COST-BENEFIT ANALYSIS FOR ENERGY EFFICIENT REGRIGERATORS AND FREEZERS IN UGANDA

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BAU	business as usual
Berkeley Lab	Lawrence Berkeley National Lab
CEC	comparative energy consumption
CES	CO2 emissions savings
EAC	East African Community
EE4D	Energy Efficiency for Development
EES&L	energy-efficiency standards and labeling
ELs	efficiency levels
LCC	life-cycle cost
MEMD	Ministry of Energy and Mineral Development
MEPS	minimum energy performance standards
MRG	Model Regulation Guidelines
NEC	national energy consumption
NEqC	national equipment cost
NES	national energy savings
NOC	national operating cost
NPV	net present value
PAEC	projected annual energy consumption
PAMS	Policy Analysis Modeling System
PBP	payback period
RMS	roadmap scenarios
SADC	Southern African Development Community
U4E	United for Efficiency initiative
UBOS	Uganda Bureau of Standards
UEC	unit energy consumption
UECMax	maximum annual energy consumption
UNARA	Uganda National Association of Refrigeration and Air Conditioning
UNEP	United Nations Environment Program

1. Introduction

Lawrence Berkeley National Lab (Berkeley Lab), through the Energy Efficiency for Development (EE4D) program partnership with USAID is engaging with the Ministry of Energy and Mineral Development (MEMD) to assist in the implementation of energy-efficiency standards and labeling (EES&L). This project will provide technical assistance to the Uganda MEMD to support a reliable and impactful EES&L program focused on refrigeration.

The collaboration builds on previous engagement to assess the energy-efficiency potential of the country and develop an Energy-Efficiency Roadmap [1]. It also builds on the United Nations Environment Program's (UNEP) United for Efficiency (U4E) initiative in support of regional harmonization efforts in the East African Community (EAC) and the Southern African Development Community (SADC) regions to leverage the large potential of energy-efficient and climate-friendly cooling. The U4E initiative has developed Model Regulation Guidelines (MRG) with efficiency levels consistent with where major international markets are anticipated to be headed. The contents are designed so that countries with no regulations or weak regulations can easily adopt requirements that are aligned with minimum energy performance standards (MEPS) and labeling requirements in some of the larger markets around the world.

Refrigeration appliances and equipment available on the market are manufactured with a wide range of energy performance. The goal of this report is to perform a cost-benefit analysis, providing policy recommendations to develop standards and labels for refrigerators in Uganda: in particular, an analysis of the cost-effectiveness of adopting the UNEP U4E MRG for refrigerators given the local context in Uganda.

After an overview of the analytical framework (Section 2), Sections 3 through 6 of the report focus on the following analyses:

Market assessment—characterizing market trends, origin and quantities of equipment imported, efficiencies, and product market shares.

Energy-use analysis—assessing potential energy savings from higher refrigerator efficiency, forming the basis for energy-savings values used in the life-cycle cost (LCC) and subsequent analyses.

Consumer impact analysis—analyzing the tradeoff between higher upfront costs and lower utility bills, including future savings scaled by a discount factor that accounts for preferences for immediate over deferred gains.

National impact analysis—enabling policymakers to consider the nationwide magnitude of efficiency impacts based on refrigerator sales and stock.

The cost-benefit analysis provides the basis for recommendations to adopt a roadmap for MEPS for refrigeration products in Uganda.

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[1] https://ee4d.org/wp-content/uploads/sites/40/2021/05/energy_efficiency_roadmap_for_uganda_final_web-1.pdf

2. Analytical Framework

2.1 U4E Model Regulation Guidelines

U4E and Berkeley Lab developed MRGs for selected products commonly used in residential and light commercial applications, including refrigerating appliances (U4E, 2019a). The model regulations are voluntary guidance to assist governments that are considering a regulatory or legislative framework for MEPS and energy labels. U4E's model regulation provides guidelines and core requirements for energy efficiency, refrigerants, testing, and functional performance. An accompanying, supporting document provides the underlying rationale and methodologies (U4E, 2019b). In the case of refrigerating appliances, the MRGs build on the most common test procedures (IEC 62552: 2015) and energy efficiency levels 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, India, etc…

2.2 Scope and Product Classes

This analysis supports a regulation that applies to the scope defined in the U4E MRGs for refrigerators: all refrigerating appliances of the vapor compression type, with a rated volume at or above 10 Liters (L) and at or below 1,500 L, powered by electric mains and offered for sale or installed in any application[2].

The analysis uses the following three product classes from the regulations:

Refrigerators: Refer to refrigeration products that have at least one fresh food compartment and typically have a frozen food section (rather than a separate freezer compartment), hence single-door products fall into refrigerators. They are also called compact refrigerators.

Refrigerator-freezers: Refer to refrigeration products that have at least one fresh food compartment and at least one freezer compartment, two doors or more.

Freezers: Refer to the refrigeration products with only frozen compartments, at least one of which is a freezer compartment.

2.3 Efficiency Level Definition

The cost-benefit analysis considers impacts for a set of ranked efficiency levels (ELs), from Uganda's current baseline to the most advanced technologies. The following Els are considered targets for policy scenarios:

- EL0: Uganda Baseline (described in the energy use section)
- EL1: 25% below MRG
- EL2: MRG
- EL3: 25% above MRG
- EL4: 50% % above MRG

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[2] The U4E MRGs do not apply to: a) wine storage appliances; b) refrigerating appliances with a direct sales function; c) mobile refrigerating appliances; d) appliances where the primary function is not the storage of foodstuffs through refrigeration; e) other products that do not meet the definition of a refrigerator, refrigerator-Freezer, or freezer; and f) refrigerating appliances other than vapor compression types.

2.4 Analysis Period

Building on the recommendations from U4E in support of regional harmonization efforts in the EAC and SADC (U4E 2021), a roadmap is analyzed for MEP that could take effect in 2023 and 2025 with results to 2030 and 2040.

3. Market Assessment

This market assessment gives an overall picture of Uganda's refrigerating products market as defined here, including a characterization of market trends and quantities of equipment imported and produced locally. Additionally, a database of models found on the local market offers additional information on product brands, model numbers, product characteristics, energy consumption, and retail price.

3.1 Main Actors

An important element of developing a MEPS program is to identify relevant stakeholders to guide our data collection and form stakeholder committees to provide feedback while developing the program. The following table builds on previous research from the team and other collaborators (Marambe et al., 2021) (de la Rue du Can, et al. 2017)

Table 1 Main actors and stakeholders for energy-efficiency standard and labelling program in Uganda

Main Actors	***Description/Role***	***EE Activity***
Ministry of Energy and Mineral Development	MEMD is mandated by the government of Uganda with the development of strategies and policies that safeguard and promote sustainable use, exploitation, and utilization of energy and mineral resources in Uganda for the country's social and economic development. MEMD is also responsible for formulating energy policy and oversees the electric power subsector's operations.	The Energy Efficiency and Conservation Department began operating in the financial year 2014/2015. Key functions are to develop strategies and programs to improve energy efficiency and conservation.
Electricity Regulatory Authority (ERA)	ERA is the regulator of the electricity sector, including the generation, transmission, distribution, sale, export, and import of electricity in Uganda.	Promoting energy efficiency and Demand-Side Management are part of ERA's 9 Strategic Objectives for 2014 to 2023 (ERA, STRATEGIC PLAN 2014/15 – 2023/24). ERA has also developed a Demand-Side Management Plan.
Uganda National Bureau of Standards (UNBS)	UNBS is a statutory body under the Ministry of Trade, Industry, and Co-operatives, established under the UNBS Act Cap 327 in 1989. The institution is	UNBS issued five MEPS in 2012 for lighting, refrigerators, freezers, motors, and air conditioners. No regulation exists to enforce these

	mandated with the formulation, promotion and enforcement of standards in Uganda for the protection of public and safeguard of the environment against harmful products.	MEPS, so they have not been made mandatory.
Uganda Revenue Authority (URA)	URA is mandated with the facilitation of imports and exports in the country, among other duties, and controls all the regulated products into the country.	Used appliances are banned from entering Uganda.
Uganda National Association of Refrigeration and Air conditioning (UNARA)	Association of professionals in the field of refrigeration and air conditioning.	Major stakeholder supplying refrigerators to Uganda consumers.
UMEME	UMEME Co. Ltd. is the largest power distributor in Uganda, distributing 97% of electricity in the country. In 2012, UMEME became a listed company on the Uganda Securities Exchange.	In 2012, UMEME launched an energy-efficiency campaign called “Save Power, Save Money” to educate its customers about responsible energy usage.
Gayaza Electronics Works	Local manufacturer-assembler (approximately 1,400 units per year).	Not at the moment.

3.2 Historical Trade Flows

Trade flows are analyzed using the United Nations COMTRADE database (UNCOMTRADE, 2021) to estimate the trade value of different refrigerating products imported to Uganda. Imports data were provided by the Uganda Bureau of Standards (UBOS) to complement the UNCOMTRADE database in year 2019 and 2020.

A combination of different codes from the harmonized system to cover the relevant classes included within the scope of regulation:

- **Refrigerators**: 841821 - Refrigerators; for household use, compression-type, electric or other
- **Refrigerator-freezers**: 841810 - Refrigerators and freezers; combined refrigerator-freezers, fitted with separate external doors, electric or other
- **Other Refrigerators**: 841829 - others
- **Freezers**: 841830 – Freezers, of the chest type, not exceeding 800l capacity and
- **Freezers** 841840 – Freezers, of the upright type, not exceeding 900l capacity

Figure 1 shows the annual imports into Uganda by trade value ($) for refrigeration products between 2010 and 2020. Imports are growing rapidly, especially since 2017, at a rate of 13% per year.

Figure 1 Imports of domestic refrigerators and freezers by trade value (US$)

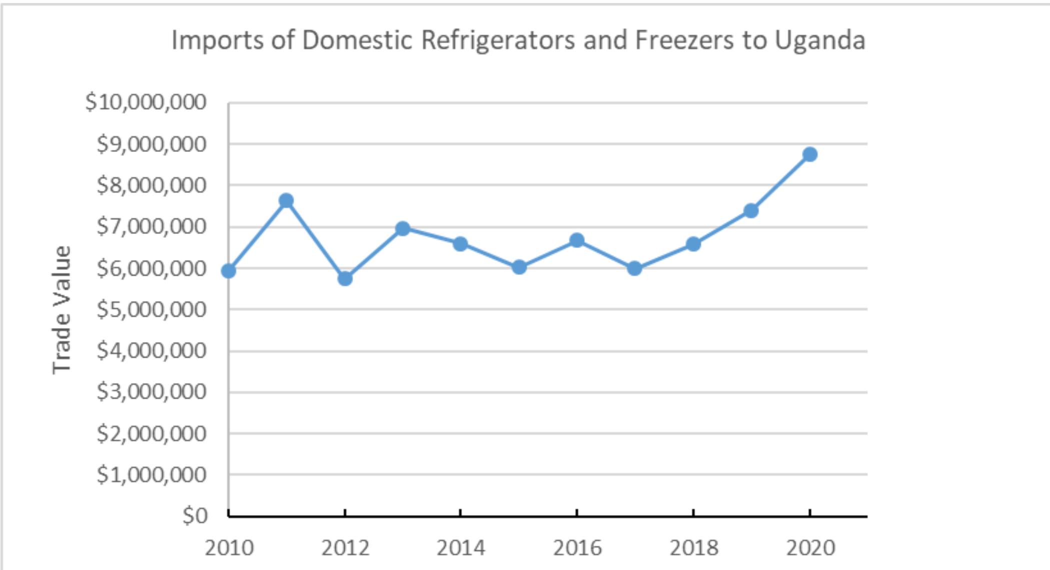
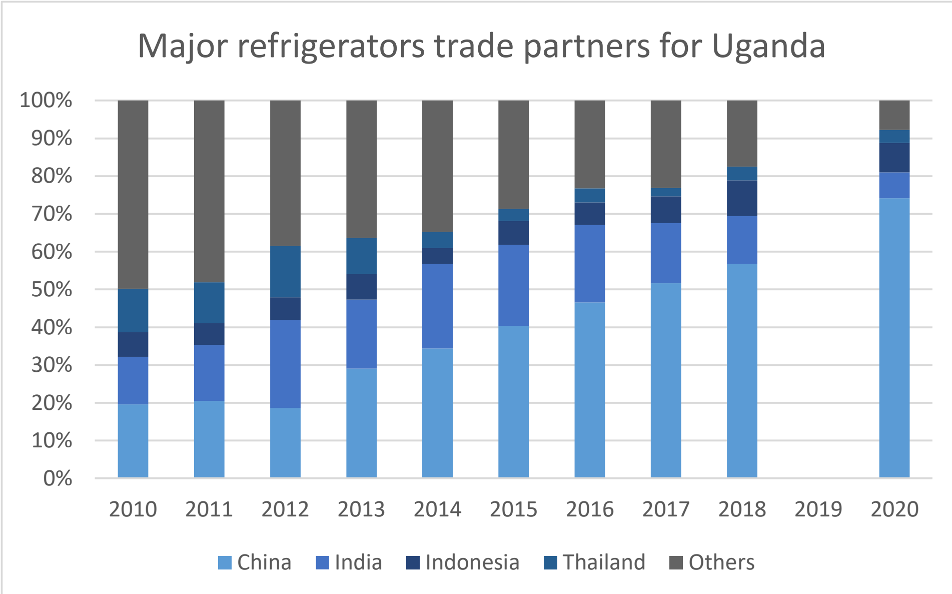


Figure 2 shows the countries of origin for refrigeration products imported by Uganda between 2010 and 2020, including refrigerators, refrigerator–freezers, and freezers. Over the years, China has become, by far, the main trading partner for Uganda representing more than 70% of imports in 2020. The other major trading partners include India, Indonesia, and Thailand.

Figure 2 Trade partners for imported refrigeration products between 2010 and 2020 (COMTRADE database)



*2019 import data are missing in the COMTRADE database

UBOS reports that 123,000 refrigeration products entered Uganda in 2019 and 135,000 in 2020.

3.3 Current Stock Estimates

Refrigerators and freezers are found in households and in small commercial applications in Uganda. In the residential sector, ownership of refrigerators is reported by the latest MEMD National Electrification Survey 2018 (MEMD, 2020). The survey found that 24.6% of grid users own refrigerators. Considering the electrification rate in that year (24%), the average ownership of refrigerators in estimated at 6%. Another survey (UBOS, 2018) reports ownership at 4.9% in 2016/2017 and 2.3% in 2012/2013. These data are used to calculate sales to the residential sector for Section 6 of this report.

The total number of commercial refrigeration products used in Uganda is not known. Section 6 estimates model sales of refrigerators and freezers.

3.4 Refrigerators Models Database

Refrigeration appliances and equipment are manufactured with a wide range of energy performance. Extensive field and desk research was conducted to compile market data on popular refrigerators being sold in Uganda, including searches on retail websites and online catalogues from local shops and surveys as well as visits to small shops in Kampala. Data were collected on different aspects of the product market including manufactures, retailers, and product class (refrigerators, refrigerator-freezers, freezers). Out of the 25 popular manufacturers listed in Table 2, eight manufacturers were unique to the data gathered from the small shops and not available online.

For each product model available, parameters such as product class, type, model number, energy use or unit energy consumption (UEC) (kWh/year), total capacity and compartment size, cost and manufacturer and efficiency rating (i.e., energy use) when available. Data from 120 models were collected from the sources described in Table 2:

Table 2 Sources used to build models database

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	Indesit	Whirlpool	Beko
(Supermarket)	Solstar	Sayona	Hitachi
	Icecool	Smartec	Bosch
	Sharp	Beko	Venus
	Daewoo		

Because there is no mandatory regulation in place for refrigeration products in Uganda, energy consumption of the product was often missing in the data collected. For this reason, the certification database from neighboring country Kenya was used (Energy & Petroleum Regulatory Authority, 2020), which has a S&L program in place and shares common models with the Uganda market. The following section on energy use explains in detail how the data were adjusted and used to characterize the efficiency of refrigeration products sold in the Ugandan market.

3.5 Product Class Market Shares and Capacity

These sources were used to estimate the product classes market shares:

- Uganda National Association of Refrigeration and Air Conditioning (UNARA) (submitted to Berkeley Lab)
- UBOS imports data (submitted to Berkeley Lab)
- ENERGY4IMPACT small business survey (ENERGY4IMPACT, 2017)
- MEMD report on electrical appliance efficiency levels on the Ugandan market (GIZ, 2014)

The following market shares were estimated:

Table 3 Estimated refrigeration product classes and their share in Ugandan market

	Estimated Market Shares by Various Sources				
Product class	**UNARA**	**UBOS**	**small business survey ENERGY4IMPACT**	**GIZ**	**Berkeley Lab assumption**
Refrigerators (1-door)	80%	56%	37%	31.0%	33%
Refrigerator-freezers (2-doors)	15%	3%	40%	32.8%	33%
Freezers	5%	46%	23%	36.2%	33%

In addition, UNARA estimates the following typical volumes by product class:

Table 4 Estimated typical volume by product class

Product class	**Capacity of typical models (L)**
Refrigerators (1-door)	100-150
Refrigerator-freezers (2-doors)	200
Freezers	100-500

UNARA data are in line with averages derived from the models database; these estimates are used in the remainder of the analysis.

4. Energy Use Analysis

The energy use analysis, which assesses potential energy savings from increasing refrigerator efficiency, forms the basis for the energy-savings values used in the LCC and subsequent analyses. The goal of the energy use analysis is to generate a range of energy use values reflecting actual equipment used in the field.

4.1 Energy Use Calculation

UEC was collected as part of the model database described above. Data were available for 42 models of refrigerators-freezers, and only 5 and 4 models of refrigerators and freezers, respectively. Out of these data points, UEC was collected for 16 models from the Kenya Standard and Labelling database.

In general, the declared UECs are based on energy consumption values obtained from test standards that are defined by specific test methods. In the case of the data from the Kenya database, collected values were adjusted to reflect a difference in test methods in the MRG.

While the standard for measuring refrigerator energy consumption is broadly similar across countries, a number of factors can result in variations in energy consumption values across countries. In particular, specifications for ambient temperature can result in differences in internal compartment temperature as well as additional features in the test procedure.

While Kenya's test procedure for energy efficiency S&L for refrigerating appliances is based on the same test methods as the model regulation guidelines (IEC 62552: 2015), it uses a different energy calculation (or metric)[3]. It is necessary to take into consideration the difference between Kenya's comparative energy consumption (CEC) which appears in the label and the energy use calculation in the MRG. For energy consumption data reported in the S&L Kenya database, an adjustment factor was applied to reflect the energy consumption defined in the Model Regulation Guidelines based on appliance performance data. The assumptions used in this analysis to convert the CECs from the Kenya S&L database to the energy consumption under the U4E MRG are presented below. They should be regarded as indicative, and not as exact, conversion factors.

[3] IEC 62552: 2015 defines two methods for calculating daily energy consumption, one for MEPS (E_{daily}_MEPS) and the other for labels (E_{daily}_Label). While the E_{daily}_MEPS is based on 32°C, the projected annual energy consumption (PAEC) is calculated for 28°C based on E_{daily}_Label (measured at 16°C and 32°C), adjusted defrost energy consumption, and load processing energy consumption. PAEC tends to be greater than E_{daily}_MEPS.

Table 5 Assumptions used for normalization to U4E MRG

Product Category	Kenya CEC	Energy Consumption in the U4E MRG (for reference ambient temperature 24°C)
Refrigerators	100%	58%
Refrigerator-freezers	100%	61%
Freezers	100%	78%

These factors were applied to the 16 models for which UEC was collected from the Kenya database in an effort to normalize the UEC collected to the U4E MRG.

In order to compare the energy use data points to the model regulation, formulas in the table below were applied, as defined in (U4E, 2019):

Table 6 Maximum annual energy consumption (UECMax) as defined by the model regulations

Reference Ambient Temperature	Product Category	UECMax (kWh/year)
24°C	**Refrigerators**	0.163×AV+102
	Refrigerator-freezers	0.222×AV+161
	Freezers	0.206×AV+190

Where AV is the adjusted volume, defined as:

$$AV = ff + K * fr * 1.1$$

Where:

ff = volume of the fresh food compartment (if any)

fr = volume of the freezer compartment (if any)

K = volume adjustment factor for the freezer compartment (if any), as calculated per the equation below:

$$K = \frac{\mathrm{T1} - \mathrm{Tc}}{\mathrm{T1} - \mathrm{T2}}$$

T1 is reference ambient temperature selected by the country (24°C), T2 is temperature of fresh food compartment (4°C), and Tc is temperature of the individual compartment concerned.

The result of the energy use analysis is presented in the figure below:

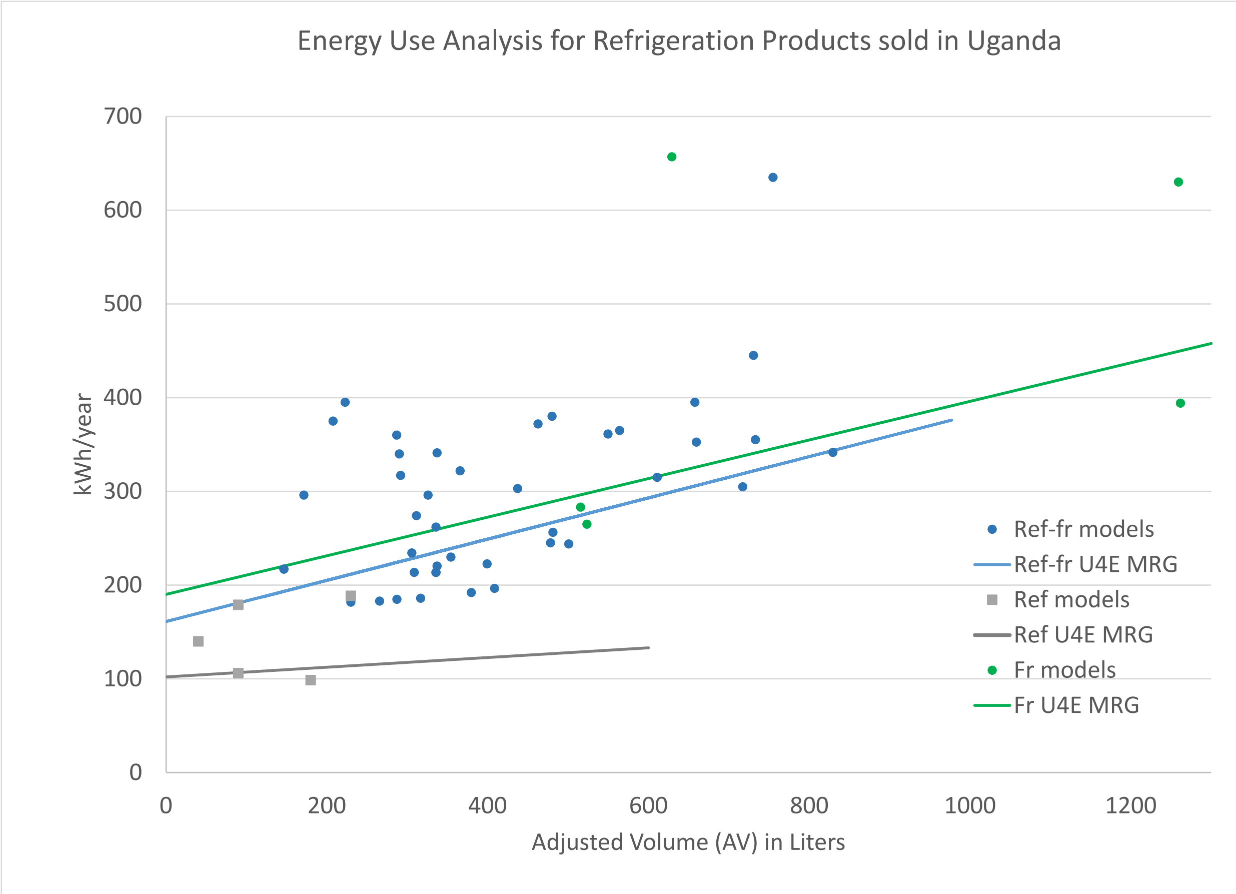


Figure 3 Annual energy use of models found on the Uganda market and U4E model regulation guidelines

Note: Ref-Fr = Refrigerator-freezers; Ref = Refrigerators; Fr = Freezers

This comparison of estimated energy consumption and MRG levels showed that a significant number of models do not meet the standards set in the MRG (i.e, 60% of refrigerators, 60% of refrigerator-freezer, 40% of freezers have energy consumption above the maximum allowed by the MRG). Similar results were found in Kenya and Rwanda. According to the test data provided by the UNEP U4E initiative on 25 refrigerating appliance models available in Kenya and Rwanda, the energy efficiency of 10 models is 2%-19% less than MRG minimum efficiency requirements (24C degrees ambient temperature). Fifteen models meet the efficiency requirements.

4.2 Baseline Definition

Given the general lack of energy consumption data, it is difficult to derive an efficiency distribution for a baseline. This analysis assumes that, on average, all models meet a minimum efficiency level. In the case of refrigerator-freezers, with 42 energy consumption data points, an average efficiency of the models representing the least efficient models on the market, represented by the bottom 20% of the market was calculated. The analysis showed that the efficiency of these models was roughly equivalent to the China 2015 MEPS (GB 12021.2-2015). There are two compensating errors in the dataset: on the one hand, it is expected that products that do not declare test energy consumption are on the low efficiency side (and even below the Chinese MEPS). On the other hand, products entering the market with a declared energy consumption (and a label) may have a higher efficiency since they come from a regulated market. Without any test data certified by a standard program in Uganda, it is impossible to know the baseline with certainty. Since 80% of sales come from China, it was 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.

This analysis defines an efficiency index of 1 for the model regulation. An index below 1 means that the product doesn't pass the model regulation, while an efficiency above 1 means that the product passes the model regulation. Using the average size of each refrigeration product class from UNARA, average baseline efficiency and energy consumption is calculated as follows:

Table 7 Baseline efficiency and corresponding UEC

	Refrigerators	**Refrigerator-Freezers**	**Freezers**
Average size (L)	125	200	300
Efficiency (Index)	0.57	0.65	0.52
UEC* (kWh/year)	217	334	677

*UECs are calculated using the China MEPS parameters

4.3 Average UEC at Various ELs

Tables 8 through 10 show the resulting UEC values for the ELs considered. EL0 is the baseline and EL1 through EL4 represent different policy cases (see Section 2.3 for a description).

Table 8 Annual UEC at the EL considered for refrigerators (125-L)

	EL0	**EL1**	**EL2 (MRG)**	**EL3**	**EL4**
Efficiency (Index)	0.57	0.75	1.00	1.25	1.5
UEC (kWh/year)	217	166	124	100	83

Table 9 Annual UEC at the EL considered for refrigerator-freezers (200-L)

	EL0	**EL1**	**EL2 (MRG)**	**EL3**	**EL4**
Efficiency (Index)	0.65	0.75	1.00	1.25	1.5
UEC (kWh/year)	334	289	217	174	145

Table 10 Annual UEC at the EL considered for freezers (300-L)

	EL0	EL1	EL2 (MRG)	EL3	EL4
Efficiency (Index)	0.56	0.75	1.00	1.25	1.5
UEC (kWh/year)	677	469	352	281	235

Note that the energy consumption of freezers is large, equivalent to the consumption of three refrigerators, and two refrigerator-freezers.

5. Consumer Impact Analysis

Implementation of efficient technologies generally results in added production costs, which are passed down to the consumer in the form of higher retail prices. The LCC calculation analyzes the trade-off between these increased first costs, and subsequent savings, in the form of lowered utility bills. The LCC analysis takes into account the preference for immediate (versus deferred) gains by scaling future energy cost savings by an appropriate discount factor.

The calculation is implemented in the Policy Analysis Modeling System (PAMS) model[4], an easy-to-use software tool that assesses the costs and benefits of S&L programs and identifies the most attractive targets for appliance efficiency levels.

5.1 Methodology

LCC is the sum of the purchase price and the electricity bills over the lifetime of the appliance. It is given by

$$LCC = EC + \sum_{n=1}^{L} \frac{OC}{(1+DR)^n}$$

Where:

EC = equipment cost (retail price),

n = the year of operation,

OC = the annual operating cost,

L = lifetime of the appliance in years

Operating cost is summed over each year of the lifetime of the appliance L.

Operating cost is calculated by multiplying the UEC, in kWh, by the price of energy (*P*, in dollars per kWh) as follows:

$$OC = UEC \times P$$

[4] More information is available at: https://ee4d.org/wp-content/uploads/sites/40/2021/08/Policy-Analysis-Modeling-System-PAMS.pdf

UEC and energy price are assumed constant from year to year. The fact that future costs are less important to consumers than near-term costs is taken into account by dividing future operating costs by a *discount factor* $(1+DR)^n$, where *DR* is the discount rate.

The payback period (PBP) refers to the time it takes a consumer to recover the assumed higher purchase cost of more energy-efficient products through lower operating costs. Numerically, the PBP is the ratio of the increase in purchase cost (from a less to a more efficient design) to the decrease in annual average operating cost. This calculation does not use a discount rate to discount future operating costs.

The equation for determining PBP is:

$$PBP = \frac{\Delta EC}{\Delta OC}$$

5.2 Purchase Price Analysis

The average price of the baseline units vs more efficient units (also called the cost vs efficiency curve) is a critical input to the cost-benefit analysis. An engineering-based cost curve was used to determine the final price to the Ugandan consumer. Combinations of components and their costs to make more efficient units was considered. Cost estimates were based on research by Park, et al. (2019), which analyzed design options from an inefficient baseline (roughly equivalent to the baseline in Uganda) to super-efficient technologies. The cost curve is presented in the following graph:

Figure 4 Price vs efficiency from Park, et al. (2019)

The Uganda models database was then used to calibrate the curve to reflect local baseline efficiency and consumer price. The results for the three product classes are presented below:

Table 11 Purchase price at the ELs considered for one-door refrigerator

	EL0	EL1	EL2 (MRG)	EL3	EL4
Average efficiency (Index)	0.57	0.75	1.00	1.25	1.5
Price (US$)	$174	$202	$249	$301	$340

Table 12 Purchase price at the ELs considered for two-door refrigerator-freezers

	EL0	EL1	EL2 (MRG)	EL3	EL4
Average efficiency (Index)	0.65	0.75	1.00	1.25	1.5
Price (US$)	$371	$403	$497	$600	$679

Table 13 Purchase price at the ELs considered for freezers

	EL0	EL1	EL2 (MRG)	EL3	EL4
Average efficiency (Index)	0.52	0.75	1.00	1.25	1.5
Price (US$)	$ 421	$512	$ 631	$763	$866

5.3 Other Inputs Data

The following table summarizes input data used to calculate LCC.

Table 14 Summary of inputs into the LCC analysis

Input	Description	Average Value	Source
UEC	Representative unit's average annual energy consumption for different ELs	Tables 8-10	Energy use analysis

Equipment Cost	Representative unit's average purchase price for different ELs	Tables 11-13	Equipment price analysis
Lifetime (L)	Average lifetime	15 years	Authors' estimate/ stakeholder feedback
Consumer Discount Rate (DR)	Real interest rate	14.6%	(World Bank, 2021)
Electricity Price	Representative electricity cost for consumers	Residential: 750 Ush/kWh Commercial: 640 Ush/kWh (weighted average = $0.20/kWh)	(UMEME, 2020)

5.4 Results

The table below presents the results of the LCC and PBP for the base case (no policy) and for the scenario adopting the model regulation for each product type (i.e., refrigerators, refrigerator-freezers and freezers), as provided by PAMS:

Table 15 Summary of results of consumer impacts for refrigerators for a MEPS at EL2 (MRG)

Unit Level Results for Refrigerators		
	Base Case	Standard Case
Purchase price	**$174**	**$249**
UEC in kWh/year	**217**	**124**
Annual electric bill	**$43**	**$25**
LCC	**$430**	**$395**
Efficiency improvement		**43%**
Payback time (years)		**4.06**
Lifetime (years)		**15**
LCC savings		**$35**

Table 16 Summary of results of consumer impacts for refrigerator-freezers for a MEPS at EL2 (MRG)

Unit Level Results for Refrigerator-freezers		
	Base Case	Standard Case
Purchase price	**$371**	**$497**
UEC in kWh/year	**334**	**217**
Annual electric bill	**$66**	**$43**
LCC	**$764**	**$752**
Efficiency improvement		**35%**
Payback time (years)		**5.44**
Lifetime (years)		**15**
LCC savings		**$12**

Table 17 Summary of results of consumer impacts for freezers for a MEPS at EL2 (MRG)

Unit Level Results for Freezers		
	Base Case	Standard Case
Purchase price	**$421**	**$631**
UEC in kWh/year	**677**	**352**
Annual electric bill	**$134**	**$69**
LCC	**$1,219**	**$1,046**
Efficiency improvement		**48%**
Payback time (years)		**3.27**
Lifetime (years)		**15**
LCC savings		**$173**

In addition, Tables 18-20 show the results for every efficiency level EL analyzed.

Table 18 Summary of results of LCC analysis under all scenarios for refrigerators

Efficiency Level	Efficiency (%)	Average Purchase Price (US$)	UEC (kWh/yr)	Average Annual Electricity Bill (US$)	Average LCC (US$)	LCC Savings (US$)	Payback Period (years)
EL0	0.57	$174	217	$43	$430		
EL1	0.75	$202	166	$33	$397	$33	2.7
EL2 (MRG)	1.00	$249	124	$25	$395	$35	4.1
EL3	1.25	$301	100	$20	$418	$12	5.4
EL4	1.50	$340	83	$16	$438	$(7)	6.2

Table 19 Summary of results of LCC analysis under all scenarios for refrigerator-freezers

Efficiency Level	Efficiency (%)	Average Purchase Price (US$)	UEC (kWh/yr)	Average Annual Electricity Bill (US$)	Average LCC (US$)	LCC Savings (US$)	Payback Period (years)
EL0	0.65	$371	334	$66	$764		
EL1	0.75	$403	289	$57	$743	$21	3.6
EL2 (MRG)	1.00	$497	217	$43	$752	$12	5.4
EL3	1.25	$600	174	$34	$805	$(41)	7.2
EL4	1.50	$679	145	$29	$849	$(85)	8.2

Table 20 Summary of results of LCC analysis under all scenarios for freezers

Efficiency Level	Efficiency (%)	Average Purchase Price (US$)	UEC (kWh/yr)	Average Annual Electricity Bill (US$)	Average LCC (US$)	LCC Savings (US$)	Payback Period (years)
EL0	0.52	$421	677	$134	$1,219		
EL1	0.75	$512	469	$93	$1,065	$154	2.2
EL2 (MRG)	1.00	$631	352	$69	$1,046	$173	3.3

EL3	1.25	$763	281	$56	$1,095	$124	4.4
EL4	1.50	$866	235	$46	$1,142	$77	5.1

For the refrigerators category, the policy case LCC are lower than the base LCC of $430 in every scenario but EL4. This means that all efficiency levels are found to be cost effective for the consumers, with the exception of EL4 (LCC=$438). The largest benefits are found at EL1 and EL2 (MRG), with respective savings of $33 and $35 over the lifetime of the refrigerator (discounted at 14.6%).

In the refrigerator-freezers category, the policy case LCC are lower than the base LCC of $764 in every scenario but EL3 and EL4. In other words, all efficiency levels are found to be cost effective for the consumers, with the exception of EL3 and EL4 (respectively LCC=$805 and LCC=$849). The largest benefits are found at EL1 and EL2 (MRG), with respective savings of $21 and $12 over the lifetime of the refrigerator-freezer (discounted at 14.6%).

For the freezers category, the policy case LCC are lower than the base LCC of $1219 in every scenario. Hence, all efficiency levels are found to be cost effective for the consumers. The largest benefits are found at EL1 and EL2 (MRG), with respective savings of $154 and $173 over the lifetime of the refrigerator (discounted at 14.6%). This is the product category that shows the largest benefits to consumers, due to the large energy consumption of the appliance.

Sensitivity Analysis Scenario:

According to the Rocky Mountain Institute (RMI, 2018), in Uganda “the mismatch between supply and demand could increase total electricity costs by over $950 million per year and increase the cost of service to more than $0.30/kWh”. This increase in tariffs would have a significant impact on the cost-benefit analysis. A sensitivity analysis explored the future cost of electricity to quantify the impacts of a high electricity price. The results are presented in the tables below:

Table 21 Summary of results of LCC analysis under high electricity price scenario for refrigerators

Efficiency Level	Efficiency (%)	Average Purchase Price (US$)	UEC (kWh/yr)	Average Annual Electricity Bill (US$)	Average LCC (US$)	LCC Savings (US$)	Payback Period (years)
EL0	0.57	$174	217	$65	$563		
EL1	0.75	$202	166	$50	$499	$65	1.8
EL2 (MRG)	1.00	$249	124	$37	$471	$92	2.7
EL3	1.25	$301	100	$30	$479	$84	3.6
EL4	1.50	$340	83	$25	$489	$75	4.1

Table 22 Summary of results of LCC analysis under high electricity price scenario for refrigerator-freezers

Efficiency Level	Efficiency (%)	Average Purchase Price (US$)	UEC (kWh/yr)	Average Annual Electricity Bill (US$)	Average LCC (US$)	LCC Savings (US$)	Payback Period (years)
EL0	0.65	$371	334	$100	$968		
EL1	0.75	$403	289	$87	$920	$48	2.4
EL2 (MRG)	1.00	$497	217	$65	$885	$83	3.6
EL3	1.25	$600	174	$52	$911	$57	4.8
EL4	1.50	$679	145	$43	$937	$31	5.4

Table 23 Summary of results of LCC analysis under high electricity price for freezers

Efficiency Level	Efficiency (%)	Average Purchase Price (US$)	UEC (kWh/yr)	Average Annual Electricity Bill (US$)	Average LCC (US$)	LCC Savings (US$)	Payback Period (years)
EL0	0.52	$421	677	$203	$1,633		
EL1	0.75	$512	469	$141	$1,351	$281	1.5
EL2 (MRG)	1.00	$631	352	$106	$1,261	$372	2.2
EL3	1.25	$763	281	$84	$1,267	$366	2.9
EL4	1.50	$866	235	$70	$1,285	$347	3.3

In this case, benefits are generally greater for consumers, with an average of $182 LCC savings (vs $76 in the reference case scenario)

6. National Impact Analysis

Policymakers not only consider financial impacts on individual users, but also the magnitude of efficiency impacts on the nation as a whole. This is where the sales and stock of refrigerators are taken into account. Here, national impact was calculated using PAMS.

6.1 Methodology

There are two main calculations for the impact of a minimum efficiency standard at the national level: national energy savings (NES) and net present value (NPV). NES is the total electricity saved in the policy scenario versus the business as usual (BAU) scenario over the 2023-2040 forecast period. NPV is the discounted net benefit of financial savings to the entire market of consumers.

In some sense, national impacts are a scaling up of unit-level impacts to cover the whole market. National impacts also introduce an important time component to the evaluation of program impacts. MEPS generally affect new products sold on the market only but do not affect products already installed before the MEPS implementation date. Therefore, in the first year after standards are implemented, savings are usually small because the standard only affects products purchased in that year. As time goes on, more and more of the stock is made up of products purchased after standards took effect and that reflect the MEPS efficiency level. The national impacts calculations describe the evolution of the stock and give a profile of costs and benefits over time.

6.2 National Stock and Sales Forecast

The number of refrigerators in use in Uganda were calculated, referred to as the “stock” in the rest of the document, with the diffusion (or average ownership, see Section 3.3) rates of the appliance in households:

$$\text{Stock (y)} = \text{Diffusion (y)} \times \text{HH (y)}$$

Where:

Diffusion (y) = Number of units per household in year y

HH (y) = Number of households in year y.

In order to project diffusion rates (to project the stock), a macroeconomic model developed by Berkeley Lab (McNeil and Letschert, 2010) is used in the PAMS model for refrigerators:

$$Diff = \frac{\alpha}{1 + \gamma \times e^{(\beta_1 \times Inc + \beta_2 \times E + \beta_3 \times U)}}$$

Where:

Inc (y) = household income (GDP per household) in year (y)

U (y) = urbanization rate in year (y)

E (y) = electrification rate in year (y)

With α, β1 β2, β3 and γ respectively equal to 1.40,-1E-05, -3.59, -2.240, and 126.

The results of the macroeconomic model are presented in the following graph:

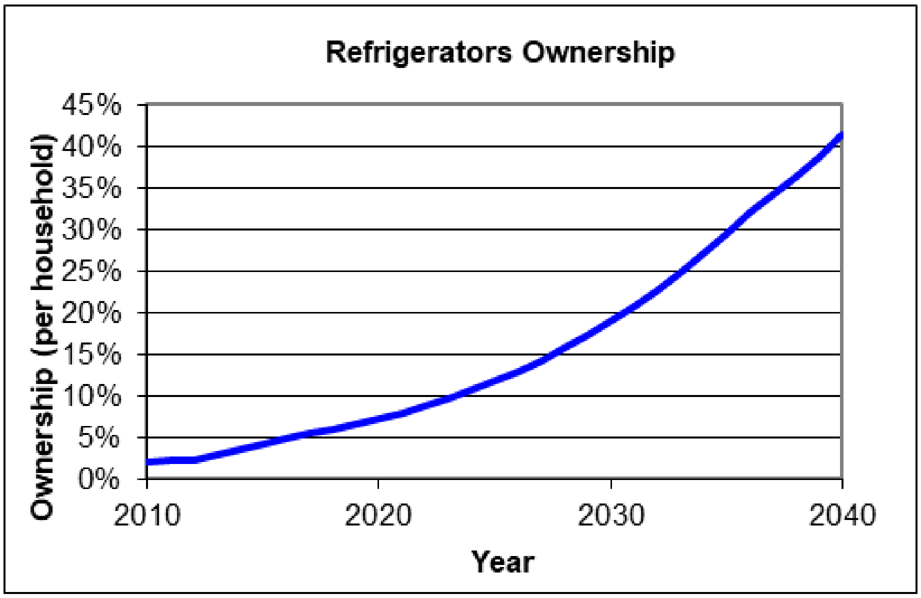


Figure 5 Household refrigerators penetration rate (2010-2040)

The macroeconomic model predicts that the diffusion of refrigerator is 4% in 2018, compared to 6% found in the electrification survey of that year. The model is calibrated to match field data.

Sales in every year of the forecast period are then calculated as the sum of increase in stock of refrigerators and the replacement of retired refrigerators:

$$Sales\ (y) = FP(y)+Rep(y)$$

Where:

FP(y) = first purchase in year y

Rep(y) = replacement in year y

The diffusion model described above is used to calculate first purchases, FP as the difference in stock in every year:

$$FP(y) = Stock(y)-Stock(y-1)$$

Where:

Stock(y) = number of units in operation in the country in year y

Stock(y-1) = number of units in operation in the country in year y-1

In addition to first purchases, the replacement of refrigerators is calculated as an annual retirement probability that varies as a function of refrigerator age, given by:

$$P_{R(age)} = \frac{1}{1 + e^{(age-L)/D_{age}}}$$

Where:

$P_{R(age)}$ = probability of retirement at a given product age.

L = average lifetime of the product.

D_{age} = mean deviation of replacement ages, assumed to be 2 years.

Finally, replacements in each year are given by the relationship:

$$Rep(y) = \sum_{age=1}^{2L} Stock(y-1, age) \times P_{R(age)}$$

The sales calculated for the household sector are then compared to the statistics from UBOS as described in the market assessment (Section 3). The difference in units imported and estimates from the stock turnover is allocated to (1) freezer category and (2) units going to small businesses. The result section explains this calibration in more detail.

6.3 National Energy Savings and Emission Reductions Calculation

NES is defined as the difference in energy consumption between the BAU scenario and the policy scenario. In the BAU scenario, all products are assumed to be operating at the baseline efficiency. In the policy scenario, products purchased after the standards program implementation date (a user-adjustable parameter) are assumed to operate at the efficiency determined by a specific design option combination chosen by the model user.

PAMS calculates NES in each year by comparing the national energy consumption of the product under study in the BAU scenario and the policy scenario, according to:

$NES = NEC_{BAU} - NEC_{Policy}$

In turn, the national energy consumption (NEC) of the national stock of products in year y is given by:

$$NEC_{BAU} = \sum_{age} \text{Stock (y)} \times UEC_{BAU}(y - age)$$

Where the UEC is determined according to the year of purchase (y-age). The UEC differs between the BAU and policy scenario for years after the MEPS implementation date because of the improvement in efficiency resulting from the standards, according to the following relationship:

$UEC = UEC_{BAU} \times Efficiency_{BAU}/Efficiency_{Policy}$

Finally, CO_2 emissions savings (CES) are calculated from energy savings by applying carbon factors to site energy savings according to:

$$CES = \frac{NES}{1 - TD} \times CaF$$

Where:

TD = the fraction of energy lost in electricity transmission and distribution.

CaF = the carbon factor derived from the fraction of fossil-fuel generation.

6.4 Net Present Value Calculation

The NPV of a policy measures the policy's net financial benefit to the nation as a whole. As in the case of NES, the NPV calculation is somewhat parallel to the unit LCC calculation. National financial impacts in year (y) are the sum of equipment (first) costs and user operating costs. National equipment cost (NEqC) is equal to the retail price times the total number of sales:

$$NEqC = EC \times S(y)$$

Where:

EC = equipment cost (retail price).

S(y) = sales in a given year.

Likewise, national operating cost (NOC) is simply the total (site) energy consumption times the energy price:

$$NOC = NEC(y) \times P$$

The net savings in each year arise from the difference in first and operating costs in the MEPS scenarios versus the BAU scenario of NEqC and NOC. The NPV of the policy option is then defined as the sum over the 2023-2040 forecast period of the net national savings in each year, multiplied by the appropriate national policy discount rate:

$$NPV = \sum_{y} (\Delta NOC(y) + \Delta NEC(y)) * (1 + DR_N)^{-(y-y_0)}$$

Where:

DR_N = national policy discount rate

y_0 = current year (2021), which differs from the policy implementation year (2023).

6.5 Input Data Summary

The following table summarizes the inputs used in the national impact analysis.

Table 24 Summary of inputs for national impact analysis

Input	Description	Value	Source
Macroeconomic variables	Income, electrification, urbanization	Times series (see annex)	(World Bank, 2021) (National Planning Authority, Uganda vision 2040
Demographic Data	Population, household size	Times series (see annex)	(World Bank, 2021)
UEC at different ELs	UECs calculated in accordance with the Model Regulation Guidelines method	Tables 8-10	Energy use analysis

Costs at different ELs	Retail price estimates	Tables 11-13	Regression analysis
National policy discount rate (DR_N)	Based on the social discount rate applied to government projects	6.5%	(centralbanking.com, 2021)
CO_2 emission factor	Electricity-specific emission factors	0.454 kg CO_2/kWh	(de la Rue du Can, et al., 2017)
Transmission and distribution factor	Includes losses in transmission and distribution	17.1%	(Electricity Regulatory Authority, 2021)

6.6 Results

Figure 6 shows the calculated sales calibrated to the UBOS data. Those sales represent all the refrigeration products entering the Ugandan market, including refrigerators, refrigerator-freezers, and freezers going to the household sector and small businesses.

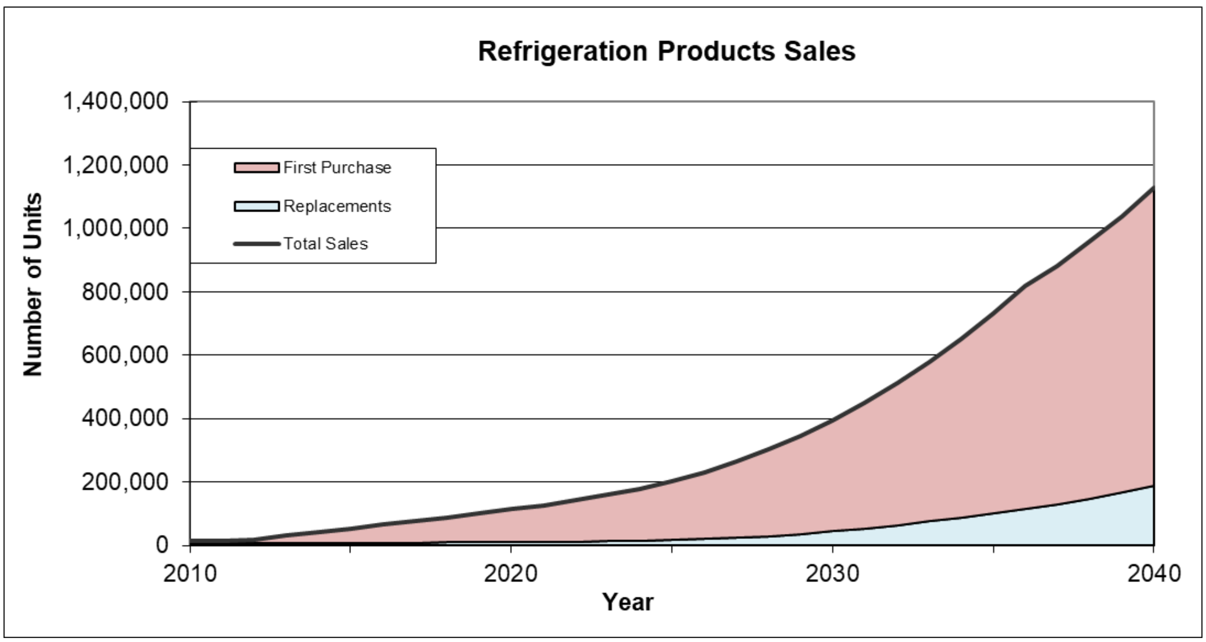


Figure 6 Household and small businesses refrigeration products sales estimates (2010-2040)

The following graph shows the total sales along with the estimated market shares by sector:

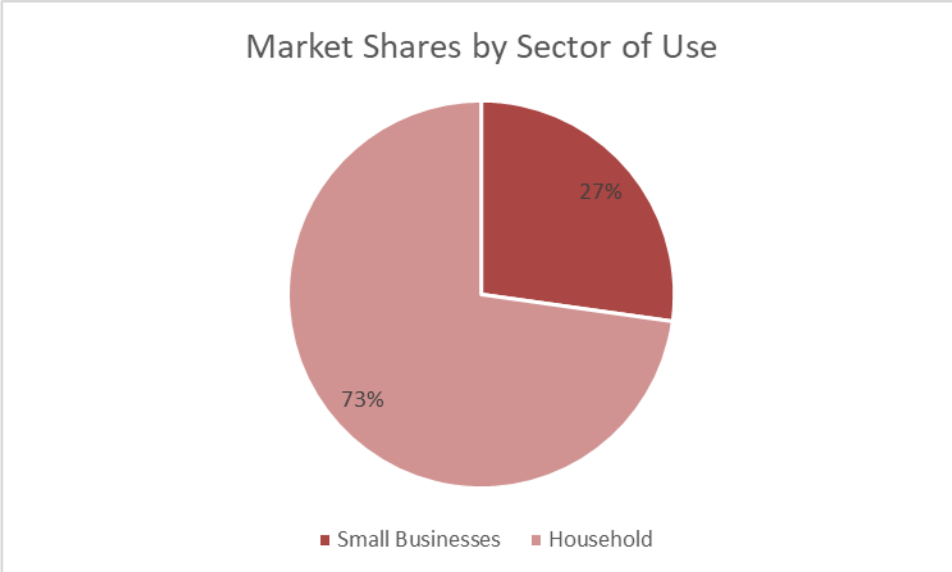


Figure 7 Household and small businesses market share estimates (2010-2040)

In addition, it is assumed that small businesses have more freezers than households (2/3 of freezers vs 1/3 refrigerators and refrigerators-freezers). The following table summarizes the calculated market shares that will be applied to the savings for each product class when presenting the results in Table 26 to Table 28):

Table 25 Summary of market shares allocation by product class and sector

Market shares	*Refrigerators*	*Refrigerator-freezers*	*Freezers*	*Total*
Households	29%	29%	15%	73%
Small Businesses	5%	5%	18%	27%
Overall	**33%**	**33%**	**33%**	**100%**

As Ugandan households and small businesses obtain refrigeration products for the first time, most of the sales are first purchase. In 2019, an estimated 123,000 refrigerators, refrigerators-freezers, and freezers were sold in Uganda, in accordance with UBOS data. This allows for a calculated average annual growth rate of 12% between 2021 and 2040. By 2040, the Ugandan market will be an estimated 1.2 million units per year.

Because the highest consumer benefits are found, on average, under the MRG scenario (EL2), the national reference scenario reflects the adoption of the MRG at a date deemed feasible (2023). The following tables present the national impact results assuming the MRG are adopted in 2023 by Uganda:

Table 26 Summary of national results by product class under Reference Scenario (MRG adopted in 2023)

National Level Results for:	Refrigerators	Refrigerator-freezers	Freezers	Total
Total Electricity Cost Savings through 2040 (millions $US)	208	261	726	1,194
Total Incremental Equipment Cost through 2040 (millions $US)	105	177	296	577
Net Present Benefit (millions $US)	103	84	430	617
Benefit/Cost Ratio	2.0	1.5	2.5	2.1
Net Present Benefit to Households (millions $US)	91	153	198	442
Net Present Benefit to Small Businesses (millions $US)	14	11	232	258
Site Energy Savings in				
2030(GWh)	56	70	196	323
2040(GWh)	242	303	845	1,390
Site Energy Savings through				
2030(TWh)	213	267	745	1,226
2040(TWh)	1,693	2,124	5,918	9,735
CO_2 Emissions Mitigation through				
2030(MT)	0.1	0.1	0.4	0.7
2040(MT)	0.9	1.2	3.2	5.3

*Discounted at 6.5% to year 2021

In addition, to take into account the regional harmonization discussions led by U4E in the EAC region, roadmap scenarios (RMS) are presented that set ambitious targets in 2025, with an intermediate step to give time to market players (in Uganda and the EAC region) to transition their supply chain towards more efficient products. Another argument in favor of the RMS is that the delayed implementation gives time for Uganda to benefit from the economy of scale of energy-efficient refrigerators in the region and globally, as countries are gradually adopting the MRG around the world. Given that 80% of Uganda refrigeration products come from China, which has standards well below the MRG, the authors agree with this approach and discuss the RMS in the remainder of the document.

RMS considered are:

- RMS1: 25% below MRG- in 2025 – (Adoption of EL1 in 2025)
- RMS2: 25% below MRG- in 2023 and MRG in 2025 – (Adoption of EL2 in 2025)
- RMS3: MRG in 2023 and 25% above MRG in 2025 – (Adoption of EL3 in 2025)
- RMS4: 25% above MRG- in 2023 and 50% above MRG in 2025 – (Adoption of EL4 in 2025)

Table 27 Summary of national impact analysis results under all RMS

		RMS1: 25% below MRG in 2025	RMS2: 25% below MRG in 2023 MRG in 2025	RMS3: MRG in 2023 25% above MRG in 2025	RMS4: 25% above MRG in 2023 50% above MRG in 2025
Site Energy Savings in	2030 (GWh)	153	298	389	449
	2040 (GWh)	771	1,365	1,724	1,962
Site Energy Savings through	2030 (TWh)	474	1,054	1,437	1,681
	2040 (TWh)	5,029	9,287	11,912	13,639
CO_2 Emissions Mitigation through	2030 (MT)	0.3	0.6	0.8	0.9
	2040 (MT)	2.8	5.1	6.5	7.5
Total Electricity Cost Savings through 2040*	Million US$	619	1,141	1,462	1,674
Total Incremental Equipment Cost through 2040*		195	546	942	1,254
Net Present Benefit*		424	595	521	420
Net Present Benefit to Households*		243	346	289	217
Net Present Benefit to Small Businesses*		181	249	232	203

*discounted at 6.5%

At the national level, all roadmap scenarios have a positive impact on energy savings, emission reductions, and consumer finances. Out of the RMS, the highest financial benefits are afforded by the adoption of the MRG in 2025, with an intermediate step in 2023, representing $595 Million (US$) of cumulative (2023–2040) savings. In addition, the potential savings for refrigerators translates into 1383 GWh in electricity savings annually by 2040, 9.3 TWh cumulative savings (2023–2040), and 5.1 million tons of avoided CO_2 emissions (cumulative 2023–2040).

Sensitivity Analysis Scenario:

As in the case of the LCC, a sensitivity analysis with a high electricity price of 30 cts/kWh is used, as forecasted by RMI (RMI, 2018). The results are presented below:

Table 28 Summary of financial impact analysis results under high electricity prices (million US$)

	RMS1: 25% below MRG in 2025	RMS2: 25% below MRG in 2023 MRG in 2025	RMS3: MRG in 2023 25% above MRG in 2025	RMS4: 25% above MRG in 2023 50% above MRG in 2025
Total Electricity Cost Savings through 2040*	940	1,733	2,222	2,543
Total Incremental Equipment Cost through 2040*	195	546	942	1,254
Net Present Benefit*	745	1,188	1,280	1,289
Net Present Benefit to Households*	432	712	765	765
Net Present Benefit to Small Businesses*	313	476	515	524

*discounted at 6.5%

In this case, RMS3 provides the highest financial benefits to the consumers.

7. Recommendations

Results of this analysis show that residential consumers and small businesses will benefit the most in scenarios targeting the MRG in 2023. However, in order to allow time to transition supply chains and benefit from global and regional economies of scale, delaying the adoption of the MRG to 2025 is recommended, with an intermediate step in 2023, in line with the regional harmonization recommendations from U4E:

- Step 1: By 2023, a MEPS at 0.75 is adopted.
- Step 2: By 2025, MRG is adopted.

Adoption of the MRG roadmap results in the largest NPV for consumers ($595 million), with a cost/benefit ratio of 1:2 between each amount of money invested by consumers ($546 million) and national benefits in terms of electricity savings ($1,141 million). Overall, the NPV of the program represents $346 million for households and $249 million for small businesses. These will translate in additional purchase power for households and investments for small businesses, leading to increased standards of living and productivity.

In addition, U4E MRG have defined voluntary label thresholds, 25%, and 50% above the MEPS, which correspond respectively to EL3 and EL4 in this analysis. Although not the focus of this analysis, these levels may or may not have a positive financial impact for consumers, on average. However, this would improve energy efficiency in the market. For this reason, design of complementary programs is recommended to accelerate adoption of high-efficiency refrigeration products and to drive down costs. For example, financial incentives and other mechanisms such as bulk procurement programs or “cash-back” rebates could be explored. Ways that the cost-benefit analysis can inform the design of such policies will be explored next.

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9. Annex

Annex I – Variables for macro-economic modeling (2000-2040)

Year	Urbanization	Electrification	Household Income
2040	26.4%	80.0%	$12,264
2039	25.8%	77.5%	$12,086
2038	25.2%	74.9%	$11,909
2037	24.7%	72.4%	$11,732
2036	24.1%	69.8%	$11,555
2035	23.5%	67.3%	$11,379
2034	23.0%	64.7%	$11,204
2033	22.4%	62.2%	$11,030
2032	21.8%	59.6%	$10,856
2031	21.3%	57.1%	$10,684
2030	20.7%	54.5%	$10,512
2029	20.2%	52.0%	$10,342
2028	19.7%	49.5%	$10,173
2027	19.2%	46.9%	$10,006
2026	18.7%	44.4%	$9,840
2025	18.1%	41.8%	$9,675
2024	17.7%	39.3%	$9,511
2023	17.3%	36.7%	$9,350
2022	16.8%	34.2%	$9,189
2021	16.4%	31.6%	$9,031
2020	16.0%	29.1%	$8,874
2019	15.7%	26.5%	$8,707
2018	15.4%	24.0%	$8,668
2017	15.1%	22.8%	$8,629
2016	14.8%	21.7%	$8,590
2015	14.5%	20.5%	$8,551
2014	14.3%	19.4%	$8,512
2013	14.0%	18.2%	$8,473
2012	13.8%	17.0%	$8,434

2011	13.5%	15.9%	$8,395
2010	13.3%	14.7%	$8,356
2009	13.2%	13.5%	$8,317
2008	13.0%	12.4%	$8,278
2007	12.9%	11.2%	$8,239
2006	12.7%	10.1%	$8,200
2005	12.6%	8.9%	$8,161
2004	12.5%	7.7%	$8,034
2003	12.4%	6.6%	$7,907
2002	12.3%	5.4%	$7,780
2001	12.2%	4.3%	$7,654
2000	12.1%	3.1%	$7,527

Year	Population	Household Size
2040	74455000	3.55
2039	72941800	3.6
2038	71433200	3.65
2037	69930736	3.7
2036	68435146	3.75
2035	66889000	3.8
2034	65398800	3.85
2033	63920880	3.9
2032	62452784	3.95
2031	60992547	4
2030	59438000	4.05
2029	58009200	4.1
2028	56580400	4.15
2027	55151600	4.2
2026	53722800	4.25

2025	52294000	4.3
2024	50983400	4.35
2023	49672800	4.4
2022	48362200	4.45
2021	47051600	4.5
2020	45741000	4.55
2019	43299680	4.594
2018	40858360	4.638
2017	38417040	4.682
2016	35975720	4.726
2015	33534400	4.77
2014	32358560	4.816
2013	31182720	4.862
2012	30006880	4.908
2011	28831040	4.954
2010	27655200	5
2009	27887360	5.048
2008	28119520	5.096
2007	28351680	5.144
2006	28583840	5.192
2005	28816000	5.24
2004	27914600	5.27
2003	27013200	5.3
2002	26111800	5.33
2001	25210400	5.36
2000	24309000	5.39