Energy Policy 120 (2018) 354–364

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Energy efficiency as a means to expand energy access: A Uganda roadmap

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ARTICLE INFO

Keywords:
Energy efficiency
Sustainable energy
Sub-Saharan Africa
Clean energy
Integrated resources planning

ABSTRACT

While energy efficiency can contribute significantly towards improving access to modern energy services, energy sector investments in many developing countries have largely focused on increasing energy access by increasing supply. This is because the links between energy efficiency and energy access, is often overlooked. This oversight of energy efficiency is frequently a missed opportunity, as efficiency is often a very cost-effective energy resource. In combination with grid expansion and new clean energy generation, efficiency efforts can help to ensure that reliable power is provided to the maximum number of customers at a lower cost than would be required to increase generation alone.

In this paper we describe an analysis method for determining a country's energy efficiency priorities and devising an action plan to integrate energy efficiency as a resource for meeting a nation's energy access goals. We illustrate this method with a detailed case study of Uganda. If the most efficient technologies on the market were adopted in Uganda, 442 MW of generation-level demand could be offset and energy access for an additional 6 M rural customers could be achieved by 2030. Of this technical potential for efficiency, 91% is cost-effective, and 47% is economically achievable under conservative assumptions.

1. Introduction

The benefits of energy efficiency (EE) are numerous and contribute to reducing power plant fuel inputs, thereby saving money, reducing harmful pollution, and enhancing energy security. Even more important for developing economies, EE helps investments in new power generation meet the energy needs of a greater number of citizens by reducing inefficient electricity use. Integration of EE into projects focused on expanding the electricity grid and new clean energy generation will not only reduce electricity demand and help optimize the power supply, but also increase the number of customers that can be served reliably at minimum cost.

Various studies have demonstrated a large, untapped energy efficiency potential, globally (IEA, 2016), in different countries (Meng et al., 2016; Craig and Feng, 2017; Sanstad et al., 2014), and for different sectors (Trianni et al., 2016; Jeong et al., 2017; Li and Tao, 2017). Furthermore, some studies show that the cost of energy savings resulting from EE implementation is far below energy supply costs and retail rates (McNeil et al., 2013; Wachsmuth et al., 2015). Hoffman et al. (2017) show that the savings-weighted average total cost of saved electricity across 20 U.S. states is only $0.046 per kilowatt-hour (kWh). The puzzling discrepancy between what is cost-effective and the current level of investment in EE is often referred to as the *EE gap* (Eto et al., 1996; Backlund et al., 2012). Researchers have investigated the market barriers that hinder EE investments and prevent decsionmakers from reaching rational choices that would help close this gap (Sathaye and Murtishaw, 2004; Sorrell et al., 2004; Jollands et al., 2010; Murphy and Meier, 2011; Bukarica and Tomšić, 2017). Trianni et al. (2014) developed a scheme for classifying EE measures, to provide insight into barriers that hinder their adoption, and Wentemi and Thollander (2013) studied the barriers and drivers of industrial EE in Ghana. A large number of enabling policies and programs have been devised to remedy these market failures and to help narrow the gap.

The existing literature provides important analyses of EE's potential, along with meaningful information on programs that help remove market barriers. However, analyses rarely look at EE's potential in the context of a country's entire economy or offer a method to prioritize the programs and policies needed to tap this potential. Moreover, no economy-wide EE analysis exists for countries in sub-Saharan Africa, and no analysis exists that shows the potential of EE as a resource to increase energy access in developing economies.

Those who evaluate countries with a very low electrification rate

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https://doi.org/10.1016/j.enpol.2018.05.045
Received 29 January 2018; Received in revised form 14 May 2018; Accepted 16 May 2018

often conclude that investment should focus mainly on expanding electricity supply by building new capacity and spreading the grid. While such investments are certainly needed, investments that optimize the use of the electricity supplied also contribute to increased energy access. Energy efficient technologies help free capacity, enabling energy services to be provided to more households. Moreover, such freed megawatts (MW) often come at a much lower cost than new capacity additions. For example, in the Uganda case study described herein, a recent compact fluorescent light (CFL) distribution program freed up 32 MW with an investment of only US$0.05 million (M) per MW, while the average investment cost per MW for new capacity is US$2.6 M. In countries like Uganda, with relatively high electricity tariffs ranging from US$0.10 per kilowatt-hour (kWh) for industrial consumers to US $0.18 per kWh for household consumers, EE represents a very competitive energy resource. Energy efficiency can complement capacity-adding efforts by ensuring that the power supply is optimized in the most affordable way.

The links between EE and energy access, and the multiple economic, environmental, health, and social benefits of EE, have largely been overlooked by many stakeholders in Sub-saharan African countries, including the international donor community. Energy efficiency and energy access are sometimes viewed as competing for funding rather than elements that be addressed together to ensure more widespread energy access (CLASP and World Bank, 2015). Moreover, EE has been perceived as a short-term solution to power outages and load shedding, rather than as a source of energy for future electricity planning. A recent report from the Regulatory Indicators for Sustainable Energy (RISE) database shows that in the least electrified countries policy makers are not paying nearly as much attention to EE as they are to renewable energy (RISE, 2016).

The World Bank and other international organizations recognize EE as one of the three pillars for ending energy poverty and securing access to affordable, reliable, and sustainable energy. However, little has been done to demonstrate the value of energy efficiency in countries with very low electricity access and to help prioritize investment. Some recent analyses have shown the link between energy efficiency and energy access in off-grid settings. For example, Phadke et al. (2015) shows that super-efficient off-grid appliances enable consumers to purchase smaller (and therefore less expensive) solar photovoltaic panels, lowering energy costs to customers by as much as 50%. However, no analysis has been done to show this linkage for on-grid customers at a national level.

This paper attempts to fill this gap and to encourage more research to demonstrate the contribution of energy efficiency to energy access. We present a comprehensive approach to help countries integrate EE as a resource in national energy planning as a means of increasing energy access. The approach links the potential of energy efficient technologies and processes with a set of concrete actions that can be implemented to track progress and narrow the EE gap. First, we present our methodology approach to assessing EE's energy-savings potential and to identifying and prioritizing the programs needed to tap this potential. We then describe a case study in Uganda, where these methodologies have been applied. This paper provides a systematic approach that can be used to better integrate EE as a cost-effective prime resource of choice for energy access development.

2. Methodology

2.1. Technical, economic, and achievable economic potential

Just as transmission lines are the infrastructure for power grids, data and analytic methods are the infrastructure for market deployment of efficiency at scale. Our method uses data and analytics to calculate energy efficiency's technical, economic, and achievable economic potential for a country (Fig. 1) (Rufo and Coito, 2002; EPA, 2007; Swisher et al., 1997). It begins by gathering detailed information on the country's current energy use and then breaking down electricity consumption for each economic sector by end use, based on assumptions of equipment penetration and unit energy consumption. End-use consumption figures are then translated to peak-demand contribution estimates by coincident factors that estimate peak-demand contribution relative to total electricity consumption. Finally, utility growth projections, along with regional and national level planning data, are used to project electricity consumption and demand estimates for future years.

The technical potential for each end use is calculated by examining the impact of different efficiency measures utilizing a top down approach. For instance, the impact of incorporating solar water heaters for the residential water heating end use or efficient motors for the industry motor end use. The impact is estimated using savings percentage estimations, along with scaling factors for the measure's relative applicability to the end use.

The economic and achievable economic potentials are each calculated from the technical potential by removing measures that are not cost-effective for the end user. Cost-effectiveness for the end user is assessed over a measure's lifetime. The only difference between the economic and achievable economic potentials is the discount rate assumed for the time value of money. For the economic potential, a societal discount rate of 7% is assumed; whereas, for the achievable economic potential, a discount rate of 20% is assumed. The social discount rate attempts to reflect the social view of how the future should be valued against the present. Therefore, the cost benefits calculated with a societal discount rate provides an assessment of investment for the benefits of society. We used an estimate of 7%, which is consistent with current guidelines from the Office of Management and Budget (Broughel, 2017; Masiga et al., 2013). In contrast, we applied a financial discount rate that characterizes the private investments to estimate the achievable potential. In this case, the 2010 World Bank estimate lending rate of 20% was used (World Bank, 2017). This reflects the high interest rates available for financing EE in developing countries, as well as the low confidence in EE investments that can be a common barrier in countries that have limited experience with EE technologies and programs.

For the cost data, all measures that can be implemented as either replacements on burnout or retrofits are assumed to be implemented using a replacement-on-burnout methodology. Therefore, an incremental cost of implementing the measures is used rather than the full cost. The cost effectiveness of the measures has been calculated using the metric of Cost of Conserved Energy (CCE). This metric is calculated as the annualized incremental cost divided by the annual energy savings (Meier, 1984). The CCE is an investment metric that allows EE measures to be compared among themselves and against competing energy supplies. Energy efficiency measures with a CCE below the cost of electricity supply are considered cost effective.

For the achievable economic scenario, low, medium, and high cases of the potential are calculated to show the uncertainty of the results associated with the range of potential savings and applicability.

2.2. Energy efficiency policy roadmap

Although a single entity can produce considerable electric power, saving the same amount of power often requires the contribution of multiple entities. Thus, harnessing EE potential requires a comprehensive package of enabling programs and policies to address market barriers in a multitude of sectors and sub-sectors. These packages are based on three basic types of policy instruments: regulations,

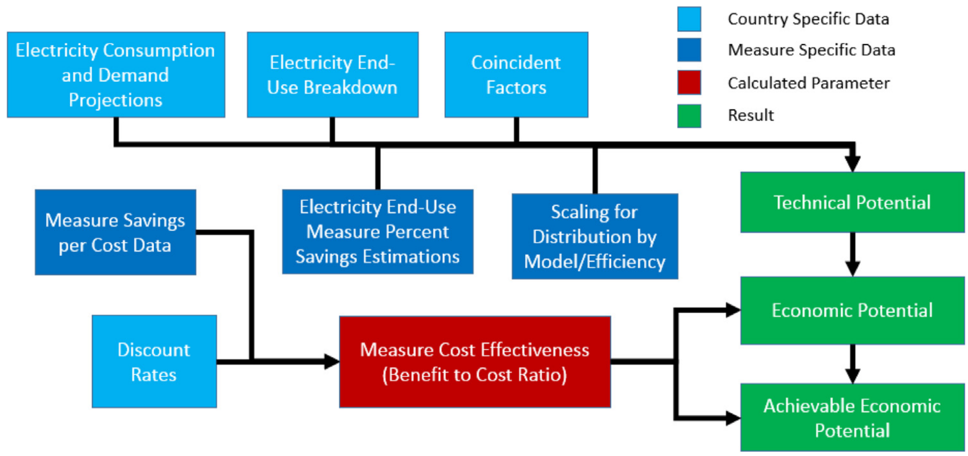

Fig. 1. Framework for calculating energy efficiency's technical, economic, and achievable economic potentials.

knowledge diffusion, and financial incentives. A combination of instruments has been shown to accelerate EE improvements (along with target setting and continuous monitoring) (Kern et al., 2017). The three instruments are commonly developed into sectoral and, in some case, sub-sectoral EE enabling policies and programs that can target one or more technologies and practices. Examples of such enabling tools include efficiency standards and labeling (S&L), building codes, voluntary agreements, target setting, information diffusion, capacity building, public awareness, bulk procurement, financial rebates, standard offer programs, and concessional interest rates.

Once enabling policies and programs are identified as appropriate for a country's EE strategy, they need to be prioritized into a roadmap of actions to be taken over time. We propose a multi-criteria decision analysis (MCDA) for this purpose. It is a reliable, transparent methodology that can be used to rank alternative initiatives in the presence of numerous objectives and constraints, and it allows decision makers to integrate various program impacts into decision making and to control the relevance of various impacts. MCDA techniques have been applied extensively to energy and environmental investment decisions, as noted by Huang et al. (2011). Moreover, MCDA allows inclusion of qualitative aspects, which can significantly influence the decision process. MCDA generally consists of (1) selecting a number of criteria relevant to stakeholder interests, (2) weighting each criterion, (3) selecting a qualitative or quantitative measurement for each criterion, (4) rating the criteria for each recommendation, and (5) ranking the recommendations based on the scores. Table 1 summarizes the criteria selected for prioritizing policy instruments in the Uganda roadmap described in Section 3.

Table 2 shows the ranking scale for each criterion. Some criteria are based on a quantitative assessment and are estimated using modeling

Table 1
Definition of analysis criteria.

Criteria	Description	Estimation
Energy savings	The level of energy savings is estimated based on the sectoral level energy savings estimates.	Quantitative
First Cost to Government	First cost to government is estimated based on the cost of program implementation.	Quantitative
Speed of Implementation	Speed of implementation reflects the complexity of implementing a program and the level of stakeholder engagement needed.	Qualitative
Prerequisite to Other Measures	Prerequisite to other criteria reflects the level at which a program or policy enables other programs and measures to be implemented successfully.	Qualitative
Multiple Benefits	Investment in energy efficiency can deliver many different environmental, social, and economic benefits. Multiple benefits are evaluated such as the life-cycle impact of the program on greenhouse gas emissions, pollution, waste reduction, and the potential to increase jobs and competition and foster the development of the local manufacturing industry.	Qualitative

Table 2
Ranking Criteria for MCDA.

		Score		
Criteria	Weight (%)	1	2	3
Technical Electricity Consumption Savings by 2030	100	< 100 GWh[a]	100–500 GWh	> 500 GWh
First Cost to Government (four-year budget)	100	Above US$500k	US$250–500k	US$0–250k
Speed of Implementation	100	Extended > 5 year	Moderate 2–5 years	Rapid < 2 years
Prerequisite to Other Measures	200	Highly independent	Somewhat independent	Highly enabling
Multiple Benefits	100	Low: No major co-benefits	Medium: Contributes to local competitiveness	High: Contributes significantly to creating jobs as well as enhancing the sustainability of economic development

[a] GWh: gigawatt-hours.

Table 3
Barriers to Energy Efficiency in Uganda.

	Barriers	Description	Remedy/Opportunity
Regulatory	**Lack of policies and regulations to enforce EE**	Processes and procedures to enforce and prioritize EE requirements have not been put in place.	Enactment of the Energy Efficiency and Conservation Bill is needed to provide the legal basis for elaboration and enforcement of the national policy.
	Lack of prioritization of investment in EE	Although EE is recognized as a resource to meet energy demand (UG, 2015), it is not yet prioritized in investment decisions.	• Integrate EE in resource planning • Mandate that large energy users invest in EE • Regulate products sold in the market
Informational	**Limited information and knowledge about the benefits of EE**	Those making purchasing decisions do not have information about the energy performance of technologies, and there is an inadequate awareness of the benefits of EE investment.	Develop programs to inform private-sector investment decisions: • Appliance labeling • Awareness campaigns • Incentivized audits • Recognition awards • Best practices • Training
	Inadequate technical expertise	Expertise on EE opportunities and benefits assessment is currently inadequate.	• Build capacity and create certification schemes to develop an established professional community • Collaborate with UNBS* and ECREEE* to establish a testing facility to enforce market verification
Economic and Financial	**Lack of access to affordable capital and financing**	Uganda is among the countries with the highest cost of financing in the world. Affordability of financial services in Uganda ranks 121 (out of 144 countries). In comparison, Kenya and Rwanda rank 64 and 56, respectively (World Bank, 2015).Commercial banks in Uganda do not have experience with financing EE projects and do not fully understand the profitability of EE loans.	• Provide affordable financing for EE investment • Support financial intermediaries to invest in energy-savings opportunities • Support financing access to energy service companies • Establish funding for EE investments by leveraging funding from public (government and development partner) and private stakeholders • Develop guarantee fund to cover deflationary risk

tools. Others are based on a qualitative assessment using expert judgment. The weights of each of the criteria should be set to reflect their desired level of importance for influencing the final decision. For example, the decision criterion “Prerequisite to other measures” is given a higher weight in Table 2 to emphasize its importance in enabling additional energy savings.

3. Case study: Uganda energy-efficiency roadmap

Power Africa and the United Nations SEforALL Initiative collaborated with more than 24 stakeholders in Uganda to develop an EE roadmap that prioritizes policies for achieving EE. The roadmap's objective was to complement Uganda's SEforALL agenda and investment prospectus (SEforALL, 2015, 2017) by providing detail on electricity EE opportunities and support for designing and implementing electricity EE policies and programs.

In this section, we first provide a short background on Uganda's energy situation. Next, we describe the main barriers to EE investment, followed by an assessment of the technical, economic, and achievable economic EE potential. Finally, we develop an EE roadmap for Uganda.

3.1. Background

Uganda's current economic growth and rapid urbanization are driving a steady increase in energy demand. Electricity demand is increasing at a rate of 8.2% annually, which translates to 125,000 new customers every year. Power generation capacity tripled over 13 years to an estimated 900 MW in 2015 (Uganda Government, 2015). However, an estimated 74% of Uganda's population still does not have a grid connection, solar home system, or diesel generator (SEforAll, 2015).

Investment in Uganda's energy sector has focused mainly on increasing energy access by increasing supply. Recent success in attracting private investment to develop new power capacity is evident in the Bujagali hydropower plant (250 MW), which is currently meeting 49% of the country's electricity needs. Additional planned capacity includes construction on the River Nile of the Karuma and Isimba dams (total of 783 MW, December 2018) and Ayago Dam (840 MW, 2022) to produce hydroelectricity. Moreover, Uganda launched an innovative feed-in tariff program, the Global Energy Transfer Feed-in Tariff (GET FiT), to fast-track the development of 170 MW of smaller, renewable energy investments. However, additional capacity comes at a hefty cost. On average, the investment cost per megawatt is US$2.6 M (de la Rue du Can et al., 2017) and household electricity tariffs are currently US

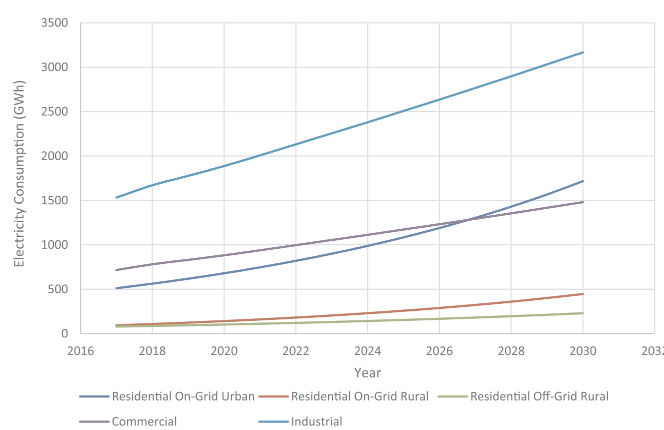

Fig. 2. Electricity consumption projections for energy-efficiency potential calculations, 2016–2030.

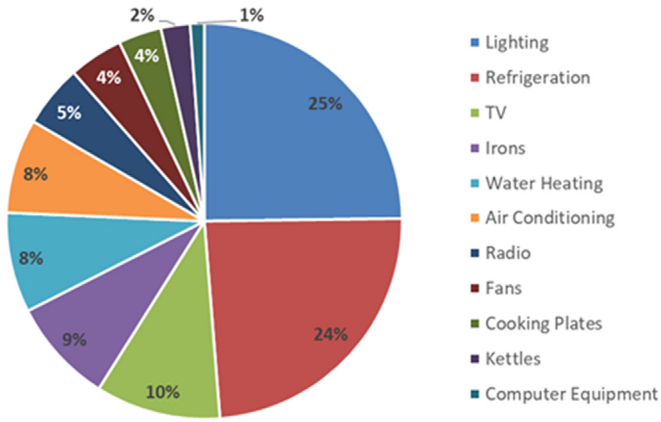

Fig. 3. Electricity consumption end-use breakdown 2030 – on-grid urban residential.

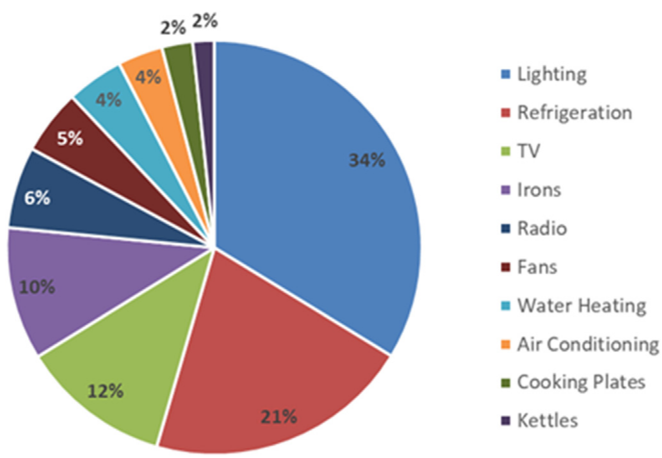

Fig. 4. Electricity consumption end-use breakdown 2030 – on-grid rural residential.

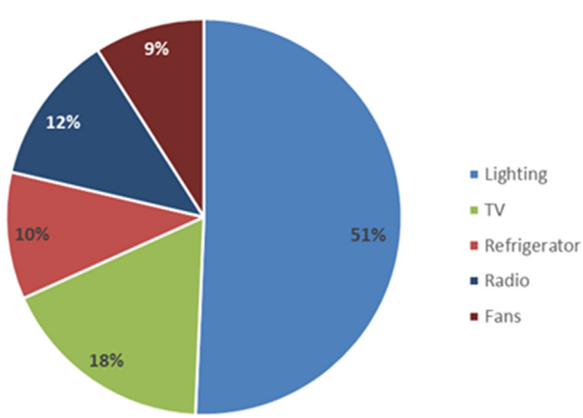

Fig. 5. Electricity consumption end-use breakdown 2030 – off-grid residential.

$0.18 per kWh.

The links between EE and energy access, and the multiple benefits of EE for the level and quality of energy available, have been largely overlooked by many stakeholders in Uganda, including the international donor community. Energy efficiency and energy access are sometimes viewed as competing for funding rather than elements that can work together to improve access to energy services. Moreover, EE has been perceived as a short-term solution to power outages and load

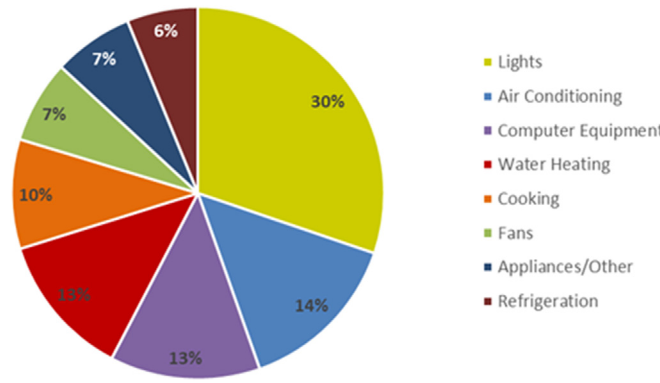

Fig. 6. Electricity consumption end-use breakdown 2030 – commercial.

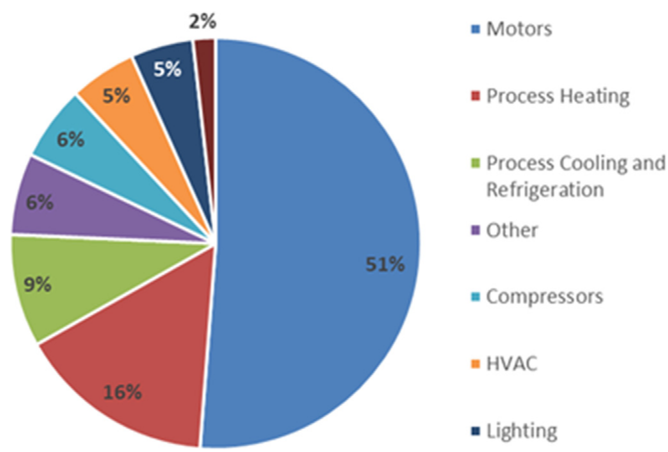

Fig. 7. Electricity consumption end-use breakdown 2030 – industrial.

shedding without taking into account that it is also a source of energy for future electricity planning.

In the mid-2000s, Uganda's energy sector faced acute power shortages that led to the implementation of demand-side management programs. Between 2007 and 2012, Uganda implemented two successful programs with assistance from the World Bank and the German Gesellschaft für Internationale Zusammenarbeit (GIZ) agency: (1) a compact fluorescent light (CFL) distribution program that reduced power demand by 32 MW with an investment of only US$0.05 M per MW, and (2) a Power Factor Correction Program, which reduced demand by 8.6 MW and helped stimulate the creation of EE consulting companies in Uganda.

Today, GIZ is the only donor agency that provides a comprehensive, sustained energy efficiency program in Uganda. That support led to the recent draft of the Energy Efficiency and Conservation Bill, which will create the regulatory frameworks, data systems, and stakeholder relationships needed to conduct a successful energy efficiency program.

3.2. Barriers to energy efficiency

Despite the apparent business case for EE, a significant share of the potential to improve EE in Uganda remains untapped, and the level of investment in EE remains low. We determined barriers to EE investment based on consultation with 24 local stakeholder groups[1] in the country

[1] Representing industry's associations, energy companies, government agencies, consumer's associations, universities, program development groups, and donor agencies. The full list is available in de la Rue du Can et al. (2017).

and analysis of the country's current experience with energy efficiency. Table 3 summarizes the results of our barriers analysis and includes a first assessment of remedies and opportunities associated with these barriers. These remedies and opportunities are further developed in Section 3.3.4, which describes Uganda's EE action roadmap.

3.3. Electricity savings potential

The energy savings potential is calculated following the methodology described in Section 2. First, electricity consumption is broken out by sector and by end use. Then electricity consumption is projected according to national plans. Finally, the technical, economic, and achievable potentials are calculated by examining the impact of different efficiency measures.

3.3.1. Electricity consumption and demand forecasts

Energy-consumption projections for the commercial and industrial sectors are based on the Uganda Power Sector Investment Plan (PSIP) (Parsons Brincherhoff, 2011). Growth of the on-grid urban and rural residential sectors is calculated based on the number of planned new connections outlined in Uganda's SEforALL Action Agenda (SEforALL, 2015). Approximately 2.5 M additional on-grid connections are planned from 2017 to 2030, 53% of which will be urban. The projections for the off-grid residential sector are calculated from international reports on the growth of the solar industry in sub-Saharan Africa. A growth rate of 6% is assumed for off-grid connections, based on reviewing historical growth in electrification (Global LEAP, 2016; GOGLA, 2016). Total electricity consumption was 2932 GWh in 2017 and is projected to be 7038 GWh in 2030. Fig. 2 shows the resulting projections for each of the five sectors. The industrial sector is anticipated to continue to have the most influence on energy consumption. However, because of increased electrification and greater consumption per household, domestic-sector consumption is projected to grow faster than commercial-sector consumption. Therefore, by 2030, total residential consumption is expected to be 60% greater than total projected commercial consumption.

3.3.2. Energy consumption per end use

Two distinct methods are used to calculate the sector end-use breakdowns—one for the commercial and industrial sectors, and one for the residential sectors.

For the commercial and industrial sectors, the building/facility stock for each sector is broken down using customer data from the utility, UMEME (2016). The total sector end-use breakdown is calculated by aggregating the end-use breakdowns for each building/facility type within the sector. The building/facility level end-use breakdowns for the commercial sector are predominantly estimated from Ugandan energy audit reports provided by MEMD; where data are missing, regional and international data are used to fill the gaps. And for the industrial sector, the building/facility level end-use breakdowns are estimated from MECS (Manufacturing Energy Consumption Survey) data modified for Uganda (US DOE, 2010) according to industry sub-sectors.

In contrast to the commercial and industrial sector approach, end-use breakdowns for the residential sectors are calculated using a bottom-up model of average household energy consumption. For the residential sectors, the main data sources are a household electricity consumption survey (GTZ, 2008), a market technology survey (GIZ, 2014), the 2014–15 Uganda Malaria Indicator Survey (UBOS and ICF International, 2015), and the draft Energy Efficiency Strategy for Uganda (GIZ, 2009). The resulting breakdown is shown in Figs. 3–7.

3.3.3. Coincidental factors

To estimate demand savings for each sector, peak demand was broken down by end use, applying coincident factors to translate the electricity consumption breakdowns to the units of electricity demand. The coincident factor for each end use specifies what percentage of the end-use consumption can be assigned to the peak-demand period. Fig. 8 shows the average daily load shape for the grid, with a clear peak at the end of the day from residential consumption. For this analysis, the peak-demand period is defined as 6 P.M.–12 A.M., based on the peak tariff definition from UMEME. Therefore, for end uses such as residential lighting, the coincidence factor is high (80%); whereas, for residential refrigeration, the coincidence factor is low (25%) because this end use operates throughout the day. Appendix (Table 8) shows the coincidence factors for the end uses within each sector.

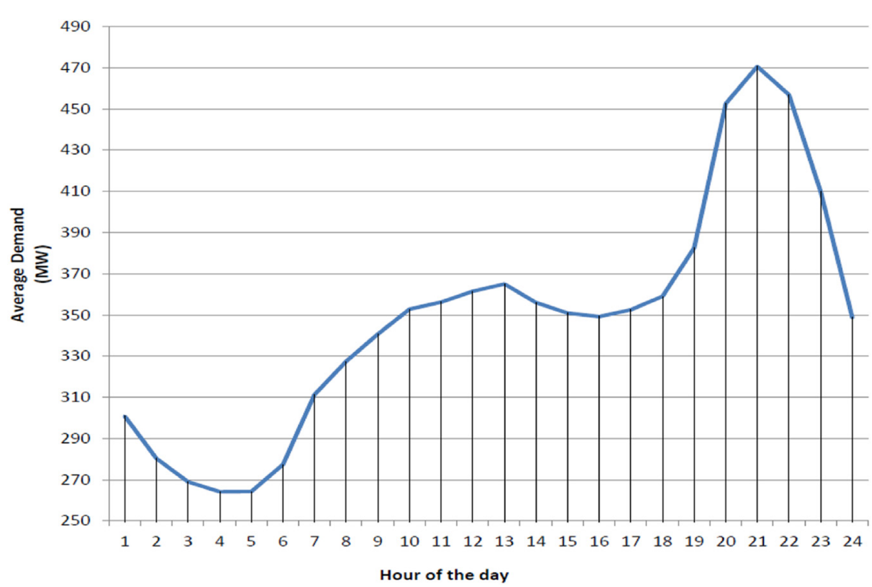

Fig. 8. Average daily demand, June 2012 – July 2013 (ERA, 2016).

Table 4
Data collection.

Customer and building characterization by sector	This includes the number of customers by sector, sub-sector, and rate class; new construction growth rates (historical and projected); and building system characteristics and efficiencies.
Market data on energy-efficient technologies	An example of the type of market data gathered is the availability of CFLs in Kampala.
Appliance and technology market saturation surveys	An example of market saturation data is the percentage of homes that currently have high-efficiency appliances.
Energy end-use disaggregation for each sector and sub-sector	Estimations of energy demand disaggregated into a large number of end-use categories.
Planning assumptions	Utility retail rates for all rate classes, discount rate for economic analysis, line losses, and electricity growth projections.
Research or feasibility studies on EE technologies	Research reports that describe penetration of energy efficiency technologies as well as energy audit reports from different types of companies.
Cost of energy-efficient and standard technologies	This includes equipment, materials, and appliance costs collected from the market place.

3.3.4. *Energy-efficiency measures*

The technologies we considered in assessing electricity savings potential were selected based on information and data gathered from research, local audit documents, surveys, and collaboration with stakeholders from the residential, commercial, and industrial sectors. The first step in our assessment entailed gathering the information shown in Table 4.

We examined 59 EE measures to calculate the overall EE potential in Uganda. The key assumptions for each measure are presented in Appendix 1 to Appendix 3, with separate tables for the residential, commercial, and industrial sectors. These measures are assumed to represent the types of measures and associated savings possible within each sector; however, the list of measures is not intended to be comprehensive. Data for the energy savings, lifetime, and cost estimates of each energy efficiency measure were gathered from different sources. For the residential sector, assumptions mainly came from *Efficiency Levels of Electrical Appliances on the Ugandan Market,* a recent survey conducted by GIZ (2014). Additional data were gathered from country-specific analyses such as Silva and Mugisha (2005) and Kaggwa (2016), and data collected directly from the retail market on costs of equipment. For the commercial and industrial sectors, data mostly came from energy audits conducted in the country (Envidatec, 2015a, 2015b, 2015c; EECD, 2015; GTZ, 2007; Ministry of Energy and Mineral Development (MEMD), 2015a, 2015b). Country-specific data were prioritized, but in some cases, due to the lack of available data, estimates from other African countries and emerging economies, such as ICF (2016a, 2016b), were also used, as well as data from more advanced economies (ENERGY STAR, 2016a, 2016b). More details are in a comprehensive report prepared for Power Africa and SEforAll (de la Rue du Can et al., 2017). Given the limited national data availability and the disparate nature of the data sources, results should be taken as a first-level estimation of the EE potential at the national level. An uncertainty analysis was performed to provide upper and lower bounds for the energy-savings potential estimate as shown in Appendix 1 to Appendix 3. A more detailed analysis specific to the focus of a particular EE program should be conducted prior to designing the program.

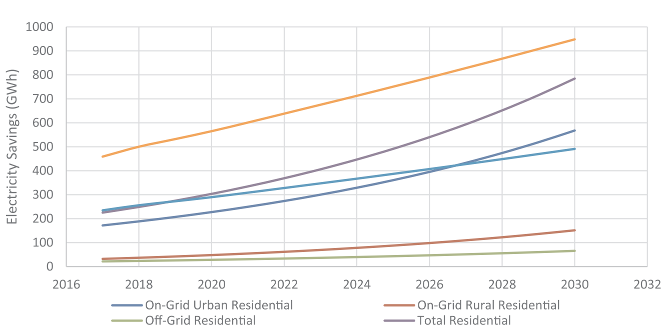

Fig. 9. Technical electric saving potential per sector in Uganda, 2017–2030, including residential sub-sectors.

The cost-per-kilowatt-hour data presented in Appendix 1 to Appendix 3 were scaled for the low and high scenarios, based on the changes in savings percentages for the measures. Note that the cost data in Appendix 1 to Appendix 3 are presented in terms of the incremental cost per average annual savings. These data are used as an input along with retail rates and measure lifetime values to calculate the CCE for each measure, which is shown in Fig. 10 in Section 3.3.4.

3.3.5. *Results*

The roadmap assessment indicates a significant opportunity for EE to mitigate growing electricity consumption and demand in Uganda. Considering available technology and best practice, our analysis of the estimated technical potential for savings in the year 2030 indicates that 2224 GWh of meter-level consumption could be saved across all sectors (see Fig. 9), which is equivalent to 31% of the forecasted load. Energy-efficiency consumption savings translate into peak demand savings, and thus the ability to provide electricity to more consumers without additional power plants. Energy-efficiency improvements can save an estimated 341 MW of on-grid meter-level peak demand and an additional 15 MW of off-grid demand. Assuming Uganda's current transmission and distribution loss rate of 22.8%, EE can offset 442 MW of generation-level demand, which is nearly 2.5 times the demand that will be supplied by the Isimba Dam (183 MW). Uganda's demand projections show no sign of declining in the short term, so EE offers an opportunity to extract the maximum value from each power generation facility. The technical potential also shows significant non-energy benefits, with EE measures reducing carbon dioxide (CO_2) emissions by an estimated 10.6 M tonnes.

Another non-energy benefit comes in the form of increased access to electricity. With EE helping to manage load growth, electricity capacity that is added to the grid can be used to increase access for new customers. Assuming a total electricity consumption of 1060 kWh per year per urban customer and 369 kWh per year per on-grid rural customer (Parsons Brincherhoff, 2011), the on-grid savings from efficiency in 2030 could allow grid access to an estimated additional 2.1 M urban customers or 6 M rural customers, without adding generation capacity. In other words, including efficiency in the national planning process could mean adding the supply for 6 M rural customers without adding new generation, at a cost that is likely to be lower than the cost of building additional generation capacity.

Of the 2224 GWh of technical potential, approximately 91% is included in the economic potential (2022 GWh), and 47% is included in the achievable economic potential (1052 GWh, medium case). This illustrates a significant opportunity for EE to cost-effectively benefit the economy.

Fig. 10 shows a breakdown of the top EE opportunities, prioritized by end-user CCE. Highly cost-effective opportunities are found in a multitude of sectors and end uses, including on-grid residential lighting, commercial water heating, and industrial motors. The largest

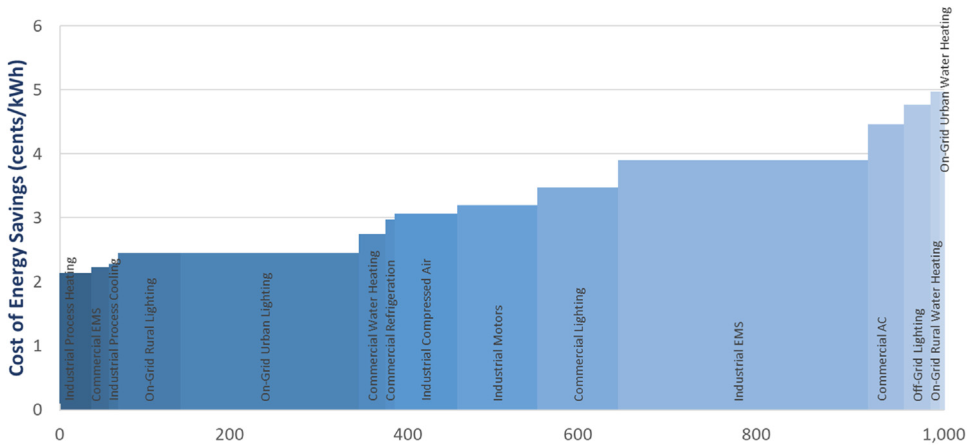

Fig. 10. Top opportunities for achievable economic potential, medium case, prioritized by end-user cost of conserved energy.

opportunity is implementing energy audits coupled with energy management systems (EMSs) in the industrial sector. The magnitude of this opportunity strongly supports the priority given to EMSs in the EE action plan described below.

An uncertainty analysis of the achievable economic potential indicates that even under conservative assumptions, EE can still save 663 GWh of electricity by 2030 in the low case scenario. This equates to approximately 16% of the anticipated load growth over the next 13 years. Thus, even when unfavorable estimates are used, EE makes a significant contribution to meeting Uganda's power needs for years to come.

3.4. Uganda energy efficiency roadmap

An energy-efficiency roadmap identifies programs and policies that can remove barriers and enable investment in EE. Many EE programs and policies have been implemented worldwide with various levels of success. The goal of Uganda's roadmap is to build on this experience to recommend programs that are most relevant to local needs. Our recommendations build on several types of strategies that are considered basic building blocks of EE: energy performance standards, target setting, information diffusion, capacity building, public awareness, and financing support. Fig. 11 lists the policies and programs considered and the detailed score for each recommendation from our MCDA approach. As described in the Methodology Section 2.2, scores are composed of quantitative metrics and qualitative judgments. We developed a simple spreadsheet tool containing all the recommendations and criteria rankings, which we shared with Uganda's Ministry of Energy and Mineral Development. The ministry's inputs helped to determine scores for the criteria "speed of implementation," "prerequisite to other measures," and "multiple benefits." The Ministry also provided data on implementation costs. The spreadsheet tool will support the Ministry's further decision making, based on additional expert assessment.

The ranked list of recommendations was divided into four lists to order programs implementation according to their level of priority. Each list contains four or five program recommendations. Fig. 12 shows the resulting roadmap. Recommendations categorized as "cross cutting" apply to more than one sector.

3.4.1. First order of priority programs

The EE program recommendations with the highest scores include:

- Enacting the Energy Efficiency and Conservation Bill (EECB)
- Prioritizing EE in Integrated Resource Planning (IRP)
- Developing regulations for energy audits for large energy users
- Developing regulations for EMS for large energy users
- Enforcing the existing S&L program

These programs target sectors that have the greatest potential to

List of Energy Efficiency Recommendations	Energy Savings	First Cost to Government	Speed of Implementation	Prerequisite to Other Measures	Multi-Benefits	Average Score	RANK
Weigth	0.10	0.10	0.10	0.20	0.10		
Support and Expand Current Policies and Programs							
Enact EE & Conservation Bill	2	3	3.0	3.0	2.9	**2.8**	1
Create an EE and Conservation Fund	3	1	1.0	2.9	1.9	**1.9**	13
Enforce EE Standard & Labeling	3	2	2.0	3.0	2.4	**2.5**	5
Develop Regulations for Energy Audits	3	3	2.5	2.7	2.3	**2.7**	3
Develop Regulations for Energy Management System	3	3	2.7	2.2	2.3	**2.6**	4
Develop Training and Accreditation Scheme	1	2	2.2	2.4	2.3	**2.0**	10
Expand Standards and Labeling Program	3	2	2.0	2.7	2.4	**2.4**	6
Encourage Market for Energy Access	2	3	2.2	2.3	2.2	**2.4**	8
Recognize Champions of EE	1	3	2.0	1.8	1.6	**1.9**	12
Set Industry Targets	3	3	2.0	2.0	2.0	**2.4**	7
Encourage Small and Medium Enterprise EE	2	2	2.0	1.8	2.3	**2.0**	9
Encourage Clean Industry Development	2	1	1.8	2.1	2.3	**1.8**	14
Develop Buildings EE Code	1	3	1.8	2.0	2.0	**2.0**	11
Develop Building Disclosure and Benchmarking	1	3	1.7	1.9	1.6	**1.8**	15
Government Lead by Example	2	1	1.0	2.5	2.0	**1.7**	16
Develop Cities/Municipal Councils EE Action Plans	2	1	1.0	1.7	2.2	**1.6**	17
Prioritize EE in Integrated Resource Planning	3	3	2.5	2.5	2.5	**2.7**	2

Fig. 11. MCDA program recommendation score.

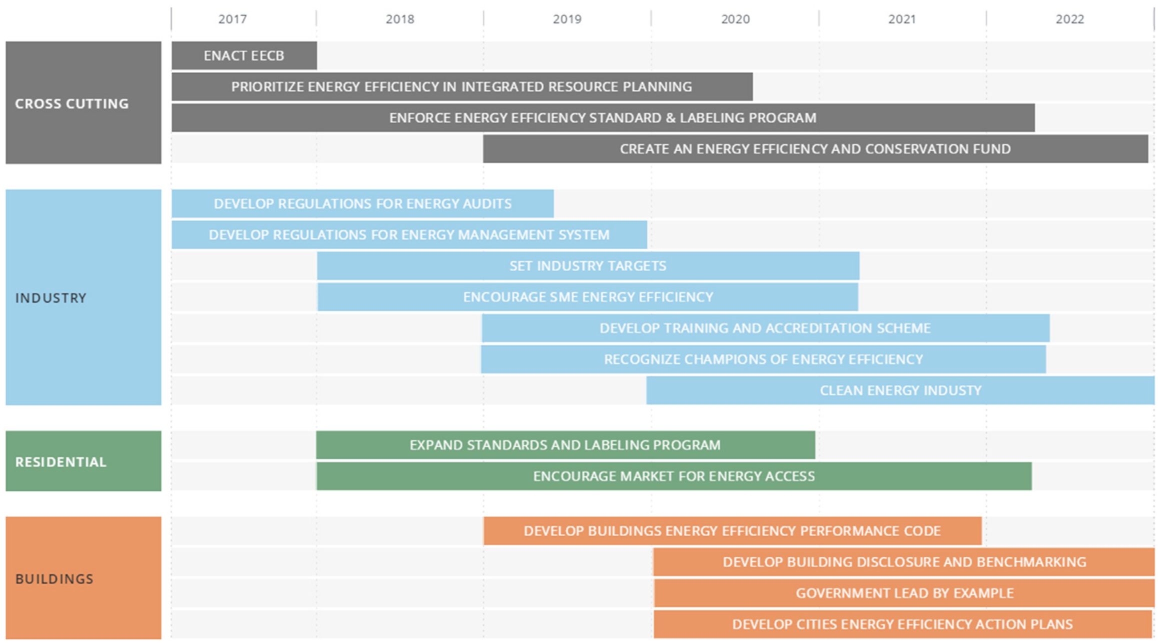

Fig. 12. Energy-efficiency roadmap for Uganda.

save energy (large industrial, on-grid residential) at relatively low implementation costs. Most important, these programs create the basis for further initiatives by establishing the regulatory frameworks needed to carry out successful EE programs. The programs also build the basis for overcoming most common barriers as described in the "remedy" column of Table 3. For example, the IRP is a process of planning to meet a country's needs for electricity through a combination of supply-side and demand-side resources over a specified future period (Satchwell et al., 2011). This process ensures that EE potential is included in national energy planning investment decisions and that a budget is allocated for its realization. The achievable economic potentials estimated in this paper can be used to develop a resource portfolio that includes energy-efficiency and set energy-savings goals.

3.4.2. Second order of priority programs

Second-priority programs include:

- Expanding Uganda's S&L program
- Encouraging the residential market for efficient products
- Setting industry targets
- Encouraging EE in small- and medium-sized industrial enterprises

Second-priority programs expand first-priority programs to reach a larger market. Residential efficiency programs will center on uptake of efficient products enabled through Uganda's S&L program. Additional products and equipment should be considered for inclusion in the program, and standards for the products already covered should be revised to reflect market changes and provide the most accurate information to customers. Uganda also has a timely opportunity to promote EE in off-grid communities. Super-efficient off-grid appliances enable consumers to purchase smaller (and therefore less expensive) solar photovoltaic panels, lowering the costs of energy service by as much as 50% (Phadke et al., 2015). In the industrial sector, programs requiring industries to set EE targets would scale up the impact of energy audits and EMSs. Programs to increase small and medium industrial enterprises' awareness of and capacity to undertake EE investments also fall into the second-priority category.

3.4.3. Third order of priority programs

Third-priority programs in Uganda's efficiency roadmap include:

- Developing training and accreditation schemes
- Developing building codes
- Recognizing EE champions
- Developing financing schemes through an EE and conservation fund

Third-priority programs include programs that have relatively higher costs of implementation and are more complex and lengthy to execute. However, these are crucial building blocks for sustaining EE investment in the long term. For example, creating technical expertise in the labor market is crucial for enabling the development of new business models, such as energy service companies. Training programs and certification schemes also create a professional community that can share information on best practices, lessons learned, and the latest developments in technology and practices. The recognition of EE champions can help to galvanize industry towards greater collaboration and more aggressive efficiency strategies. Developing EE building codes is a complex and lengthy process, but they prevent costly energy waste in air conditioning, lighting, and other energy service requirements over a building's long lifetime.

Finally, while the Energy Efficiency and Conservation Fund appears last among the cross-cutting measures, it remains highly relevant for long-term EE goals. A fund can play a significant role in supporting EE incentives and investments. Dedicating public resources to an EE fund also demonstrates national commitment to EE as a high-priority resource for meeting Uganda's energy demand.

3.4.4. Fourth order of priority programs

Fourth-priority programs include:

- Encouraging development of clean industry
- Promoting building disclosure and benchmarking
- Developing government lead-by-example programs
- Developing cities' and municipal councils' EE action plans

Fourth-priority programs are advanced and far-reaching programs that enable a more comprehensive approach to addressing remaining market barriers. They are based on implementation of actions already discussed above. For example, to develop clean energy industries, many elements must be cultivated to enable the process; advanced levels of stakeholder collaboration and a deep understanding of circular economy energy-savings potential are required. Similarly, building disclosure and benchmarking programs extend the impact of building codes by developing tools and certification methods to better track building energy performance. Data are key to energy efficiency programs, and building disclosure and benchmarking programs greatly enhance the ability of researchers and policy makers to study and compare building efficiency against other buildings and over time.

Appendix 4 through Appendix 7 show the timing for actions needed, by sector, and disaggregate the next steps needed for implementation. The schedules are based on the experience from other countries but ultimately will need to be adjusted to fit the Government of Uganda's priorities and resources as they develop.

4. Conclusions

Although improving a country's EE is a highly cost-effective way to increase energy access and avoid the cost of new generation infrastructure, many barriers prevent customers from investing in efficient technologies and processes. This Uganda case study illustrates an analysis and planning approach to identifying the steps a country needs to take to realize the full potential and benefits of EE investments. The actions needed in Uganda include establishing enabling policies and financial incentives, and developing technical expertise in the labor market to promote new business models. Uganda will benefit significantly from developing and implementing new policies that can overcome market barriers and enable integration of energy efficiency into future energy resource planning.

Leadership is essential to motivate actions and communicate vision and purpose. Uganda's government has a key role to play in leading implementation of the EE action plan. Part of the leadership commitment entails setting goals and monitoring progress to focus efforts and optimize resources. Monitoring should include regular data collection and program impact evaluation to support ongoing EE implementation and improvement. Initial program goals can be based on the potential identified in this paper's supporting analysis. For example, the Ugandan government will use the achievable economic potential of 185 MW from this analysis as an initial energy-savings goal for the EE roadmap recommendations.

To make significant progress towards the potential outlined in this analysis, it is imperative that all stakeholders, not only the national government, play a part in championing the importance of efficiency. With impacts as significant as improved grid reliability, increased energy access, emissions reductions, and high cost effectiveness, there are numerous benefits from efficiency that can appeal to stakeholders. Development organizations in particular can play a substantial role by sharing successful experiences of improving energy efficiency in other countries and committing to EE as a resource and economic growth tool. A roadmap based on a robust analysis and planning process, as illustrated in the example developed for Uganda and presented here, provides a strong framework for government, the private sector, and international development organizations to use to pursue EE in developing nations.

Acknowledgment

This work was funded by Power Africa funding under the U.S. Department of Energy Contract no. DE-AC02-05CH11231. Any errors or omissions are the authors' own.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2018.05.045.

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