Technical Appendix

Refrigerator-Freezers

1. Introduction

This appendix offers a detailed explanation of the specific assumptions used in the refrigerator-freezer module of Mepsy. For information on outputs and data sources for the parameters, please refer to the comprehensive [Mepsy Methodology] document.

The refrigerator-freezer model applies to all household-use refrigerating appliances of the vapor compression type, with a rated volume between 10 and 1,500 Liters (L), powered by electric mains and offered for sale or installed in any application. This model does not include:

- wine storage appliances,
- refrigerating appliances with a direct sales function,
- mobile refrigerating appliances,
- appliances where the primary function is not the storage of foodstuffs through refrigeration,
- other products that do not meet the definition of a Refrigerator, Refrigerator-Freezer, or Freezer, and
- other refrigerating appliances different from vapor compression type.

2. Shipments and Stock

Euromonitor publishes residential refrigerator shipments in 210 countries for 2005–2024.[1] Data for 46 countries are based on market research (e.g., reviews of official statistics, secondary reports, interviews with manufacturers and associations) while 164 are "modeled" or extrapolated based on the findings from similar countries within the same region.[2] These were

[1] Euromonitor provides shipment data for fridge-freezer and fridge-only appliances

[2] "Our Methodologies," Euromonitor, accessed January 9, 2025, https://www.euromonitor.com/our-methodologies.

then reduced to the 162 countries and included in Mepsy. Sales forecasts for the period from 2024 to 2030 were based on the compound annual growth rate (CAGR) for 2019-2024.

The stock or number of refrigerators in use in each country was estimated by accumulating shipments since 2005. Once shipped, the refrigerator enters service and remains in service until it fails beyond repair or is otherwise replaced. The Weibull Distribution function is used to model survival probabilities $P\ (x)$ of appliances and calculate the surviving stocks of a certain year (y), based on the cumulative survival appliances from the previous year $(Stock(y-1))$.[3]

$$P\ (x) = \ e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}}$$

Where:

> $P\ (x)$ is the probability that the appliance is still in use at a certain age (x);
>
> x is the appliance age;
>
> α is the scale parameter, which corresponds to the decay length in an exponential distribution, also known as lifetime. In Mepsy, we set the lifetime of refrigerator to 17 years, according to Lawrence Berkeley National Laboratory's study.[4]
>
> β is the shape parameter, which determines how the failure rate changes through time;
>
> θ is the delay parameter, which provides for a delay before any failures occur.

Mepsy also refers to LBNL study to determine a shape parameter (β) of 1.3 and a delay parameter (θ) of 8.874.[2]

Stock forecast beyond 2030: Since residential appliances are typically shared within a household, the future number of appliances in use is calculated by the equation below:[5]

$$Number\ of\ appliances\ in\ use = Household\ Ownership\ Rate\ \times Total\ Households$$

CLASP used a two-step methodology to project ownership. We first collected the latest available ownership data from the national survey and market research firms where available. If data were incomplete, we supplemented it through regression analysis.

Regression analysis is a statistical technique used to understand how changes in one or more independent variables are associated with changes in the dependent variable. Prior research found that the ownership of most household appliances is driven by macroeconomic factors

[3] LBNL. Lutz et al. 2011. Using National Survey Data to Estimate Lifetimes of Residential Appliances. https://www.osti.gov/biblio/1182737

[4] James D. Lutz et al., "Using National Survey Data to Estimate Lifetimes of Residential Appliances," *HVAC&R Research* 17, no. 5 (October 3, 2011), https://www.osti.gov/biblio/1182737.

[5] "Household Size and Composition | Population Division," accessed April 10, 2023, https://www.un.org/development/desa/pd/data/household-size-and-composition; "World Population Prospects - Population Division - United Nations," accessed April 10, 2023, https://population.un.org/wpp/.

including household income, urbanization, and electrification.[6] Therefore, CLASP utilizes beta regression analysis, which is well-suited for modeling continuous dependent variables constrained between 0 and 1.[7] The analysis correlates scaled appliance ownership (dependent variable) with the above socio-economic factors (independent/driver variables) for the same countries and for the latest year available.[8] We then used the results to close data gaps for countries missing from the surveys and project the ownership till 2050. The formula is given by:

$$logit\left(\frac{\mu_c}{\alpha}\right) = \beta_0+\beta_1 \times I_c+\beta_2 \times E_c+\beta_3 \times U_c$$

Where:

μ_c is the household ownership rate for the country (c) for a specific appliance;

α is the maximum observed ownership rate across all available data. For refrigerator, α is set at 1.5, according to Euromonitor data.[9]

β_0 is the intercept term;

$\beta_1, \beta_{2,}\beta_3$ are the coefficients for the respective independent variables;

I_c is the household income given by GDP divided by the number of households in the country, U_c is the urbanization rate, E_c is the electrification rate.

For refrigerators, a beta regression analysis was used to fill the data gap of 2019 ownership provided by Euromonitor, available for 46 countries. The results show a correlation between ownership (dependent variables) and several socio-economic factors (driver variables), including household income, electrification, and urbanization.[10,11,12,13]

$$Refrigerator\ Ownership = (-3.841 + 8.47\ \times 10^{-5} \times I_c + 0.008 \times E_c + 0.031 \times U_c\ ) \times 1.5$$

[6] Michael A. McNeil and Virginie E. Letschert, "Modeling Diffusion of Electrical Appliances in the Residential Sector," Energy and Buildings 42, no. 6 (June 1, 2010): 783–90, https://doi.org/10.1016/j.enbuild.2009.11.015.

[7] Achim Zeileis et al., "Betareg: Beta Regression," September 12, 2024, https://cran.r-project.org/web/packages/betareg/.

[8] Ownership was scaled by the maximum ownership rate, selected from the available 2019 data across all countries, to ensure the dependent variable value fall within the 0 to 1 range, enabling the use of beta regression analysis.

[9] "Euromonitor," Euromonitor, accessed January 14, 2025, https://www.euromonitor.com/.

[10] McNeil and Letschert, "Modeling Diffusion of Electrical Appliances in the Residential Sector."

[11] "GDP and Spending - Real GDP Long-Term Forecast - OECD Data," theOECD, accessed September 25, 2023, http://data.oecd.org/gdp/real-gdp-long-term-forecast.htm.

[12] "Access to Electricity (% of Population) | Data," accessed April 10, 2023, https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS.

[13] "WUP2018-F02-Proportion_Urban.Xls," accessed December 12, 2024, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fpopulation.un.org%2Fwup%2FDownload%2FFiles%2FWUP2018-F02-Proportion_Urban.xls&wdOrigin=BROWSELINK.

Based on the correlation, Mepsy fills the data gaps for the remaining countries. This relationship is then used to extrapolate ownership through 2050, incorporating projected driven variables.[14,15] The household ownership rate is then multiplied by the future number of households, estimated by the United Nations, to calculate total stock. Additional details of this approach are provided in the 'Extending-Mepsy to 2050' paper. For the period from 2050 to 2060, Mepsy extrapolates appliance stock based on the compound annual growth rate (CAGR) calculated from the data between 2045 and 2050.

3. Unit Energy Consumption, Usage, and Standards Scenarios

The Unit Energy Consumption (UEC) values used in Business-as-usual (BAU) and Global Benchmark (GB) scenarios are harmonized with United for Efficiency's estimates.[16,17] As shown in Table 1 below, U4E provided UEC values for 11 countries and regions under three scenarios, with the values further segmented by income range. Based on each country's geographic location and national income level, we were able to select the UEC values from the table for all 162 countries included in Mepsy. (Table 2)

The UEC values in the "Business-as-usual" column of Table 1 are used for the **BAU scenario** in Mepsy. The "Minimum Ambitious" UEC values are applied in the **GB scenario**. For example, for China, the UEC value under the BAU scenario is 228 kWh/yr, under the GB scenario it is 177 kWh/yr. In the **NZH scenario**, UEC values are set at 50% of the BAU levels to align with the double efficiency target outlined in the Net Zero Heroes report.

TABLE 1. UEC ASSUMPTIONS PROVIDED BY U4E FOR COUNTRIES AND REGIONS

	VOLUME			UEC(KWH/Y)		
Region	Volume of refrigerator compartment in liters (L)	Volume of freezer compartment in liters (L)	Adjusted volume in liters (L)	Business As Usual (kWh/y)	Minimum Ambition UEC (kWh/y)	High Ambition UEC (kWh/y)
ASEAN	165	85	357	342	259	129
China	157	78	333	228	177	127
LAC	188	82	373	471	263	131

[14] In the model, we use linear interpolation to ensure data availability for the intervening years. A 100% cap was applied to electrification and urbanization, meaning the rate will not increase once it reaches 100%.

[15] "Mepsy Insights: 2050 Extension Model for Longer Forecasting," Zoho Campaigns, accessed January 10, 2025, https://zc.vg.

[16] "CSA_Methodology_September2022.Pdf," accessed December 10, 2024, https://united4efficiency.org/wp-content/uploads/2022/07/CSA_Methodology_September2022.pdf.

[17] The GB scenario uses the UEC values from the Minimum Ambitious UEC in the U4E table.

Mena	245	85	437	485	278	139
Oceania	210	90	413	398	273	135
Other Regions Income* <$10,000	188	82	373	607	263	131
Other Regions Income* >$10,000	188	82	373	437	263	131
South Asia	165	85	357	342	259	129
Sub-Saharan Africa	134	76	305	340	247	123
Turky	200	100	426	347	276	138
Ukraine	188	82	373	363	263	131

*Annual income based on 2019 GDP per capital value.
**Countries with existing MEPS in place assume that new sales meet those MEPS. Where those MEPS are in line with or exceed the MEPS in the Minimum Ambition Scenario, the minimum ambition Scenario is assumed to be halfway between the local MEPS and High Ambition Scenario.

TABLE 2. 162 COUNTRIES AND CORRESPONDING REGIONS BASED ON U4E CLASSIFICIATION FOR REFRIGERATOR UEC ASSUMPTIONS

COUNTRY	CONTINENT	REGION	ISOA3	REGION (IEA CLASSIFICATION)
Albania	Europe	Southern Europe	ALB	Annual Income 2019 GDP per capita, >$10,000
Algeria	Africa	Northern Africa	DZA	MENA
Angola	Africa	Middle Africa	AGO	Sub-Saharan Africa
Argentina	Americas	South America	ARG	LAC
Armenia	Asia	Western Asia	ARM	MENA
Australia	Oceania	Australia and New Zealand	AUS	Annual Income 2019 GDP per capita, >$10,000
Austria	Europe	Western Europe	AUT	Annual Income 2019 GDP per capita, >$10,000
Azerbaijan	Asia	Western Asia	AZE	MENA
Bahamas	Americas	Caribbean	BHS	LAC
Bahrain	Asia	Western Asia	BHR	MENA
Bangladesh	Asia	Southern Asia	BGD	South Asia
Barbados	Americas	Caribbean	BRB	LAC
Belarus	Europe	Eastern Europe	BLR	Annual Income 2019 GDP per capita, >$10,000
Belgium	Europe	Western Europe	BEL	Annual Income 2019 GDP per capita, >$10,000

Belize	Americas	Central America	BLZ	LAC
Benin	Africa	Western Africa	BEN	Sub-Saharan Africa
Bhutan	Asia	Southern Asia	BTN	South Asia
Bolivia (Plurinational State of)	Americas	South America	BOL	LAC
Bosnia and Herzegovina	Europe	Southern Europe	BIH	Annual Income 2019 GDP per capita, >$10,000
Botswana	Africa	Southern Africa	BWA	Sub-Saharan Africa
Brazil	Americas	South America	BRA	LAC
Brunei Darussalam	Asia	South-Eastern Asia	BRN	ASEAN
Bulgaria	Europe	Eastern Europe	BGR	Annual Income 2019 GDP per capita, >$10,000
Burkina Faso	Africa	Western Africa	BFA	Sub-Saharan Africa
Burundi	Africa	Eastern Africa	BDI	Sub-Saharan Africa
Cabo Verde	Africa	Western Africa	CPV	Sub-Saharan Africa
Cambodia	Asia	South-Eastern Asia	KHM	ASEAN
Cameroon	Africa	Middle Africa	CMR	Sub-Saharan Africa
Canada	Americas	Northern America	CAN	Annual Income 2019 GDP per capita, >$10,000
Central African Republic	Africa	Middle Africa	CAF	Sub-Saharan Africa
Chad	Africa	Middle Africa	TCD	Sub-Saharan Africa
Chile	Americas	South America	CHL	LAC
China	Asia	Eastern Asia	CHN	China
Colombia	Americas	South America	COL	LAC
Comoros	Africa	Eastern Africa	COM	Sub-Saharan Africa
Congo	Africa	Middle Africa	COG	Sub-Saharan Africa
Costa Rica	Americas	Central America	CRI	LAC

Côte D'Ivoire	Africa	Western Africa	CIV	Sub-Saharan Africa
Croatia	Europe	Southern Europe	HRV	Annual Income 2019 GDP per capita, >$10,000
Cyprus	Asia	Western Asia	CYP	MENA
Czech Republic	Europe	Eastern Europe	CZE	Annual Income 2019 GDP per capita, >$10,000
Democratic Republic of the Congo	Africa	Middle Africa	COD	Sub-Saharan Africa
Denmark	Europe	Northern Europe	DNK	Annual Income 2019 GDP per capita, >$10,000
Djibouti	Africa	Eastern Africa	DJI	Sub-Saharan Africa
Dominican Republic	Americas	Caribbean	DOM	LAC
Ecuador	Americas	South America	ECU	LAC
Egypt	Africa	Northern Africa	EGY	MENA
El Salvador	Americas	Central America	SLV	LAC
Equatorial Guinea	Africa	Middle Africa	GNQ	Sub-Saharan Africa
Eritrea	Africa	Eastern Africa	ERI	Sub-Saharan Africa
Estonia	Europe	Northern Europe	EST	Annual Income 2019 GDP per capita, >$10,000
Eswatini	Africa	Southern Africa	SWZ	Sub-Saharan Africa
Ethiopia	Africa	Eastern Africa	ETH	Sub-Saharan Africa
Fiji	Oceania	Melanesia	FJI	Oceania
Finland	Europe	Northern Europe	FIN	Annual Income 2019 GDP per capita, >$10,000
France	Europe	Western Europe	FRA	Annual Income 2019 GDP per capita, >$10,000
French Polynesia	Oceania	Polynesia	PYF	Oceania
Gabon	Africa	Middle Africa	GAB	Sub-Saharan Africa
Gambia (Republic of The)	Africa	Western Africa	GMB	Sub-Saharan Africa
Georgia	Asia	Western Asia	GEO	MENA
Germany	Europe	Western Europe	DEU	Annual Income 2019 GDP per capita, >$10,000

Ghana	Africa	Western Africa	GHA	Sub-Saharan Africa
Greece	Europe	Southern Europe	GRC	Annual Income 2019 GDP per capita, >$10,000
Guatemala	Americas	Central America	GTM	LAC
Guinea	Africa	Western Africa	GIN	Sub-Saharan Africa
Guinea Bissau	Africa	Western Africa	GNB	Sub-Saharan Africa
Guyana	Americas	South America	GUY	LAC
Haiti	Americas	Caribbean	HTI	LAC
Honduras	Americas	Central America	HND	LAC
Hong Kong, China (SAR)	Asia	Eastern Asia	HKG	China
Hungary	Europe	Eastern Europe	HUN	Annual Income 2019 GDP per capita, >$10,000
Iceland	Europe	Northern Europe	ISL	Annual Income 2019 GDP per capita, >$10,000
India	Asia	Southern Asia	IND	South Asia
Indonesia	Asia	South-Eastern Asia	IDN	ASEAN
Iran (Islamic Republic of)	Asia	Southern Asia	IRN	South Asia
Ireland	Europe	Northern Europe	IRL	Annual Income 2019 GDP per capita, >$10,000
Israel	Asia	Western Asia	ISR	MENA
Italy	Europe	Southern Europe	ITA	Annual Income 2019 GDP per capita, >$10,000
Jamaica	Americas	Caribbean	JAM	LAC
Japan	Asia	Eastern Asia	JPN	China
Jordan	Asia	Western Asia	JOR	MENA
Kazakhstan	Asia	Central Asia	KAZ	South Asia
Kenya	Africa	Eastern Africa	KEN	Sub-Saharan Africa
Kuwait	Asia	Western Asia	KWT	MENA
Kyrgyzstan	Asia	Central Asia	KGZ	South Asia

Lao People’s Democratic Republic	Asia	South-Eastern Asia	LAO	ASEAN
Latvia	Europe	Northern Europe	LVA	Annual Income 2019 GDP per capita, >$10,000
Lebanon	Asia	Western Asia	LBN	MENA
Lesotho	Africa	Southern Africa	LSO	Sub-Saharan Africa
Lithuania	Europe	Northern Europe	LTU	Annual Income 2019 GDP per capita, >$10,000
Luxembourg	Europe	Western Europe	LUX	Annual Income 2019 GDP per capita, >$10,000
Macau	Asia	Eastern Asia	MAC	China
Madagascar	Africa	Eastern Africa	MDG	Sub-Saharan Africa
Malawi	Africa	Eastern Africa	MWI	Sub-Saharan Africa
Malaysia	Asia	South-Eastern Asia	MYS	ASEAN
Maldives	Asia	Southern Asia	MDV	South Asia
Mali	Africa	Western Africa	MLI	Sub-Saharan Africa
Malta	Europe	Southern Europe	MLT	Annual Income 2019 GDP per capita, >$10,000
Mauritania	Africa	Western Africa	MRT	Sub-Saharan Africa
Mauritius	Africa	Eastern Africa	MUS	Sub-Saharan Africa
Mexico	Americas	Central America	MEX	LAC
Mongolia	Asia	Eastern Asia	MNG	China
Morocco	Africa	Northern Africa	MAR	MENA
Mozambique	Africa	Eastern Africa	MOZ	Sub-Saharan Africa
Namibia	Africa	Southern Africa	NAM	Sub-Saharan Africa
Nepal	Asia	Southern Asia	NPL	South Asia
Netherlands	Europe	Western Europe	NLD	Annual Income 2019 GDP per capita, >$10,000
New Zealand	Oceania	Australia and New Zealand	NZL	Annual Income 2019 GDP per capita, >$10,000
Nicaragua	Americas	Central America	NIC	LAC

Niger	Africa	Western Africa	NER	Sub-Saharan Africa
Nigeria	Africa	Western Africa	NGA	Sub-Saharan Africa
North Macedonia	Europe	Southern Europe	MKD	Annual Income 2019 GDP per capita, >$10,000
Norway	Europe	Northern Europe	NOR	Annual Income 2019 GDP per capita, >$10,000
Oman	Asia	Western Asia	OMN	MENA
Pakistan	Asia	Southern Asia	PAK	South Asia
Panama	Americas	Central America	PAN	LAC
Papua New Guinea	Oceania	Melanesia	PNG	Oceania
Paraguay	Americas	South America	PRY	LAC
Peru	Americas	South America	PER	LAC
Philippines	Asia	South-Eastern Asia	PHL	ASEAN
Poland	Europe	Eastern Europe	POL	Annual Income 2019 GDP per capita, >$10,000
Portugal	Europe	Southern Europe	PRT	Annual Income 2019 GDP per capita, >$10,000
Republic of Korea	Asia	Eastern Asia	KOR	China
Republic of Moldova	Europe	Eastern Europe	MDA	Annual Income 2019 GDP per capita, >$10,000
Romania	Europe	Eastern Europe	ROU	Annual Income 2019 GDP per capita, >$10,000
Russian Federation	Europe	Eastern Europe	RUS	Annual Income 2019 GDP per capita, >$10,000
Rwanda	Africa	Eastern Africa	RWA	Sub-Saharan Africa
Saudi Arabia	Asia	Western Asia	SAU	MENA
Senegal	Africa	Western Africa	SEN	Sub-Saharan Africa
Sierra Leone	Africa	Western Africa	SLE	Sub-Saharan Africa
Singapore	Asia	South-Eastern Asia	SGP	ASEAN
Slovakia	Europe	Eastern Europe	SVK	Annual Income 2019 GDP per capita, >$10,000
Slovenia	Europe	Southern Europe	SVN	Annual Income 2019 GDP per capita, >$10,000

Solomon Islands	Oceania	Melanesia	SLB	Oceania
South Africa	Africa	Southern Africa	ZAF	Sub-Saharan Africa
Spain	Europe	Southern Europe	ESP	Annual Income 2019 GDP per capita, >$10,000
Sri Lanka	Asia	Southern Asia	LKA	South Asia
Sudan	Africa	Northern Africa	SDN	MENA
Suriname	Americas	South America	SUR	LAC
Sweden	Europe	Northern Europe	SWE	Annual Income 2019 GDP per capita, >$10,000
Switzerland	Europe	Western Europe	CHE	Annual Income 2019 GDP per capita, >$10,000
Syrian Arab Republic	Asia	Western Asia	SYR	MENA
Tajikistan	Asia	Central Asia	TJK	South Asia
Thailand	Asia	South-Eastern Asia	THA	ASEAN
Togo	Africa	Western Africa	TGO	Sub-Saharan Africa
Trinidad and Tobago	Americas	Caribbean	TTO	LAC
Tunisia	Africa	Northern Africa	TUN	MENA
Turkey	Asia	Western Asia	TUR	Turkey
Turkmenistan	Asia	Central Asia	TKM	South Asia
Uganda	Africa	Eastern Africa	UGA	Sub-Saharan Africa
Ukraine	Europe	Eastern Europe	UKR	Ukraine
United Arab Emirates	Asia	Western Asia	ARE	MENA
United Kingdom of Great Britain and Northern Ireland	Europe	Northern Europe	GBR	Annual Income 2019 GDP per capita, >$10,000
United Republic of Tanzania	Africa	Eastern Africa	TZA	Sub-Saharan Africa
United States of America	Americas	Northern America	USA	Annual Income 2019 GDP per capita, >$10,000
Uruguay	Americas	South America	URY	LAC

Uzbekistan	Asia	Central Asia	UZB	South Asia
Venezuela, Bolivarian Republic of	Americas	South America	VEN	LAC
Viet Nam	Asia	South-Eastern Asia	VNM	ASEAN
Yemen	Asia	Western Asia	YEM	MENA
Zambia	Africa	Eastern Africa	ZMB	Sub-Saharan Africa
Zimbabwe	Africa	Eastern Africa	ZWE	Sub-Saharan Africa

Glossary

Appliance stock – The total number of appliances in use within a particular country or region.

Business-as-usual (BAU) scenario – A scenario that assumes no significant changes in policies or technologies and reflects the expected energy consumption under current trends.

Compound Annual Growth Rate (CAGR) – A measure of the mean annual growth rate of a metric over a specified period of time, typically longer than one year.

Cooling Operating Days – The number of days a particular appliance is actively used for cooling or is expected to be used in a given period.

Electrification – The process of providing electrical power to a region or industry that previously did not have access to it.

Energy Efficiency Index – A metric used to assess how efficient a device is at converting energy into useful work.

Euromonitor – A global market research company that provides data and analysis on various industries, including shipments and stock data for appliances like refrigerators.

Global Benchmark (GB) scenario - This is a low-ambition policy scenario. The global benchmarks are those efficiency levels recommended by CLASP and others such as United for Efficiency. These levels are generally considered to be quite ambitious.

Harmonized Commodity Description and Coding System (HS code) – A standardized system for classifying traded products used globally.

Market share – The portion of total sales in a market captured by a particular company or product.

Net Zero Hero (NZH) sceanrio: This is a high-ambition policy scenario. This scenario aligns with the targets outlined in Net Zero Heroes report published by CLASP in 2023, which calls for doubling the efficiency of ten key appliances. This action can significantly reduce energy consumption and contribute to the achievement of Net Zero Emission (NZE) goals

Regression analysis – A statistical technique used to understand the relationship between variables.

Socio-economic factors – Aspects of society and economy that influence behavior and decisions, such as household income, education, or urbanization.

Stock forecast – An estimate of the future number of appliances in use, typically based on historical trends and projected market conditions.

United for Efficiency (U4E) – A global initiative aimed at improving energy efficiency for appliances, including providing UEC (Unit Energy Consumption) estimates for various countries and regions.

Unit Energy Consumption (UEC) – The amount of energy consumed by an appliance per year, typically expressed in kilowatt-hours (kWh).

Weibull retirement function – A statistical function used to model the lifetime and failure rate of products over time.

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