measures by Households in Kampala

Efficiency measures	Frequency	Percentage/342
Use energy saving bulbs	309	90.35
Turn off lights	298	87.13
Turn off other electricity consuming appliances before going to bed	195	57.02
Only buy energy saving appliances	52	15.20
Use alternative cheaper sources for cooking	80	23.39
Use solar and battery storage to save electricity	9	2.63

Results in Table 4 show that, for those households that have introduced energy saving measures, majority of them use energy saving bulbs (approximately 90 per cent), followed by turning off lights (87 per cent), and then turning off electricity consuming appliances before going to bed (57 per cent). Approximately 23 per cent of the households use solar and battery storage to save electricity and only 15 per cent buy energy saving appliances. Very few households (approximately 3 per cent) use solar and battery storage to save electricity.

Despite the high awareness levels (88 per cent), only approximately 57 per cent have seen energy efficiency labels on household appliances and approximately 70 per cent are likely to buy appliances with energy efficiency labels. In addition, through awareness campaigns by Umeme Uganda Ltd in conjunction with the Ministry of Energy and Mineral Development, energy efficient (LED) bulbs were distributed to households in Kampala, and approximately 41 per cent of the households in this study acknowledge receipt of the LED bulbs. For these households, approximately 45 per cent acknowledge the positive effect of led bulbs in that, they led to a reduction in the monthly electricity bill, while approximately 12 per cent claim that the monthly bill increased and approximately 43 percent claim that LED bulbs had no significant effect on the monthly electricity bill. When asked about continued use of LED bulbs, only approximately 70 per cent continued and are likely to continue using the LED bulbs. Most households (19 per cent) claim that the bulbs were not long lasting and others say that they are not available in shops and if available, they are relatively expensive. However, 92 per cent of the households appreciate that it is important to save energy (electricity) to reduce the cost of electricity.

Skewness Test
Prior to model estimation, the Schmidt and Lin, (1984) skewness test was carried out. The test indicates that Pr (No Skewness) = 0.0000, implying that the error term in not normally distributed if an ordinary least squares regression is estimated. Hence, rejecting the ordinary least squares regression and opting for a stochastic frontier model. To this effect, a truncated-normal model was estimated to simultaneously ascertain the drivers of energy efficiency among households that use grid electricity in Kampala.

Econometric Estimation
This study focuses on measuring efficiency in relation to household's demand for grid supplied electricity in equation (9). Specifically measuring the efficiency effects of behavioural change intervention *B* which is Awareness and non-price interventions *R* which include ICT Investments and Government Incentives. Other factors in this case are used as control variables. Imposing a log-log transformation, the stochastic demand frontier is specified as;

$$lnE_{gi} = \ln e_g\left(P_{gi}, P_{hi}, P_{ki}, Y_i; G_i, R_i\right) + v_i + u_i(G_i, R_i, B_i) \quad (12)$$

Where $u_i(G_i, R_i, B_i)$ represent the household's level of energy inefficiency which depends on some set of exogenous variables.

Results
Results in Table 5 indicate the drivers of energy (in)efficiency; where a positive sign indicates that a variable increases (reduces) inefficiency (efficiency) and a negative sign indicates that a variable reduces (increases) inefficiency (efficiency). Results show that those households that had knowledge of energy efficiency, energy efficiency labels and energy saving practices were less inefficient. This further justifies that awareness drives energy efficiency among households. But households that have a backup source of electricity are more inefficient.

Results in Table 5 further show that, government incentives positively affect energy efficiency among households that use grid electricity. Results show that households that received free led bulbs were less inefficient compared to those who did not receive. Results show that those households that changed from post-paid to digital prepaid meters and use individual meters and those living in planned residences are less inefficient. But households that stay in rentals and those that have a backup source of electricity are more inefficient. Results in Table 5 further show that household geographic characteristics may influence energy efficiency. Households staying in rented houses are likely to be more inefficient compared to those who were not renting. While households that were not using shared meters were likely to be less inefficient compared to those using shared meters. Results also indicate that household staying in planned residential areas or estates were likely to be less inefficient compared to those staying in unplanned residential areas. In addition, households that had a backup source of electricity were likely to be more inefficient compared to those who did not have a backup source. Results in Table 5 further show that 34 per cent of the energy consumed by households is wasted (U=0.34); while only 66 percent of the consumed energy is efficiently used (TE=0.66). These results imply that there is room for improvement in efficiency levels that can save some funds for households and government to invest elsewhere.

Table 5: Stochastic Frontier Estimation of Energy Inefficiency

Stochastic Frontier normal/tnormal model Log likelihood= -345.9243							Number of observations= 389 Wald chi2 (9) = 293.38 Prob> chi2 = 0.0000
Ln (average quarterly household grid electricity consumption)		Coefficient	Std. Error	Z	P>Z	[90% Conf. Interval]	
Inefficiency component							
	received free LED bulbs	-0.506	0.799	-0.63	0.527	-1.821	0.809
	changed from postpaid to prepaid meter	-0.698	0.854	-0.82	0.414	-2.103	0.707
	knowledge of the meaning of energy efficiency labels	-4.065	2.444	-1.66	0.096	-8.085	-0.046
	knowledge of energy efficiency and energy saving	-1.136	1.221	-0.94	0.348	-3.128	0.856
	ln (index of energy efficiency practices)	-3.073	1.864	-1.65	0.099	-6.139	-0.006
	staying in a rented house	0.925	0.674 0	1.37	0.170	-0.183	2.033
	household has an individual meter	-2.999	1.653 0	-1.82	0.070	-5.719	-0.281
	staying in planned residence	-0.611	1.041 0	-0.59	0.557	-2.323	1.101
	have a backup source of electricity	3.114	1.341 0	2.32	0.020	0.908	5.32
Usigma	constant	1.13	0.512 0	2.21	0.027	0.289	1.972
Vsigma	constant	-2.159	0.151 0	-14.34	0.000	-2.407	-1.911
	sigma_u	1.76	0.45	3.91	0.000	1.155	2.680
	sigma_v	0.34	0.026 0	13.28	0.000	0.300	0.385
	labda	5.179	0.447	11.58	0.000	4.443	5.915

Whereas results in Table 5 indicate drivers of energy efficiency among households using the stochastic frontier, these results do not show the marginal effects and would not be interpreted as elasticities. Thus results in Table 6 indicate the marginal effects of the drivers of energy efficiency among households using grid electricity in Kampala. Table 6: indicates the marginal effects of these determinants on energy inefficiency among grid electricity users.

Table 6: Marginal Effects of the Inefficiency Components among grid electricity users

Marginal Effects of Inefficiency Variables	Mean	Standard Deviation	Minimum	Maximum
received free LED bulbs	-0.052	0.041	-0.275	-0.013
Changed from post-paid to prepaid meter	-0.072	0.057	-0.38	-0.017
Knowledge of the meaning of energy efficiency labels	-0.42	0.33	-2.212	-0.101
Knowledge of energy efficiency and saving	-0.117	0.09	-0.618	-0.028
ln(index of energy efficiency practices)	-0.317	0.249	-1.672	-0.076
Staying in a rented house	0.096	0.075	0.023	0.503
Household has an individual meter	-0.31	0.224	-1.632	-0.074
Staying in planned residence	-0.063	0.05	-0.333	-0.015
Have a backup source of electricity	0.849	0.37	0.383	2.421

Results in Table 6 show that households knowledgeable about energy efficiency labels and energy saving are respectively 42 per cent and 12 per cent less likely to be inefficient relative to otherwise. Likewise, households that apply any form of energy saving practices are 31.7 per cent less likely to be inefficient as compared to those who do not practice any energy saving. Thus, households that have invested in energy saving have improved efficiency levels. This implies that awareness stimulates energy efficiency behaviours, hence supporting hypothesis one. Results further indicate that households that received free LED bulbs are 5.2 per cent less likely to be inefficient as compared to those who did not receive. Thus government incentives improve energy efficiency, supporting hypothesis two. This is because households were able to ascertain the positive effect of LED bulbs on consumption. While ICT investments positively influence energy efficiency among households that use grid electricity. Accordingly, results from Table 6 show that households that changed from post-paid to prepaid meters are 7.2 per cent less likely to be inefficient. This indicates that ICT investments positively influence energy efficiency, hence hypothesis three is supported. Similarly, households that use individual meters are 31 per cent less likely to be inefficient as compared to those who use shared meters. However, households that have alternative sources of electricity are 84.9 percent more likely to be inefficient relative to those without.

Discussion

The study examined the drivers of energy efficiency using three hypotheses stating whether; awareness, Government incentive and ICT investments positively affect energy efficiency among households that use grid electricity. Results indicate that awareness, Government incentives and ICT investments are significant drivers of energy efficiency among Ugandan households using grid electricity. Awareness is quite important in making choices to achieve energy efficiency. In the context of this study, it is argued that households that seek energy awareness in terms of identifying efficient labels, energy saving practices and saving bills are able to improve their energy efficiency levels. This is in line with other studies that assert that awareness in regard to energy efficiency involves the use of energy labels, energy standards, energy saving measures and sensitization manuals to optimize energy efficiency among users (Butler, 2018; Holtermann & Nandalal, 2015; Hordeski, 2021; IEA, 2014; Jairaj et al., 2013; Pudleiner, David et al., 2017).

Thus, awareness by households is expected to lead to behavioural change in energy use and efficiency that is also in agreement with Hassan et al. (2009) and Barbu et al. (2013). Government incentives that include free LED bulbs enable efficient use and consumption of grid electricity among various households in developing economies. This reveals that, incentives that give households an opportunity to test new (presumably better) technologies free of charge leads to sustained use of such technologies. This is in line with other studies that suggest that energy end-use efficiency policy programs are some of the key factors that have contributed to reduced energy consumption (Bungane, 2016; Jamil & Ahmad, 2010; Kwakwa, 2018; Sarkar & Singh, 2010; Schulze et al., 2016).

Another perspective in the matter is the presence of ICT investments especially where households shift from post-paid meters and embraced prepaid digital meters. Households that shifted from post-paid meters to prepaid digital meters were relatively more efficient. This confirms that the path from low energy efficiency to high energy efficiency requires the technology to facilitate demand side responses and lead to behavioural change (Ahmad, 2011; Barai et al., 2015; Barbu et al., 2013; Council W.E, 2018; Hafner et al., 2018; Hilty et al., 2009; Hordeski, 2021). All the three hypotheses were supported in affirmative. Further, results show that a substantial amount of consumed energy by households is wasted. An average efficiency estimate of 66 per cent indicate that household energy efficiency interventions or programs have a potential to improve Uganda's electrification of the current level of generation. These results therefore imply that there is room for improvement in efficiency levels that can save households and government funds for other investments. However, results further show that household geographic characteristics may influence energy efficiency. This is line with theory and thus should not be ignored in assessing energy efficiency use among households.

Conclusion and Implications

The study thus concludes that awareness, Government incentives and ICT investments are significant drivers of energy efficiency among Ugandan households using grid electricity. Further, estimates of energy efficiency indicate a substantial level of energy waste. Thus there is a potential to improve electrification of Ugandan households using energy efficiency programs. The study has revealed the importance of prepaid digital meters, publicity of energy efficiency and conservation measures including energy efficiency labels and the need to incentivize adoption of energy efficiency actions including through free energy saving bulbs. Therefore, implementing and popularizing appliance energy efficiency labels and codes may potentially increase energy efficiency levels in Uganda.

Additionally, the control variables have been revealed to play a significant role, where those using individual/unshared meters were less inefficient; inefficiency was also lower for households residing in planned estates and/or rented homes. However inefficiency levels were relatively higher for households with backup energy resources. All-inclusive awareness programmes capturing type of residence and publicity for individual meter use for tenants are pertinent.

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