Title

Energy efficiency improves energy access affordability

Authors
du Can, Stephane de la Rue
Letschert, Virginie
Agarwal, Shreya
et al.

Publication Date
2022-10-01

DOI
10.1016/j.esd.2022.09.003

Energy for Sustainable Development 70 (2022) 560–568

Contents lists available at ScienceDirect

Energy for Sustainable Development

Energy efficiency improves energy access affordability

Stephane de la Rue du Can [a,*], Virginie Letschert [a], Shreya Agarwal [a], Won Young Park [a], Usamah Kaggwa [b]

[a] Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, Berkeley, CA 94720, United States of America
[b] Ministry of Energy and Mineral Development, Uganda

ARTICLE INFO

Article history:
Received 27 May 2022
Revised 27 August 2022
Accepted 1 September 2022
Available online 15 September 2022

Keywords:
Energy efficiency
Energy poverty
Multiple benefits of energy efficiency
Sustainable development

ABSTRACT

Energy efficiency can make energy access more affordable by reducing the electricity cost burden on households and businesses. Improving products' energy efficiency helps reduce monthly energy bills— freeing up funds that can feed back into the economy, thus stimulating economic growth. To demonstrate these benefits, this paper conducts a cost-benefit analysis (CBA) and a national impact analysis (NIA) for implementing an energy-efficiency standards and labeling (EESL) program for refrigeration products in Uganda. The CBA compares the costs versus the benefits of investing in energy-efficient products for consumers: It shows that the most cost-effective products have an efficiency level 35 % higher than baseline products sold on the market. By choosing these products, consumers save, on average, US$76 over the lifetime of the product. The NIA assesses the impact of an energy-efficiency standard set at that level and shows potential cumulative savings of US$595 million (2023–2040) for households and small businesses. These savings translate into additional purchasing power for households and investments for small businesses, leading to increased living standards and economic development. This paper describes the importance of implementing energy efficiency policies and programs in emerging economies where affordability of electricity hinders electricity access. This paper provides a rigorous approach of using CBA and NIA assessments to demonstrate the economic savings for the consumers and the nation to implement EESL programs for major electric equipment.

Introduction

Energy access is essential for providing energy services such as lighting, hot water, sanitation, refrigeration, cooking, telecommunications, and more. These energy services improve health, food security, livelihoods, education, gender equality, and poverty reduction (Bhatia & Angelou, 2015; Chirambo, 2018; Rajbhandari & Zhang, 2018). Despite these critical benefits, the current state of energy access remains low globally, especially in Africa. Approximately 10 % of the global population lives without electricity (789 million people), and this percentage reaches 48 % in Sub-Saharan Africa (IEA, IRENA, UNSD, & WB, 2019). Realizing the benefits of energy access requires access beyond a simple electricity connection that provides weak and expensive access to energy services (Bhatia & Angelou, 2015; Boie et al., 2018). The United Nations (UN) Sustainable Development Goal 7 calls for "affordable, reliable, sustainable and modern energy for all" as one of the major goals to achieve universal access to modern energy (United Nations, 2015). It identifies energy efficiency as one of the main pillars to achieve this goal.

While major energy access programs have contributed to increasing the supply of available energy, less effort has stimulated the efficient and productive use of energy, which is necessary to achieve the benefits of energy access. This is especially true in East Africa, where overcapacity is particularly acute in the three largest economies—Kenya, Uganda, and Tanzania. Here, combined peak electricity demand now stands at about 3300 MW, far below the installed capacity of 5500 MW and the total capacity of 10,000 MW planned for 2030. This underutilization creates an imbalance between demand and capacity additions, driving electricity tariffs up and affecting energy access affordability. The Rocky Mountain Institute projects that this imbalance will exceed US $180 billion by 2030 in East and West Africa-more than two-and-a-half times the 2016 gross domestic product of Kenya (Wanless & Wang-thomas, 2019). Adding supply on the grid alone does not lead to increased electricity access. Electrification programs need to incorporate demand-side investment more effectively to stimulate energy access (McCall & Santana, 2018). Tarekegne (2020a) shows that the lack of human-centered considerations in electrification planning results in constructing energy infrastructure that falls short to deliver the energy services that are needed for improving livelihoods and increasing economic development. Energy efficiency investment is part of demand-side programs that improve energy access by reducing wasteful electricity use.

Several authors have discussed the multiple benefits of energy efficiency (IEA, 2014; Kamal, Al-Ghamdi, & Koc, 2019; Reuter, Patel,

* Corresponding author.
E-mail address: sadelarueducan@lbl.gov (S. de la Rue du Can).

https://doi.org/10.1016/j.esd.2022.09.003

Eichhammer, Lapillonne, & Pollier, 2020; Ürge-Vorsatz et al., 2016). Adom, Agradi, and Vezzulli (2021) used a panel dataset of 51 African countries to show that energy efficiency triggers economic growth. Similarly, Rajbhandari and Zhang (2018) examined the causal relationship between energy efficiency and economic growth based on panel data for 56 high- and middle-income economies and found evidence that energy efficiency generates long-term growth benefits. Other authors have focused on the significance of energy efficiency in attaining sustainable development (Zakari, Khan, Tan, Alvarado, & Dagar, 2022; Ziolo, Jednak, Savić, & Kragulj, 2020). Ganda and Ngwakwe (2014) and Türkoğlu and Kardoğan (2018) use recent literature to describe the multiple benefits of energy efficiency in sustainable growth and its impact on job creation and poverty reduction. Furthermore, authors have shown how energy efficiency contributes to improved health and lowered air pollution (Evens, Garascia, & Isaacson, 2017; Zhang, Zhao, Niu, & Maddy, 2016). de la Rue du Can, Pudleiner, and Pielli (2018) show the potential to expand energy access through energy efficiency and (Diawuo, Pina, Baptista, & Silva, 2018; Diawuo, Sakah, de la Rue du Can, Baptista, & Silva, 2020; Sakah, de la Rue du Can, Diawuo, Sedzro, & Kuhn, 2019) show how energy efficiency and demand side management can contribute to reduce peak demand.

However, no study has demonstrated the contribution of energy efficiency to the affordability of energy access and energy services. This study intends to fill this gap by contributing to the literature on the benefits of energy efficiency to economic development by estimating consumers' welfare gain from national investments in energy efficiency. We assess the costs and benefits of energy efficiency to consumers purchasing and operating electric equipment. While most studies that examine the economic benefits of energy efficiency correlate energy efficiency and GDP growth using a large panel of data set at the country level, we apply a bottom-up approach to estimate national economic benefits. In this paper, we demonstrate how energy efficiency provides a cost-effective way to access energy services by taking the example of refrigeration products in Uganda. Refrigeration provides a critical electricity-consuming service that meets the basic need of conserving food and reducing food waste. It is one of the first assets typically owned by households when they access electricity: next after lighting fixtures and TVs. Refrigeration products are also highly energy-intensive compared to other electric equipment owned by households and often represent the largest fraction of energy bills of households and small businesses. Therefore, reducing refrigeration products' energy consumption while providing the same service can significantly impact household welfare.

Technology has also evolved rapidly over the last 20 years. Agyarko, Opoku, and Van Buskirk (2020) show that residential refrigerators consumed on average 924 kWh per year per product in Ghana in the mid-2000s, in part due to a large share of imports of used equipment. Park, Shah, and Phadke (2019) show that models consuming about 200 kWh/year are now available for less than US$150 in many countries. The reduction of energy consumption of refrigerators has resulted from manufacturing innovation driven by the regularly revised energy performance regulations of the major economies (Wiel, Egan, & della Cava, 2006). For example, energy efficiency standards and labeling programs in the US have led to an annual 4 % decline in the average energy consumption of refrigerators between 1989 and 2010 (Van Buskirk, Kantner, Gerke, & Chu, 2014). Similar trends have been observed in other countries that have implemented and regularly revised their energy-efficiency standards and labeling (EESL) programs, including Australia, Europe, and China (Fridley, Aden, Zhou, & Lin, 2007; IEA, 2015). Brucal and Roberts (2019) also found that the price of appliance declined as a result of more stringent energy efficiency standards due to induced innovation and inter-manufacturer competition.

In order to benefit from electricity, users must be able to afford the cost of the products and the electrical energy that the appliances use. This requirement is especially true in Uganda, where the average domestic tariff is 20 cents US$/kWh. Some estimate this tariff will increase to 30 cents by 2030 due to the mismatch between supply and demand (Komakech Akena, 2020). As described by Tarekegne (2020b), many Africans cannot afford the electricity their own countries produce. For example, Mozambique export 57 % of its electricity production while its electrification rate is equal to 31 % (IEA, 2020; The World Bank, 2020). Uganda's poor grid connectivity and high utility prices have forced its users to reduce appliance usage to save energy costs. Ssennono et al. (2021) estimate that 66 % of Ugandans are energy poor, and 33 % are severely energy poor. Ugandans spend 22 % of their annual income on energy, making energy efficiency a critical opportunity to help consumers lower energy bills while increasing energy usage in appliances.

The rest of the paper is organized as follows. Section 2 presents the data collected. Section 3 discusses the methodology used to assess the cost benefits of energy-efficient refrigeration and the national impact of introducing minimum energy efficient standards (MEPS). Section 4 presents results, analysis, and discussion. Finally, Section 5 provides the conclusions and policy implications.

Material and methods

The analysis focuses on three product classes: refrigerators, which typically have at least one fresh food compartment and a frozen food section; refrigerator-freezers with at least one fresh food compartment and one freezer compartment and freezers with only frozen compartments. This section describes first the data collected to assess market sales and current stocks of refrigeration products, then the data collected to estimate the energy performance of the products sold on the market and finally the methodology used to estimate energy, environmental, and consumer impacts of EESL programs.

Annual sales and current stock of products

Local production of refrigeration products is very small in Uganda. The Uganda National Association of Refrigeration and Air Conditioning (UNARA) reports annual local production of 1440 units, therefore the vast majority of products sold on the market are imported. The Uganda Bureau of Standards (UBOS) estimated that 123,000 refrigeration products entered Uganda in 2019 and 135,000 in 2020. The United Nations Comtrade database (UN Comtrade, 2021) provided additional information on the trade value trends of different refrigerating products imported to Uganda along with their country of origin (Fig. 1). Imports are growing rapidly, especially since 2017, at 13 % per year. Over the last decade, China has become the leading trading partner for Uganda, representing more than 70 % of imports in 2020. The shares of sales by product class are estimated to be 33 % refrigerators (1-door), 33 % refrigerator-freezers (2-doors), and 33 % freezers based on several sources (Energy4Impact, 2017; GIZ, 2014; UBOS, 2021; UNARA, 2021).

The National Electrification Survey of 2018 (MEMD, 2020) found that 24.6 % of grid users own refrigerators. Considering the electrification rate in that year (24 %), the national average ownership of refrigerators is estimated at 6 % in 2018. Another survey reports ownership at 4.9 % in 2016/2017 and 2.3 % in 2012/2013.

Ugandan refrigerator models database

Refrigeration appliances and equipment are manufactured with a wide range of energy performance. As part of the study, the authors developed a database of the popular models of refrigerators sold in Uganda through online data collection from retailer websites, online catalogs for local shops, a survey of models sold in small shops in Kampala and a survey sent to the Uganda National Association of Refrigeration and Air-conditioning (UNARA). The data collected covered different aspects of the product market, including manufacturers, retailers, product class (refrigerators, refrigerator-freezers, and freezers), size, price, and unit energy consumption.

The retail of refrigeration products is commonly from small-specialized electrical and furniture shops and larger stores that display

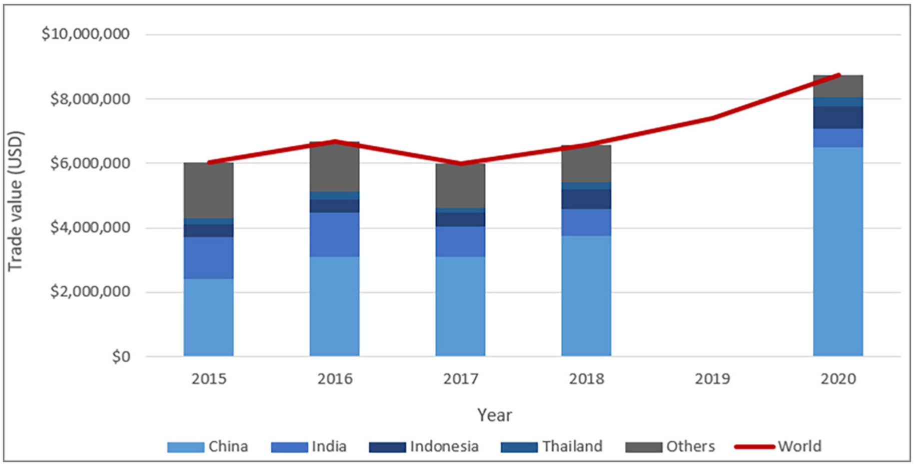

Fig. 1. Imports of domestic refrigerators and freezers by trade partners in trade value (US$).
(Source: (UN Comtrade, 2021))

their products inventories online through either their website or dedicated web search platforms. In order to have a good representation of the products sold on the Uganda market two main type surveys were used. The primary source of data collected was a survey covering small-specialized electrical and furniture shops in the city of Kampala. Characteristics for 39 different models were collected through that survey, of which 27 were unique models. The shops were selected to represent the diversity of products sold in small shops in Uganda. This survey was then complemented by an online survey that collected 113 models from larger stores. As described by (Gerke, McNeil, & Tu, 2017) online data survey provides ready available data that improves the availability of information for effective program development by increasing the understanding of the mix of product efficiencies available on the market as well as the relations among price, energy efficiency, and other product features. The authors gathered data from 4 main online retail website in Uganda as described in Fig. 2. After removing all repetitive models, the final number of unique models from the online survey was 93. Therefore, characteristics for a total of 120 unique refrigeration models sold in Uganda were gathered to inform this analysis and establish an energy consumption and price baseline that depict the current market conditions. Fig. 2 describes the retailers and manufacturers of the data collected.

Because there is no mandatory regulation for refrigeration products in Uganda, the product's energy consumption was often missing in the data collected. For example, in the sample of the 93 product models from online retailers, energy performance information about the product sold was available for only 26 % of the products—often via energy labels from other countries. This illustrates the lack of information available to households and businesses to inform their purchasing decisions. Since Kenya and Uganda have similar product models available on their markets, the product registration database available in Kenya was used to extract data on energy consumption when this information was missing from the model collected on Uganda market. Kenya's product registration database is maintained by the Energy and Petroleum Regulatory Authority to certify that products fold on their market meet MEPS (EPRA, 2022). This database is an essential element of Kenya's EESL program. The test data reported by EPRA was adjusted to take into account differences in test methods and reporting of electricity consumption with the model regulation guidelines described in Section 3.1 Energy Use Analysis (Letschert, Agarwal, de la Rue du Can, Park, & Kaggwa, 2022).

Methods

This paper provides a regulatory impact assessment (RIA) to support the adoption of EESL for refrigeration products in Uganda. It assesses the energy, environmental, and consumer impacts of setting energy efficiency standards. The RIA is composed of two major analyses: one that focuses on the impact on consumer welfare and one that provide an overall assessment for the nation as whole.

In both analyses, future energy savings are converted into present value by using a discount rate. However, two different discount rates

Retailers	**Manufacturers**		
Small shops in Kampala	Ariston	ADH	KIC
Kweli (online)	LG	Bruhm	MeWe
Jumia (online)	Samsung	DEFY	Ocean
Tuskys (Supermarket)	Changhong	Hisense	Skyworth
Game (Supermarket)	Indesit	Whirlpool	Beko
	Solstar	Sayona	Hitachi
	Icecool	Smartec	Bosch
	Sharp	Beko	Venus
	Daewoo		

Fig. 2. Retailers and manufacturers of data collected.

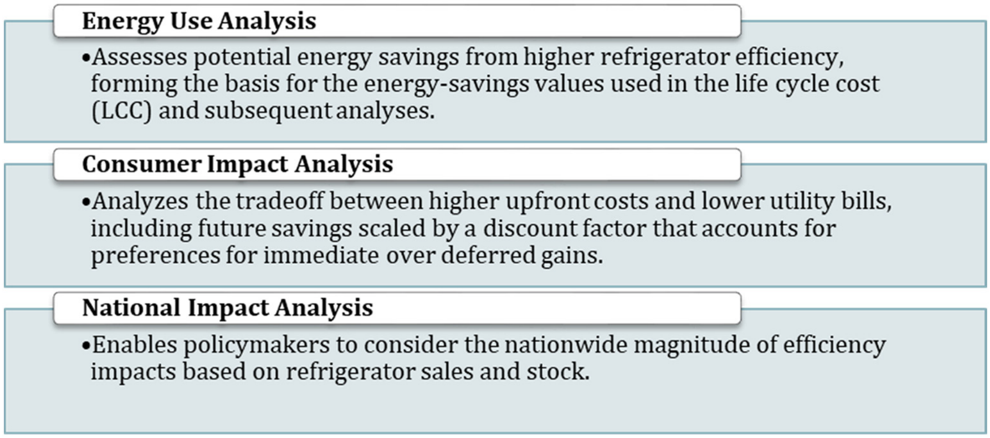

Fig. 3. Cost-benefit analysis methodology for standards and labeling.

are used. In the consumer impact analysis, a discount rate of 14.6 % is used, which corresponds to Uganda 2018 real interest rates (World Bank, 2021). This interest rate is used because it reflects the cost of financing energy efficiency available to consumers. In the national impact analysis, the Uganda policy discount rate of 6.5 % is used (IMF, 2022). The policy discount rate is used in cost-benefit analysis applied to government projects and it reflects a society's relative present valuation of resource allocation (Council of Economic Advisers, 2017; Zhuang, Liang, Lin, & De Guzman, 2007).

The consumers considered in these analyses are the households and businesses that are purchasing and operating refrigeration products.

The methodology used is described in details in (Letschert et al., 2022; Mcneil, Letschert, & Van Buskirk, 2007; Meyers, McMahon, McNeil, & Liu, 2003). It follows three main steps as summarized in Fig. 3. The Policy Analysis Modeling System (PAMS) tool was used to organize the data (Mcneil, Letschert, & Buskirk, 2007). PAMS is an excel based tool that has been used in several countries such as Chile, Indonesia and Brazil for example (Letschert et al., 2019; Letschert et al., 2020; Letschert, McNeil, Pavon, & Lutz, 2013). The methodology is also applicable for other products like airconditioners, lighting and water heating for example.

RIAs are based on costs and benefits analyses and they inform policymakers about the positive and negative effects of a proposed regulation. It is therefore an essential element for decision-making as it provide the information necessary for selecting energy efficiency levels. It also provides the supporting argumentation demonstrating the benefits of the regulation.

Calculation

Energy use analysis

The energy-use analysis assesses potential energy savings from increasing refrigeration products' efficiency. The unit energy consumption (UEC) data collected in the Uganda models database described in Section 2.2 were compared to the model regulations guidelines (MRG) developed by the United Nations Environment Programme's United for Efficiency initiative (U4E, 2019a, 2019b). MRGs provide guidelines to assist governments considering setting MEPS and energy labels. In the case of refrigerating appliances, the MRGs build on the most common test procedures (IEC 62552, 2015), and energy efficiency levels that are comparable to the levels of the most recent MEPS in major and emerging economies around the world, such as the United States, European Union, Mexico, and India among others. Fig. 4 shows the comparison of UEC found in Uganda with MRG levels. A significant percentage of models do not meet the standards recommended by the MRG.

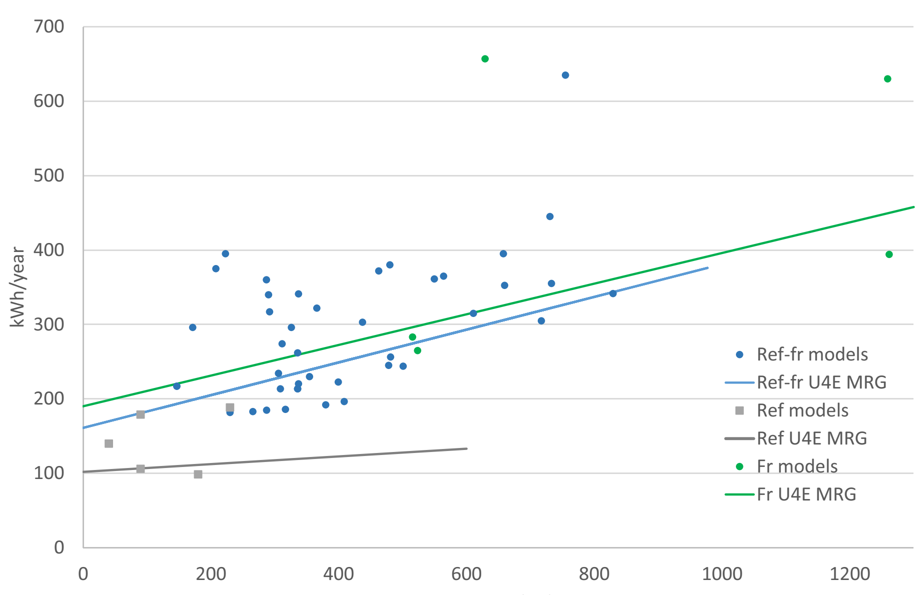

Fig. 4. Energy use for refrigeration products sold in Uganda and U4E model regulation guidelines.
Note: Ref-Fr = Refrigerator-freezers; Ref = Refrigerators; Fr = Freezers.

Table 1
Annual UEC for refrigerators, refrigerator-freezers and freezers.

	EL0	EL1	EL2 (MRG)	EL3	EL4
Refrigerators					
Efficiency (Index)	0.57	0.75	1.00	1.25	1.5
UEC (kWh/year)	217	166	124	100	83
Refrigerator – freezer					
Efficiency (Index)	0.65	0.75	1.00	1.25	1.5
UEC (kWh/year)	334	289	217	174	145
Freezer					
Efficiency (Index)	0.56	0.75	1.00	1.25	1.5
UEC (kWh/year)	677	469	352	281	235

Specifically, 60 % of refrigerators, 60 % of refrigerator-freezer, and 40 % of freezers have energy consumption above the maximum allowed by the MRG.

To estimate the baseline of the products sold in the market, we assumed that, on average, all models met a minimum efficiency level. In the case of refrigerator-freezers, with 42 energy consumption data points, we calculated an average efficiency of the least efficient models on the market, represented by the bottom 20 % of the market. The analysis showed that the efficiency of these models was roughly equivalent to the China 2015 MEPS (Standards Press of China, 2015). Since 70 % of sales come from China, we assumed that, on average, all household refrigerators and freezers products meet the China 2015 MEPS. Once a MEPS and label program is in place in Uganda, official certified data should be readily available to define the baseline efficiency in the future.

The cost-benefit analysis considers impacts for a set of ranked efficiency levels (ELs), from Uganda's current baseline to the most advanced technologies. This analysis considers the MRG as one of the efficiency improvement levels (EL2) and assesses the cost-benefits and national impact of adopting MRG as a mandatory regulation for MEPS. The following ELs are considered MEPS targets for different policy scenarios:

- EL0: Uganda Baseline
- EL1: 25 % below MRG
- EL2: MRG
- EL3: 25 % above MRG
- EL4: 50 % % above MRG

EL0 is the baseline, and EL1 through EL4 represent different MEPS policy cases. Table 1 shows the resulting UEC values for the ELs considered by product class.

Consumer impact analysis

Improving the efficiency of products often increases the production costs of electric equipment, which are then passed on to consumers through higher purchasing prices. The total cost of ownership (TCO) allows to assess the tradeoff for consumers between higher purchasing prices and energy bill savings.

TCO is calculated as the sum of the purchasing price of electric equipment and the electricity bills during its lifetime. It represents the complete cost of owning the equipment through its lifecycle and it is a factor to consider when investing in new assets. In order to take into account the time value of money, the net present value of future savings is calculated by using a discount rate equivalent to the Uganda real interest rate (Table 2).

Electricity bills, also referred to as operating costs, are calculated by multiplying the UEC in kWh by the price of electricity in US$ per kWh (Table 2) for each year of the lifetime of the equipment. Future operating costs are divided by Uganda real discount rate to calculate the present value of these future cash streams (Eq. (1)). The UEC and electricity price are assumed constant over time. The average lifetime of refrigeration products was estimated to 15 years (Lutz et al., 2011; Meyers et al., 2003). Several workshops were organized during 2021 and 2022 with local stakeholders in Uganda to review the data and validate assumptions used in the analysis.

$$\text{Total Cost of Ownership (TCO)} = \text{Puchasing Price} + \sum_{1}^{\text{lifetime}} \frac{\text{UEC} \times \text{Electricity Price}}{(1 + \text{discount rate})^{\text{lifetime}}} \quad (1)$$

Table 2 provides details about the input data used to calculate TCO in the case of Uganda.

The average purchasing price of more efficient units versus the average price of the baseline units were determined based on a cost vs. efficiency curve developed by (Park et al., 2019). This engineering-based cost curve integrates design options from an inefficient baseline (roughly equivalent to the baseline in Uganda) to super-efficient technologies. Fig. 5 presents the cost curve. Price data collected on the Ugandan market were used to calibrate this cost curve and reflect local market conditions.

Consumer benefits

TCOs were calculated for each EL and for each product class as described in Table 3. They differ significantly across the type of equipment owned. The baseline TCO is equal to US$1219 for freezers, and only US $430 and U$764 for refrigerators and refrigerator-freezers, respectively. These differences reflect the large energy consumption of freezers compared to small refrigerators.

The most cost-effective levels for consumers are found at EL1 for refrigerator-freezers and EL2 for refrigerators and freezers, with the lowest TCOs at US$395, US$743, and US$1046, respectively. This means that, by purchasing equipment with these efficiency levels, customers will save a net present value of US$35, US$21, and US$173 for refrigerators, refrigerator-freezers, and freezers, respectively, over the life of the product. In a country like Uganda, where the average GDP per capita is US$822 per year and where 42 % of the population has daily consumption of less than US$1.90 per person (World Bank, 2020, 2021), these savings represent a significant gain. These gains can then

Table 2
TCO inputs for Uganda.

Input	Description	Average Value	Source
Lifetime	Average lifetime	15 years	(Lutz, Hopkins, Letschert, Franco, & Sturges, 2011)
Consumer Discount Rate	Uganda Real interest rate	14.6 %	(World Bank, 2021)
Electricity Price	Uganda electricity cost for consumers	Residential: 750 Ush[a]/kWh[b] Commercial: 640 Ush/kWh (weighted average = $0.20/kWh)	(ERA, 2020)

[a] Ush: Ugandan shilling. The conversion rate is 1 USD = 3523.55 Ush as on June 30, 2021.
[b] kWh: kilo Watt-hour.

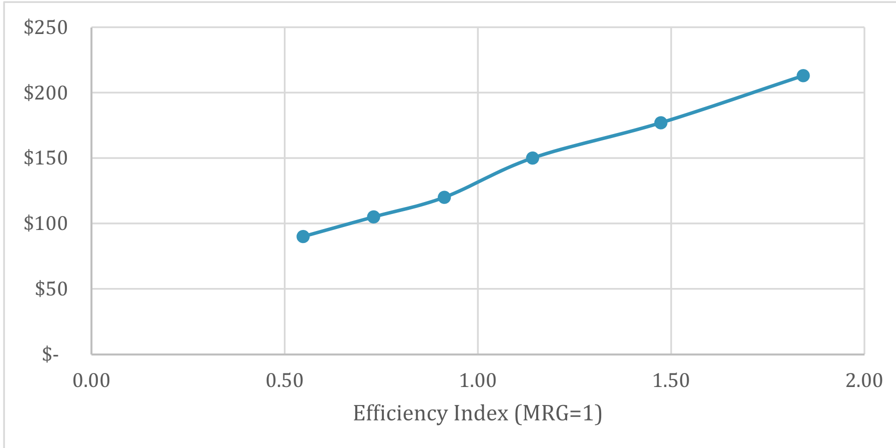

Fig. 5. Price versus efficiency.
(Source: (Park et al., 2019))

Table 3
Summary of results of TCO cost analysis under all scenarios.

Efficiency Level	Baseline	EL1	EL2 (MRG)	EL3	EL4
Refrigerator					
Efficiency Improvement		24 %	43 %	54 %	62 %
Average TCO (US$)	$430	$397	$395	$418	$438
TCO Savings (US$)		$33	$35	$12	($7)
Refrigerator-Freezer					
Efficiency Improvement		13 %	35 %	48 %	57 %
Average TCO (US$)	$764	$743	$752	$805	$849
TCO Savings (US$)		$21	$12	($41)	($85)
Freezer					
Efficiency Improvement		31 %	48 %	58 %	65 %
Average TCO (US$)	$1219	$1065	$1046	$1095	$1142
TCO Savings (US$)		$154	$173	$124	$77

TCOs are similar to Life Cycle Costs as described in (Letschert et al., 2022).

be invested or spent on other goods and services, contributing to improved quality of life and economic development.

National impacts

Policymakers consider not only the financial impacts of energy efficiency on individual users but also the magnitude of these impacts on the entire country. The national impact analysis calculates the impact of setting MEPS regulations for the country in terms of energy savings and financial gains. Therefore, two primary assessments are conducted for the 2023–2040 forecast period. The first assessment estimates the national energy savings and represents the total electricity saved by the policy measure versus the business-as-usual (BAU) scenario. These savings can also be translated into greenhouse gas emissions (GHG) savings and deferred MW investment. The second assessment represents the overall financial savings for the country. It is the sum of the net present value (NPV) of utility bills savings for the entire market of consumers.

To calculate the national impacts, ownership of refrigeration products was projected to 2040 by using a macroeconomic model developed by (McNeil & Letschert, 2010). The macroeconomic model was calibrated to match the electrification survey in 2018 (MEMD, 2020). An average annual growth rate of 2.9 % was considered for the gross domestic product (GDP). Fig. 6 presents the resulting projected rate of ownership from 2010 to 2040. With growing electricity connections, demand for refrigeration products is growing rapidly in Uganda as demonstrated by the number of imports as described in the previous section.

A stock turnover approach was used to calculate future sales and simulate how a newly introduced energy-efficiency standard affects the sales of equipment to gradually transforms the average improvement values across the entire stock of devices (de la Rue du Can et al., 2020; McNeil, Letschert, de la Rue du Can, & Ke, 2013; Mcneil,

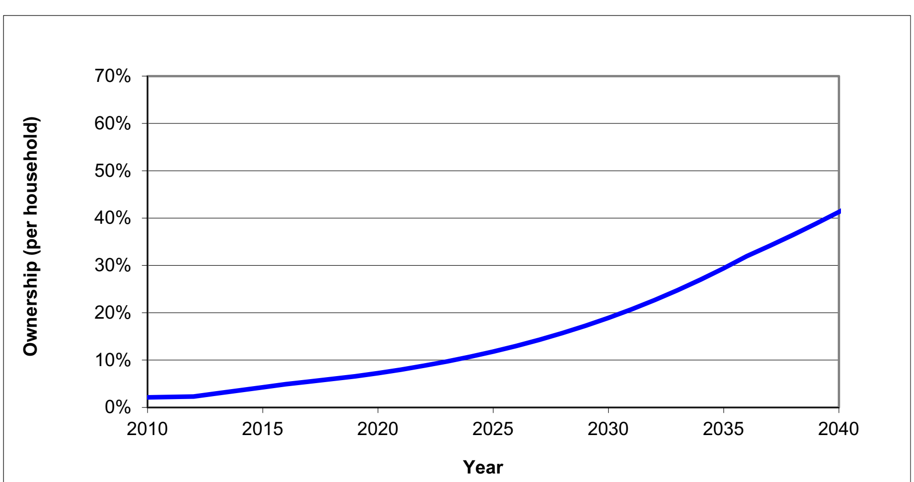

Fig. 6. Household refrigerators penetration rate (2010–2040).

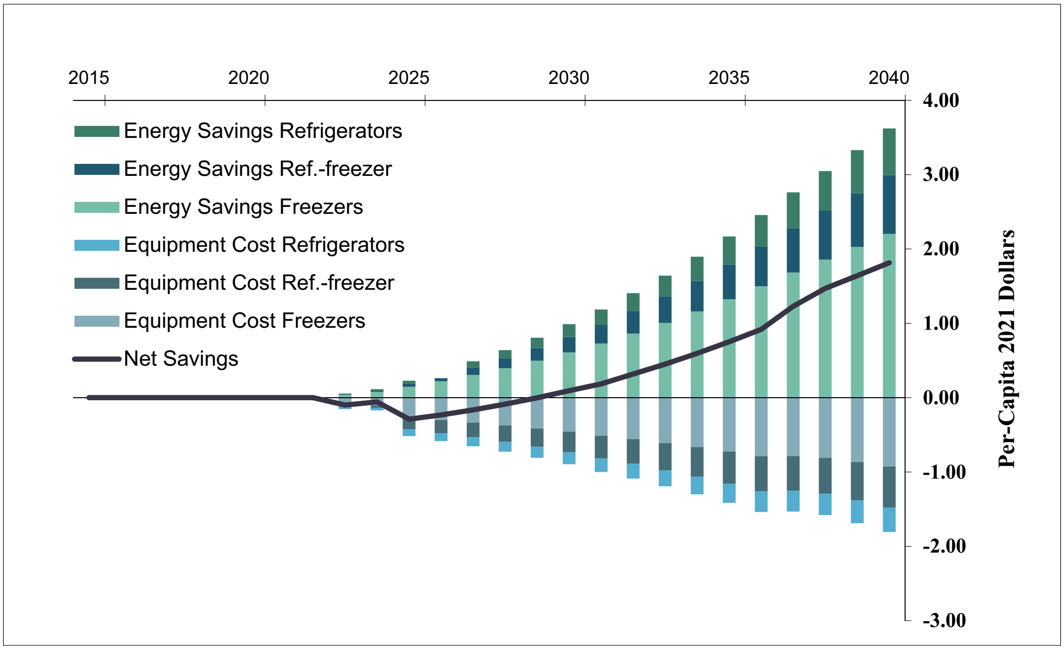

Fig. 7. Per capita national cost and savings per product category.

Letschert, Van Buskirk, et al., 2007). As efficient devices are bought, they gradually replace older, less efficient ones. The longer the lifetime of the equipment, the longer the average energy intensities of the entire installed stock of devices is affected by the new regulation.

The national energy savings were estimated as the difference in energy consumption between the business as usual scenario (BAU) and the MEPS scenario. In the BAU scenario, all refrigeration products have an average UEC of EL0 (Table 1). In the policy scenario, all products that are bought after the MEPS implementation date are assumed to be operating at the different efficiency levels determined by the ELs in Table 1. Finally, CO_2 emissions savings were calculated by applying a carbon factor to energy savings and considering the fraction of energy lost in electricity transmission and distribution (T&D) (de la Rue du Can, Price, & Zwickel, 2015). Carbon factor was estimated at 0.454 kg CO2/kWh and T&Ds were estimated at 17 %. The national present value of utility bill savings was estimated by using a national policy discount rate of 6.5 %. This discount rate is based on the social discount rate applied to government projects (IMF, 2022).

Results and policy implication

A phased approach is recommended by U4E in support of regional harmonization efforts in the EAC and the Southern African Development Community (SADC) (U4E, 2021). This phased approach consists in adopting the MRG in 2025 with an intermediate step of 25 % below MRG in 2023. This lower requirement in 2023 would give market players in Uganda and the East Africa Community (EAC) region time to transition their supply chain toward more efficient products. Building on these recommendations, a policy roadmap was developed with a first step to regulate the market to a MEPS of EL1 in 2023 and a MEPS of EL2 in 2025. Fig. 7 shows the costs and benefits per capita and per year of implementing the roadmap. Positive numbers represent the annual operating cost savings and negative numbers the annual incremental cost of equipment. The sum of these two parameters provides the annual net savings per capita. Benefits vary per type of product with freezers having the largest operating cost savings due to their relatively larger unit energy consumption.

Table 4 shows the net present value of operating cost savings and incremental equipment cost through 2040 and provides a summary of findings.

The implementation of the roadmap will result in US$595 million of cumulative (2023–2040) savings, broken down to US$ 346 million for households and US$ 249 million for small businesses. In addition, the potential savings for refrigeration products translates into 1365 GWh in electricity savings annually by 2040 and 5.1 million tons of avoided CO2 emissions (cumulative 2023–2040). Taking into account that the average capacity factor of the power mix in Uganda is 54 % and T&D is 17 %, the energy savings corresponds to 340 MW of generation capacity avoided. These savings can be used to expand energy access to 1 million households at a very low cost (compared to the cost of building new

Table 4
National level results.

		Refrigerator	Refrigerator-freezers	Freezers	Total
Net Present Value (millions $US)					
Operating Cost Savings through 2040		198	245	698	1141
Incremental Equipment Cost through 2040		99	166	281	546
Net Present Benefit		99	80	417	595
Benefit/Cost Ratio		2.0	1.5	2.5	2.1
Energy Savings (GWh) in	2030	52	63	183	298
	2040	237	297	831	1365
Energy Savings (GWh) through	2030	182	214	658	1054
	2040	1613	1995	5679	9287
CO2 Emissions Mitigation (Mt) through	2030	0.10	0.12	0.36	0.6
	2040	0.88	1.09	3.11	5.1

power plants) (USAID, 2021). This avoided capacity will also improve Uganda's energy security and independence as well as bolster the system's reliability and resilience.

Mandatory EESL programs are one of the most effective policy interventions used in developed and developing countries to enable greater uptake of energy-efficient equipment. Currently, China has the largest program globally, with over 40 products representing 55 % of final energy consumption. In the EAC region, Kenya and Rwanda developed mandatory EESL for refrigerators and air conditioners in 2016 and 2019 respectively. As the Ugandan market for electricity-consuming products grows, the government must regulate the market to protect customers—by limiting the imports of inefficient and costly products and avoiding the dumping of older technologies. Such regulation will help consumers to make informed purchase decisions about the energy performance of the products they buy and they establish a level playing field among manufacturers in relation to product energy efficiency. In a market with no EESL program, product energy performance information is nonexistent, hidden, erroneous, or confusing. As demonstrated by the cost-benefit analysis, EESL also helps improve energy access affordability.

Weak MV&E will limit the result of the EESL program. It is therefore essential that the program does not only issue regulations but also includes a robust process for monitoring, verifying and enforcing the regulations. Additionally, complementary programs such as financial incentive programs can help accelerate market transformation toward more efficient products and prepare the market for subsequent revisions of the EESL program to reach higher efficiency levels such as EL3 and EL4 (S. de la Rue du Can, Leventis, Phadke, & Gopal, 2014).

Energy efficiency brings a variety of benefits including cutting energy bills and reducing greenhouse gas emissions. Energy efficiency means using less energy to provide the same services – therefore eliminating wasteful use of energy. Many electric products use more energy than they actually need because of older technologies. Energy efficiency is one of the easiest ways to eliminate energy waste and lower energy costs for consumers. In this paper, we demonstrated the economic benefits to households and small businesses of implementing energy efficiency standards for refrigeration products. By lowering energy use, energy efficiency standards reduces monthly energy bills and makes the access to energy services more affordable for consumers. Some energy-efficient refrigeration products cost more to purchase, but we demonstrated in the consumer impact analysis that the higher purchase price is more than offset by the present discounted value of bill savings, therefore reducing energy costs for consumers and businesses. Cost-benefit analyses are needed to set energy efficiency standards at the level that is cost effective for consumers and national impact analyses demonstrate the overall national economic benefits.

Conclusion

Energy efficiency is considered by many policy makers and energy experts around the world as a key priority to achieve sustainable energy development. Energy efficiency is part of the three pillars with renewable energy and energy access identified by the United Nations to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030 corresponding to Sustainable Development Goal 7(SDG7). However, energy intensity has improved on average by only 1.3 % a year over the last 5 years, well below the 2.6 % needed to reach SDG7 (IEA, 2021). In Africa, only a handful of countries has implemented mandatory EESL programs, which are the cornerstone of energy efficiency. This paper demonstrates how cost benefit analysis can support the development and implementation of energy efficiency standards in countries where energy access is a national priority.

This analysis demonstrates how energy efficiency directly reduces the cost burden of energy usage to consumers, making energy access more affordable and helping countries to achieve SDG7. The paper provides a regulatory impact assessment necessary for the government of Uganda to support the implementation of EESL and recommends adopting the United Nations Model Regulation Guidelines in 2025, with an intermediate step in 2023. The analysis shows that the overall energy savings potential for the nation is significant, representing US $595 million of cumulative (2023–2040) savings, including US$346 million for households and US$249 million for small businesses. The implementation of the EESL program for refrigeration products benefits households and small businesses by allowing them to save money and reinvest in products and activities that improve their quality of life and bolster the nation's economic development.

A comprehensive data collection was conducted to gather data on the characteristics of the refrigeration products sold in Uganda for this study. However, limitations on the assessment of energy savings remain. Some are due to the nature of energy savings that cannot be measured directly. Instead, energy savings are calculated based on assuming a counterfactual energy consumption scenario, i.e. estimating what the energy use would have been had the program not been implemented. Other limitations lay in assessing the speed to which sales of equipment will grow. Established methods were used but uncertainties remain notably due unpredictable economic conditions. An average annual growth rate of 2.9 % was used for the GDP in this study.

Energy efficiency is often overlooked by governments in developing countries due to the distributed nature of the benefits that originate from a multitude of different electric equipment used by numerous actors. However, benefits for consumers can be significant as demonstrated by this paper and can reach a large number of people through energy bill reduction, increased energy services access, economic stimulus and GHG mitigation. EESL programs also address a fundamental market barrier that is the lack of accurate information about the energy performance of equipment sold. Monitoring, verification, and enforcement (MV&E) implementation strategies need to complement regulations to ensure the effectiveness of the program. The methodology described in this study can be used by other countries and for other products and the corresponding PAMS tool is available with default data that can be calibrated to represent country specific market characteristics.

Funding resources

This work was funded by United States Agency for International Development under the U.S. Department of Energy Contract no. DE-AC02-05CH11231. Any errors or omissions are the authors' own.

Declaration of competing interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-fi nancial interest (such as personal or professional relationships, affi liations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

References

Adom, P. K., Agradi, M., & Vezzulli, A. (2021). Energy efficiency-economic growth nexus: What is the role of income inequality? *Journal of Cleaner Production*, *310*, Article 127382. https://doi.org/10.1016/j.jclepro.2021.127382.

Agyarko, K. A., Opoku, R., & Van Buskirk, R. (2020). Removing barriers and promoting demand-side energy efficiency in households in Sub-Saharan Africa: A case study in Ghana. *Energy Policy*, *137*(November 2019), Article 111149. https://doi.org/10.1016/j.enpol.2019.111149.

Bhatia, M., & Angelou, N. (2015). *Beyond connections energy access redefined. World Bank. Energy Sector Management Assistance Program (ESMAP)* (pp. 1–224). The World Bank.

Boie, I., Steinbach, J., Christ, C., Belbin, N. A., Lösch, O., Denishchenkova, A., & Ordonez, J. (2018). Next level sustainable energy provision in line with people's needs: A proposal for extending the Multi-Tier Framework for monitoring the SDG7. Retrieved fromhttps://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccx/Review-of-the-monitoring-framework/Fraunhofer-ISI_SDG7-Review_Study_full_report.pdf.

Brucal, A., & Roberts, M. J. (2019). Do energy efficiency standards hurt consumers? Evidence from household appliance sales. *Journal of Environmental Economics and Management*, *96*, 88–107. https://doi.org/10.1016/j.jeem.2019.04.005.

Chirambo, D. (2018, October 1). Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030. *Renewable and Sustainable Energy Reviews*, *94*, 600–608. https://doi.org/10.1016/j.rser.2018.06.025.

Council of Economic Advisers. (2017). Retrieved from*Discounting for public policy: Theory and recent evidence on the merits of updating the discount rate* (pp. 1–16). https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf.

de la Rue du Can, S., Leventis, G., Phadke, A., & Gopal, A. (2014). Design of incentive programs for accelerating penetration of energy-efficient appliances. *Energy Policy, Elsevier*, *72*(C), 56–66. https://doi.org/10.1016/j.enpol.2014.04.035.

de la Rue du Can, S., Price, L., & Zwickel, T. (2015). Understanding the full climate change impact of energy consumption and mitigation at the end-use level: A proposed methodology for allocating indirect carbon dioxide emissions. *Applied Energy*, 159. https://doi.org/10.1016/j.apenergy.2015.08.055.

de la Rue du Can, Stephane, Lethabo, T., Heaps, C., Moonsamy, R., Covary, T., & McNeil, M. (2020). South Africa ' s appliance energy efficiency standards and labeling program: Impact assessment. Retrieved fromhttps://eta-publications.lbl.gov/sites/default/files/south_africa_appliance_energy_efficiency_sl_impacts._final_february_2020_1.pdf.

de la Rue du Can, Stephane, Pudleiner, D., & Pielli, K. (2018). Energy efficiency as a means to expand energy access: A Uganda roadmap. *Energy Policy*, *120*(January), 354–364. https://doi.org/10.1016/j.enpol.2018.05.045.

Diawuo, F. A., Pina, A., Baptista, P. C., & Silva, C. A. (2018). Energy efficiency deployment: A pathway to sustainable electrification in Ghana. *Journal of Cleaner Production*, *186*, 544–557. https://doi.org/10.1016/j.jclepro.2018.03.088.

Diawuo, F. A., Sakah, M., de la Rue du Can, S., Baptista, P. C., & Silva, C. A. (2020). Assessment of multiple-based demand response actions for peak residential electricity reduction in Ghana. *Sustainable Cities and Society*, *59*, Article 102235. https://doi.org/10.1016/j.scs.2020.102235.

Energy4Impact (2017). *Grid powered refrigeration.* (November).

Epra (2022). Registers ofelectric appliances meeting MEPS. Retrieved fromhttps://www.epra.go.ke/services/energy-efficiency-project/registers-of-energy-efficiency-and-management-licensed-practitioners/.

ERA (2020). *Schedule of base end-user tariffs applicable for the supply of electricity by UMEME.*

Evens, A., Garascia, M., & Isaacson, M. (2017). Utilities and health: Energy efficiency as a common link. *Electricity Journal*, *30*(5), 10–14. https://doi.org/10.1016/j.tej.2017.04.009.

Fridley, D., Aden, N., Zhou, N., & Lin, J. (2007). Impacts of China's current appliance standards and labeling program to 2020. Retrieved from*LBNL-62802*. https://eta.lbl.gov/publications/impacts-china-s-current-appliance.

Ganda, F., & Ngwakwe, C. C. (2014). Role of energy efficiency on sustainable development. Retrieved January 8, 2022, fromhttps://www.researchgate.net/publication/339714231_Role_of_Energy_Efficiency_on_Sustainable_Development.

Gerke, B. F., McNeil, M. A., & Tu, T. (2017). The International Database of Efficient Appliances (IDEA): A new tool to support appliance energy-efficiency deployment. *Applied Energy*, *205*, 453–464. https://doi.org/10.1016/j.apenergy.2017.07.093.

GIZ (2014). *Efficiency levels of electrical appliances on the Ugandan market.*

IEA (2014). Capturing the multiple benefits of energy efficiency. *Capturing the multiple benefits of energy efficiency*. https://doi.org/10.1787/9789264220720-en.

IEA (2015). Retrieved from*Achievements of appliance energy efficiency standards and labelling programs: A global assessment* (pp. 28). www.iea-4e.org.

IEA (2020). *World energy balances and statistics. Paris, France.*

IEA (2021). Energy efficiency 2021. Retrieved fromwww.iea.org/t&c/.

IEA, IRENA, UNSD, & WB, W. (2019). The energy progress report SDG7: The energy progress report. Retrieved from*IEA, IRENA, UNSD, WB, WHO (2019), tracking SDG 7: The energy progress report 2019, Washington DC* (pp. 176). www.worldbank.org.

IEC 62552 (2015). *International standard. IEC 62552-1. 6(5).* (pp. 13).

IMF (2022). *Uganda - IMF country report no. 22/77. Wasgington DC.*

Kamal, A., Al-Ghamdi, S. G., & Koc, M. (2019, August 1). Revaluing the costs and benefits of energy efficiency: A systematic review. *Energy Research and Social Science*, *54*, 68–84. https://doi.org/10.1016/j.erss.2019.03.012.

Komakech Akena, A. (2020). Achievements and challenges of Uganda's Power Sector. Retrieved fromhttps://rmi.org/achievements-and-challenges-of-ugandas-power-sector/.

Letschert, V., Agarwal, S., de la Rue du Can, S., Park, W. Y., & Kaggwa, U. (2022). *Cost-benefit analysis for energy-efficient refrigerators and freezers in Uganda.*

Letschert, V., Price, S., Shaffie, A., Park, W. Y., Karali, N., Abhyankar, N., & Pasek, A. (2020). *Accelerating the transition to more energy efficient air conditioners in Indonesia.*

Letschert, V. E., Karali, N., Park, W. Y., Shah, N., Jannuzzi, G., Lamberts, R., & Carvalho, S. M. (2019). The manufacturer economics and national benefits of cooling efficiency for air conditioners in Brazil. Retrieved from*Eceee summer study proceedings, 2019-June* (pp. 1563–1572). https://international.lbl.gov/publications/manufacturer-economics-and-national.

Letschert, V. E., McNeil, M. A., Pavon, M., & Lutz, W. F. (2013). *Design of standards and labeling programs in Chile: Techno-economic analysis for refrigerators.* *https://doi.org/10.2172/1171355.*

Lutz, J. D., Hopkins, A., Letschert, V., Franco, V. H., & Sturges, A. (2011). Using national survey data to estimate lifetimes of residential appliances. *HVAC and R Research*, *17*, 726–736. https://doi.org/10.1080/10789669.2011.558166.

McCall, M., & Santana, S. (2018). *Closing the circuit: Stimulating end-use demand for rural electrification.* Rocky Mountain Institute. https://doi.org/10.1109/MSPEC.2008.4659385.

McNeil, M. A., & Letschert, V. E. (2010). Modeling diffusion of electrical appliances in the residential sector. *Energy and Buildings*, *42*(6), 783–790. https://doi.org/10.1016/j.enbuild.2009.11.015.

Mcneil, M. A., Letschert, V. E., & Buskirk, R. D. Van (2007). *User instructions for the policy analysis modeling system (PAMS).* Berkeley: LBNL, LBNL-17974 (November).

McNeil, M. A., Letschert, V. E., de la Rue du Can, S., & Ke, J. (2013). Bottom-Up Energy Analysis System (BUENAS)-an international appliance efficiency policy tool. *Energy Efficiency*, *6*(2), 191–217. https://doi.org/10.1007/s12053-012-9182-6.

Mcneil, M. A., Letschert, V. E., & Van Buskirk, R. D. (2007). Methodology for the policy analysis modeling system (PAMS). *Methodology of the policy analysis modeling system.*

MEMD (2020). *National electrification report for energy for rural transformation-ERT III baseline survey, 2018.* (January).

Meyers, S., McMahon, J. E., McNeil, M., & Liu, X. (2003). Impacts of US federal energy efficiency standards for residential appliances. *Energy*, *28*(8), 755–767. https://doi.org/10.1016/S0360-5442(02)00188-3.

Park, W. Y., Shah, N., & Phadke, A. (2019). Enabling access to household refrigeration services through cost reductions from energy efficiency improvements. *Energy Efficiency*, *12*(7), 1795–1819. https://doi.org/10.1007/s12053-019-09807-w.

Rajbhandari, A., & Zhang, F. (2018). Does energy efficiency promote economic growth? Evidence from a multicountry and multisectoral panel dataset. *Energy Economics*, *69*, 128–139. https://doi.org/10.1016/j.eneco.2017.11.007.

Reuter, M., Patel, M. K., Eichhammer, W., Lapillonne, B., & Pollier, K. (2020). A comprehensive indicator set for measuring multiple benefits of energy efficiency. *Energy Policy*, *139*, Article 111284. https://doi.org/10.1016/j.enpol.2020.111284.

Sakah, M., de la Rue du Can, S., Diawuo, F. A., Sedzro, M. D., & Kuhn, C. (2019). A study of appliance ownership and electricity consumption determinants in urban Ghanaian households. *Sustainable Cities and Society*, *44*, 559–581. https://doi.org/10.1016/j.scs.2018.10.019.

Ssennono, V. F., Ntayi, J. M., Buyinza, F., Wasswa, F., Aarakit, S. M., & Mukiza, C. N. (2021). Energy poverty in Uganda: Evidence from a multidimensional approach. *Energy Economics*, *101*(June). https://doi.org/10.1016/j.eneco.2021.105445.

Standards Press of China. (2015). *GB 12021.2-2015 The maximum allowable values of the energy consumption and energy efficiency grade for household refrigerator.*

Tarekegne, B. (2020). Just electrification: Imagining the justice dimensions of energy access and addressing energy poverty. *Energy Research & Social Science*, *70*, Article 101639. https://doi.org/10.1016/J.ERSS.2020.101639.

The World Bank. (2020). *World Bank Data.*

Türkoğlu, S. P., & Kardoğan, P. S.Ö. (2018). The role and importance of energy efficiency for sustainable development of the countries. *Lecture Notes in Civil Engineering*, *7*(January), 53–60. https://doi.org/10.1007/978-3-319-64349-6_5.

U4E (2019a). *Model regulation guidelines - Climate-friendly and energy-efficient refrigerators.*

U4E (2019b). *Model regulation guidelines - Supporting information.*

U4E (2021). *Minimum energy performance standards for refrigerating appliances.*

UBOS (2021). *Refrigerator survey 2019-2020.*

UN Comtrade (2021). United Nations Commodity Trade Statistics Database (UN Comtrade). Retrieved June 1, 2021, fromhttps://comtrade.un.org/.

UNARA (2021). *Electricity-Distribution-Statistics survey database.*

United Nations. (2015). *World population prospects: The 2015 revision, key findings and advance tables. Working paper no. ESA/P/WP.241. Vol. 1.*United Nations, Department of Economic and Social Affairs, Population Division. https://doi.org/10.1017/CBO9781107415324.004.

Ürge-Vorsatz, D., Kelemen, A., Tirado-Herrero, S., Thomas, S., Thema, J., Mzavanadze, N., & Chatterjee, S. (2016). Measuring multiple impacts of low-carbon energy options in a green economy context. *Applied Energy*, *179*, 1409–1426. https://doi.org/10.1016/J.APENERGY.2016.07.027.

USAID (2021). *Energy mix diversification strategy for the Uganda Electricity Generation Company Ltd (" Uegcl ")* (pp. 1–97) (July 2008).

Van Buskirk, R. D., Kantner, C. L. S., Gerke, B. F., & Chu, S. (2014). A retrospective investigation of energy efficiency standards: Policies may have accelerated long term declines in appliance costs. *Environmental Research Letters*, *9*(11), Article 114010. https://doi.org/10.1088/1748-9326/9/11/114010.

Wanless, E., & Wang-thomas, S. (2019). *Creating a profitable balance.* Retrieved fromRocky Mountain Institute. https://rmi.org/wp-content/uploads/2018/05/seed_supply_imbalance.pdf.

Wiel, S., Egan, C., & della Cava, M. (2006). Energy efficiency standards and labels provide a solid foundation for economic growth, climate change mitigation, and regional trade. *Energy for Sustainable Development*, *10*(3), 54–63. https://doi.org/10.1016/S0973-0826(08)60544-X.

World Bank. (2020). KEY INDICATORS lower middle income line(%) non-poor poor bottom 40 top 60. Retrieved fromwww.worldbank.org/poverty.

World Bank. (2021). *The World Bank Data Bank World development indicators database.*

Zakari, A., Khan, I., Tan, D., Alvarado, R., & Dagar, V. (2022). Energy efficiency and sustainable development goals (SDGs). *Energy*, *239*, Article 122365. https://doi.org/10.1016/j.energy.2021.122365.

Zhang, F., Zhao, P., Niu, M., & Maddy, J. (2016). The survey of key technologies in hydrogen energy storage. *International Journal of Hydrogen Energy*, *41*(33), 14535–14552.

Zhuang, J., Liang, Z., Lin, T., & De Guzman, F. (2007). Theory and practice in the choice of social discount rate for cost-benefit analysis: A survey. Retrieved fromwww.adb.org/economics.

Ziolo, M., Jednak, S., Savić, G., & Kragulj, D. (2020). Link between energy efficiency and sustainable economic and financial development in OECD countries. *Energies*, *13*(22), 5898. https://doi.org/10.3390/EN13225898 2020, Vol. 13, Page 5898.