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Energy efficiency deployment: A pathway to sustainable electrification in Ghana

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A B S T R A C T

Electricity is a key input for socio-economic development and its demand is expected to grow rapidly throughout the world, especially in developing countries. In Ghana, where supply challenges persist with increasing residential demand, promoting energy efficiency in households is a needful pathway. This study aims at estimating energy consumption, energy savings and peak demand reduction by introducing different standards and labelling regimes for some household appliances under different gross domestic product (GDP) scenarios for the period 2020–2050. The analysis concentrates on 5 intensive energy consuming appliances: refrigerator, freezer, air conditioner, washing machine and television; and 4 lighting technologies. A bottom-up and a top-down approach were adopted to estimate electricity consumption with the dynamic characteristics of data such as appliance ownership, population and GDP. The summary results indicate that with the implementation of the various energy efficiency scenarios, the energy consumption of the 5 appliances and 4 lighting technologies can be reduced by 24–51% in 2050 while the estimated potential cumulative energy savings range 31–104 TWh for the 30-year period. The peak demand reduction in 2050 ranges 721–2952 MW for all scenarios considered and represents 40–165% of Ghana's peak demand in 2013. Refrigerators were found to account for the highest share of the cumulative energy savings, 37–57%, while televisions contribute the highest, 28–42%, to peak demand reduction by 2050. The methods deployed in this study can easily be adapted for related studies in other countries with even little household load data, providing an important instrument for helping decision makers set adequate energy efficiency policies.

1. Introduction

Electricity is a key input for socio-economic development in every modern society. The use of electricity in modern services has increased tremendously in recent years and its demand is expected to grow rapidly throughout the world, especially in developing countries (Saidur et al., 2007). In Ghana, demand has witnessed a gradual rise with an average annual growth rate of 3.3% between 1990 and 2013 (IEA, 2017). This surge is attributed to factors such as the increasing economic growth, population, electricity accessibility, urbanization and commercial/service activities. The country saw an all-time real GDP growth of about 14% in 2011 (World Bank, 2017) and achieved a 80.50% electrification rate (The Presidency of Ghana, 2016) in 2016. Similarly, residential demand is increasing meteorically and presently accounts for 35% of the total electricity consumption (IEA, 2017). This occurrence may be justified by the change in lifestyle and increasing appliance ownership. This pattern is likely to exacerbate with increasing household income levels and the purchase of second-hand appliances, which have flooded the Ghanaian electrical market (Gyamfi et al., 2015). The Energy Foundation of Ghana presupposes that a significant proportion of total electricity generated is wasted because of the use of inefficient second-hand appliances (Agyarko, 2013).

Unfortunately, in Ghana, the power sector faces several challenges in the area of supply-demand balances alongside electricity tariff regulations (Diawuo and Kaminski, 2017), which has had dire consequences on its ability to meet the increasing demand and

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thereby creating periodic load rationing. In the short term, strict implementation of energy efficiency (EE) measures as part of Demand Side Management (DSM) programs could be one of the strategies to reduce these impacts. In fact, the Heads of State within the Economic Community of West Africa States (ECOWAS) have prioritised EE as a special purpose vehicle to meet the region's energy supply challenge. This has been formalised with the adoption of the ECOWAS Energy Efficiency Policy (EEEP) in 2013 (ECREEE, 2014).

Energy efficiency (EE) in this context means using less energy to provide the same service and it is usually considered as the most cost-effective solution for toppling supply challenges. It reduces the amount of new power plant capacity needed to meet demand and provides economic benefits for both utility companies and consumers (Dixon et al., 2010; UNIDO, 2009). Furthermore, it encourages households to replace their outmoded appliances for more efficient ones, hence promoting a shift in energy sources from fossil fuels to grid electricity in the residential sector (Ashina and Nakata, 2008). Though Ghana has started implementing EE for some appliances, a comprehensive research to understand its impact on future dynamics is scanty. Some of the few studies conducted in this area (Constantine et al., 1999; Gyamfi et al., 2017; Letschert and McNeil, 2014) gather data on appliance energy use through survey, review of EE regulation, its impact and saving potential. Constantine et al. (1999) for example concluded that with the introduction of minimum standards for refrigerators, the country could save US$50 million by 2010 and CO_2 emission of 230,000 tonnes over the same time period.

In this context, this study develops a methodology to comprehensively estimate energy consumption, energy savings and peak demand reduction of household appliances by introducing different standards and labelling regimes under different GDP scenarios for the period 2020–2050 in Ghana. A hybrid approach is used, combining a bottom-up approach to estimate electricity consumption with top-down data from population, GDP and appliance ownership. In this study, 5 intensive electricity consuming household appliances (refrigerator, freezer, air conditioner, washing machine and television) and 4 lighting technologies (incandescent lamp, fluorescent lamp, compact fluorescent lamp and light emitting diode) were modelled.

This paper contributes to the literature in many ways. First, the mathematical model used is unique, for instance, the appliance ownership is modelled to capture the evolutional dynamics of appliance penetration and saturation in different market evolution scenarios, as well as the simulation of the effect of different regimes of standards and labelling programs for household appliances, which is rarely present in most studies. Secondly, this study provides extensive data support to existing household appliance information in Ghana which is presently unavailable. Finally, most often than not energy efficiency potential assessment and its opportunities in many developing and underdeveloped countries is rarely discussed because it is generally assumed that income levels are too low to use most efficient appliances. This study has demonstrated that there exist substantial potential and benefits from residential energy efficiency programs and therefore this study can provide key learning and experience curve to guide other countries. In fact, this can be a valuable information for decision makers, in setting adequate energy efficiency policies for the future in these countries.

The remaining of the paper is organized as follows. Section 2 provides an overview of energy efficiency impact and standards and labelling programs in Ghana. Section 3 explains the methodological pathways, scenario definitions and data assumptions. Section 4 shows the results on the evolution of individual appliance electricity demand, total electricity demand, energy savings, peak demand reduction and its analysis. Section 5 concludes the paper.

2. Literature review

2.1. Status of EE standards and labelling in Ghana

A sizeable fraction of the Ghanaian electrical market is flooded with second-hand appliances. To curb this increasing phenomenon, energy efficiency regulation through the Energy Commission (EC) have so far been enacted for lighting (CFL), air conditioners, refrigerators and freezers (Energy Commission, 2017) and will be described next.

2.1.1. Lighting

In Ghana, the very first regulation was enacted in 2005 for compact fluorescent lamp (CFL) and air conditioner. The regulation was enhanced to further protect consumers against counterfeit, sub-standard and unreliable CFLs through the introduction of minimum energy efficiency performance standards (MEPS) and labelling under the legislative instrument (L.I 1815) (UNEP, 2012). To verify compliance with MEPS, test facilities were installed at the Ghana Standards Authority (GSA) to enforce at least a minimum lifetime of 6000 h for CFL and efficacy of 33 lm/W. This led the government of Ghana to replace 6 million incandescent lamps with CFL in 2007 at a cost of US$ 15.5 million. This resulted in peak savings of 124 MW and peak electricity consumption of 72.8 GWh (Gyamfi et al., 2017). Subsequently, a survey conducted in 2009 indicated that CFL penetration had increased from 20% in 2007 to 79% and the number of incandescent lamps in the market had reduced from 58% in 2007 to 3% (Energy Commission, 2009a). Besides, the Energy Commission of Ghana has commenced regulation processes to increase the penetration of light emitting diode (LED). In fact, fiscal incentives such as import duty and VAT on its importation has been waived since 2011.

2.1.2. Air conditioner

Ghana does not manufacture its own air conditioners, so they are imported from developed or developing countries owning their own manufacturers such as China. Koizumi (2007) suggests an 8% potential to reduce air conditioners consumption through the proper enforcement of standards. Air conditioners regulation (L.I 1815) was introduced in 2005 due to its contribution to peak load and simplicity in regulation enforcement because the appliance market consists of new equipment. The program faced challenges after the MEPS implementation since a labelling program had not been established to inform wholesalers, retailers and even customs officials of the standards. This resulted from lack of testing facilities and trained staff due to financial constraints. Consequently, the energy efficiency ratio (EER) remained relatively low with yearly improvement of 0.7% from EER of 2.5 W/W from 2000 to 2005. The MEPS was amended and revised in 2008 to have at least a minimum EER of 2.8 W/W (Gyamfi et al., 2017).

2.1.3. Refrigerator and freezer

MEPS regulation and labelling for refrigerator, refrigerator-freezer and freezer were introduced under the legislative instrument (L.I 1958) which was passed into law by the Parliament of Ghana in 2009 (Energy Commission, 2009b). Subsequently, an