Technical Appendix

Residential Water Heaters

1. Introduction

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

CLASP developed a model to assess the energy and CO_2 emissions impact of residential hot water heaters, which includes seven product categories:

- Air sourced heat pump (ASHP)
- Electric storage heater
- Electric instant heater
- Gas storage heater – condensing
- Gas storage heater – non-condensing
- Gas instant heater – condensing
- Gas instant heater – non-condensing

2. Shipments and Stock

Annual sales of each product category were obtained from BSRIA's World Market for Water Heating & Solar Thermal Report.[1] Market volume trajectory was available from 2019 to 2024 for 21 countries and regions, including the European region, the Southeast Asian region (Indonesia, Malaysia, Thailand, Philippines, Vietnam, and Cambodia), the Middle Eastern & African region (Saudi Arabia, United Arab Emirates, Iran, Algeria, Egypt, Morocco, and Tunisia), and the American region (Mexico, Brazil), Australia, New Zealand, China, South Korea, India and Uzbekistan). The compound annual growth rate (CAGR) from 2020 to 2024 was used to project shipments through 2060.

We estimated the stock or number of water heaters in use in each country by accumulating shipments since 2005. Once shipped, water heaters enter service and remain in service until they fail beyond repair or are otherwise replaced. We used the Weibull Distribution function to model survival probabilities $P\ (x)$ of appliances and

1 "BSRIA Inc. - Providing Global HVAC Market Intelligence and Research," accessed January 17, 2025, https://www.bsria.com/us/.

calculate the surviving stock of a certain year (y), based on the cumulative survival appliances from the previous year $(Stock(y-1))$.[2]

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

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 different lifetime for each of water heater product type see Table 1),

β is the shape parameter, which determines how the failure rate changes over time,

θ is the delay parameter, which introduces a delay before any failures occur.

Based on the Lawrence Berkeley National Laboratory (LBNL) study, Mepsy determines a shape parameter (β) of 2 and a delay parameter (θ) of 0.[2]

3. Unit Energy Consumption, Usage, and Standards Scenarios

The calculation of the Unit Energy Consumption (UEC) for a water heater involves estimating the energy required to heat water over a certain period (usually a year) and considering standby energy losses. This is the general process to calculate the UEC for a water heater:

1. The energy required to heat water is calculated using the following formula:

$$E_{heating} = \frac{Capacity \times WC \times \Delta\, T}{COP} \times 365$$

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

In which,

$$\Delta T = T_{Final} - T_{Initial}$$

Where:

$Capacity$ is the specific heat capacity of water, which is 0.0011628 (kWh/deg C) in Mepsy;

WC is the volume of hot water used per household per day in liters;[3]

ΔT is the temperature difference between the cold-water inlet temperature ($T_{Initial}$) and the desired temperature of the heated water (T_{Final});

COP is the coefficient of performance for a specific water heater, representing the amount of heating or cooling output produced per unit of electricity consumed.

2. Water heaters also consume energy to maintain the temperature of the water even when it is not being used, known as standby losses. The standby energy consumption can be calculated as:

$$E_{standby} = P_{standby} \times 365$$

Where:

$P_{standby}$ is the standby power consumption of the water heater in kWh per day.

Therefore, the total unit energy consumption (UEC) is the energy required to heat the water (annual heating energy) and the standby energy:

$$UEC = E_{standby} + E_{heating}$$

CLASP made assumptions for key countries where primary data was available and further grouped the countries based on water temperatures as shown in Table 1 and Table 2.

[3] if the country has 0 liters of hot water consumption per household per day, then temperature difference will be calculated using the cold-water inlet temperature and average use temperate water. WC will choose the volume of warm water used per household per day in liters.

TABLE 1. LIFETIME FOR DIFFERENT WATER HEATER PRODUCT TYPE

CATEGORY	LIFETIME (YEAR)
Heat pump	15
Electric storage heater	8
Electric instant heater	8 (primarily, for most countries) 2.8 (where small capacity units are common) 20 (where heavy duty, large capacity units are common)
Gas storage heater – condensing	12
Gas storage heater – non-condensing	12
Gas instant heater – condensing	8 20 (where heavy duty, large capacity units are common)
Gas instant heater – non-condensing	8 20 (where heavy duty, large capacity units are common)

TABLE 2. OTHER ASSUMPTIONS FOR WATER HEATER IN 162 COUNTRIES

COUNTRY	GROUP	REGION	DAILY PER-HOUSEHOLD HOT WATER CONSUMPTION (L)	DAILY PER-HOUSEHOLD WARM WATER CONSUMPTION (L)	AVG. INLET TEMP (DEG C)	AVG. TEMP AT WATER HEATER (DEG C)	AVG. USE TEMP (DEG C)
Albania	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Algeria	0	Northern Africa	0.0	150.0	22.1	60.0	40.0
Angola	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Argentina	South America	South America	0.0	108.0	20.4	60.0	38.2
Armenia	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Australia	0	Australia and New Zealand	88.0	0.0	13.5	60.0	40.0
Austria	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
Azerbaijan	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Bahamas	0	Central America	0.0	236.0	21.0	60.0	45.0
Bahrain	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Bangladesh	0	Southern Asia	174.8	0.0	23.7	65.0	40.0
Barbados	0	Central America	0.0	236.0	21.0	60.0	45.0
Belarus	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Belgium	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
Belize	0	Central America	0.0	236.0	21.0	60.0	45.0
Benin	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Bhutan	0	Southern Asia	174.8	0.0	23.7	65.0	40.0

Bolivia (Plurinational State of)	South America	South America	0.0	108.0	20.4	60.0	38.2
Bosnia and Herzegovina	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Botswana	Africa	Southern Africa	192.0	0.0	14.0	60.0	42.0
Brazil	South America	South America	0.0	108.0	20.4	60.0	38.2
Brunei Darussalam	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Bulgaria	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Burkina Faso	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Burundi	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Cabo Verde	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Cambodia	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Cameroon	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Canada	0	Northern America	172.2	0.0	15.8	51.7	38.9
Central African Republic	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Chad	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Chile	South America	South America	0.0	108.0	20.4	60.0	38.2
China	0	Eastern Asia	0.0	150.0	12.0	65.0	39.0
Colombia	South America	South America	0.0	108.0	20.4	60.0	38.2
Comoros	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Congo	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Costa Rica	0	Central America	0.0	236.0	21.0	60.0	45.0
Côte D'Ivoire	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Croatia	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Cyprus	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Czech Republic	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0

Democratic Republic of the Congo	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Denmark	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Djibouti	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Dominican Republic	0	Central America	0.0	236.0	21.0	60.0	45.0
Ecuador	South America	South America	0.0	108.0	20.4	60.0	38.2
Egypt	0	Northern Africa	0.0	150.0	22.1	60.0	40.0
El Salvador	0	Central America	0.0	236.0	21.0	60.0	45.0
Equatorial Guinea	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Eritrea	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Estonia	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Eswatini	Africa	Southern Africa	192.0	0.0	14.0	60.0	42.0
Ethiopia	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
European Union	#N/A	#N/A	NA	NA	NA	NA	NA
Fiji	0	Melanesia	0.0	100.0	25.3	60.0	40.0
Finland	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
France	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
French Polynesia	0	Polynesia	0.0	100.0	24.4	60.0	40.0
Gabon	Africa	Middle Africa	11.7	0.0	24.6	60.0	40.0
Gambia (Republic of The)	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Georgia	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Germany	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
Ghana	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Greece	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0

Guatemala	0	Central America	0.0	236.0	21.0	60.0	45.0
Guinea	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Guinea Bissau	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Guyana	South America	South America	0.0	108.0	20.4	60.0	38.2
Haiti	0	Central America	0.0	100.0	21.0	60.0	45.0
Honduras	0	Central America	0.0	236.0	21.0	60.0	45.0
Hong Kong, China (SAR)	0	Eastern Asia	0.0	150.0	12.0	65.0	39.0
Hungary	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Iceland	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
India	0	Southern Asia	174.8	0.0	23.7	65.0	40.0
Indonesia	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Iran (Islamic Republic of)	0	Southern Asia	174.8	0.0	23.7	65.0	40.0
Ireland	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Israel	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Italy	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Jamaica	0	Central America	0.0	236.0	21.0	60.0	45.0
Japan	0	Eastern Asia	0.0	367.0	12.0	65.0	39.0
Jordan	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Kazakhstan	0	Central Asia	0.0	100.0	12.1	60.0	40.0
Kenya	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Kuwait	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Kyrgyzstan	0	Central Asia	0.0	100.0	12.1	60.0	40.0
Lao People’s Democratic Republic	0	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0

Latvia	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Lebanon	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Lesotho	Africa	Southern Africa	192.0	0.0	14.0	60.0	42.0
Lithuania	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Luxembourg	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
Macau	0	Eastern Asia	0.0	150.0	12.0	65.0	39.0
Madagascar	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Malawi	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Malaysia	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Maldives	0	Southern Asia	174.8	0.0	23.7	65.0	40.0
Mali	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Malta	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Mauritania	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Mauritius	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Mexico	0	Central America	0.0	236.0	21.0	60.0	45.0
Mongolia	0	Eastern Asia	0.0	150.0	12.0	65.0	39.0
Morocco	0	Northern Africa	0.0	150.0	22.1	60.0	40.0
Mozambique	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Namibia	Africa	Southern Africa	192.0	0.0	14.0	60.0	42.0
Nepal	0	Southern Asia	174.8	0.0	23.7	65.0	40.0
Netherlands	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
New Zealand	0	Australia and New Zealand	88.0	0.0	13.5	60.0	40.0
Nicaragua	0	Central America	0.0	236.0	21.0	60.0	45.0
Niger	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Nigeria	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0

North Macedonia	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Norway	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Oman	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Pakistan	0	Southern Asia	0.0	151.4	23.7	65.0	40.0
Panama	0	Central America	0.0	236.0	21.0	60.0	45.0
Papua New Guinea	0	Melanesia	0.0	100.0	25.3	60.0	40.0
Paraguay	South America	South America	0.0	108.0	20.4	60.0	38.2
Peru	South America	South America	0.0	108.0	20.4	60.0	38.2
Philippines	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Poland	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Portugal	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Republic of Korea	0	Eastern Asia	0.0	150.0	12.0	65.0	39.0
Republic of Moldova	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Romania	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Russia	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Rwanda	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Saudi Arabia	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Senegal	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Sierra Leone	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Singapore	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Slovakia	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
Slovenia	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Solomon Islands	0	Melanesia	0.0	100.0	25.3	60.0	40.0
South Africa	Africa	Southern Africa	192.0	0.0	14.0	60.0	42.0

Spain	EU	Southern Europe	59.0	0.0	10.0	55.0	40.0
Sri Lanka	0	Southern Asia	174.8	0.0	23.7	65.0	40.0
Sudan	0	Northern Africa	0.0	150.0	22.1	60.0	40.0
Suriname	South America	South America	0.0	108.0	20.4	60.0	38.2
Sweden	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
Switzerland	EU	Western Europe	59.0	0.0	10.0	55.0	40.0
Syrian Arab Republic	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Tajikistan	0	Central Asia	0.0	100.0	12.1	60.0	40.0
Thailand	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Togo	Africa	Western Africa	100.0	0.0	26.8	60.0	40.0
Trinidad and Tobago	0	Central America	0.0	236.0	21.0	60.0	45.0
Tunisia	0	Northern Africa	0.0	150.0	22.1	60.0	40.0
Turkey	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Turkmenistan	0	Central Asia	0.0	100.0	12.1	60.0	40.0
Uganda	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Ukraine	EU	Eastern Europe	0.0	150.0	-5.1	60.0	39.0
United Arab Emirates	0	Western Asia	0.0	150.0	11.1	60.0	40.0
United Kingdom of Great Britain and Northern Ireland	EU	Northern Europe	59.0	0.0	10.0	55.0	40.0
United Republic of Tanzania	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
United States of America	0	Northern America	172.2	0.0	15.8	51.7	38.9
Uruguay	South America	South America	0.0	108.0	20.4	60.0	38.2
Uzbekistan	0	Central Asia	0.0	100.0	12.1	60.0	40.0
Venezuela, Bolivarian Republic of	South America	South America	0.0	108.0	20.4	60.0	38.2

Viet Nam	ASEAN	South-Eastern Asia	0.0	150.0	26.3	60.0	40.0
Yemen	0	Western Asia	0.0	150.0	11.1	60.0	40.0
Zambia	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0
Zimbabwe	Africa	Eastern Africa	0.0	100.0	22.2	60.0	40.0

TABLE 3. STANDBY POWER (KW/DAY) ASSUMPTION IN 162 COUNTRIES

COUNTRY	GROUP	REGION	ELECHP BAU STANDBY (KWH/D)	ELECSTOR BAU STANDBY (KWH/D)	ELECINST BAU STANDBY (KWH/D)	GASSTORCOND BAU STANDBY (KWH/D)	GASSTORNC BAU STANDBY (KWH/D)	GASINSTCOND BAU STANDBY (KWH/D)	GASINSTNC BAU STANDBY (KWH/D)
Albania	EU	Southern Europe	1.2	1.2	0	4.8	4.8	0	0
Algeria	0	Northern Africa	1.2	1.2	0	4.8	4.8	0	0
Angola	Africa	Middle Africa	1.2	1.2	0	4.8	4.8	0	0
Argentina	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Armenia	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Australia	0	Australia and New Zealand	1.2	1.2	0	3.36	3.36	0	0
Austria	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0
Azerbaijan	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Bahamas	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Bahrain	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Bangladesh	0	Southern Asia	1.2	1.04	0	4.8	4.8	0	0
Barbados	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Belarus	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Belgium	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0

Belize	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Benin	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Bhutan	0	Southern Asia	1.2	1.04	0	4.8	4.8	0	0
Bolivia (Plurinational State of)	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Bosnia and Herzegovina	EU	Southern Europe	1.2	1.2	0	4.8	4.8	0	0
Botswana	sAfrica	Southern Africa	1.2	1.2	0	4.8	4.8	0	0
Brazil	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Brunei Darussalam	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Bulgaria	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Burkina Faso	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Burundi	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Cabo Verde	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Cambodia	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Cameroon	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0
Canada	0	Northern America	1.2	1.2	0	3.54	3.54	0	0
Central African Republic	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0
Chad	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0

Chile	South America	South America	1.2	1.2	0	4.8	4.8	0	0
China	0	Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Colombia	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Comoros	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Congo	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0
Costa Rica	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Côte D'Ivoire	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Croatia	EU	Souther n Europe	1.2	1.2	0	4.8	4.8	0	0
Cyprus	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Czech Republic	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Democratic Republic of the Congo	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0
Denmark	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Djibouti	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Dominican Republic	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Ecuador	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Egypt	0	Northern Africa	1.2	1.2	0	4.8	4.8	0	0
El Salvador	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Equatorial Guinea	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0

Eritrea	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Estonia	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Eswatini	sAfrica	Souther n Africa	1.2	1.2	0	4.8	4.8	0	0
Ethiopia	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
European Union	#N/A	#N/A	NA	NA	NA	NA	NA	NA	NA
Fiji	0	Melanesi a	1.2	1.2	0	4.8	4.8	0	0
Finland	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
France	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0
French Polynesia	0	Polynesi a	1.2	1.2	0	4.8	4.8	0	0
Gabon	sAfrica	Middle Africa	1.2	1.2	0	4.8	4.8	0	0
Gambia (Republic of The)	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Georgia	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Germany	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0
Ghana	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Greece	EU	Souther n Europe	1.2	1.2	0	4.8	4.8	0	0
Guatemala	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Guinea	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Guinea Bissau	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0

Guyana	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Haiti	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Honduras	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Hong Kong, China (SAR)	0	Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Hungary	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Iceland	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
India	0	Souther n Asia	1.2	1.04	0	4.8	4.8	0	0
Indonesia	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Iran (Islamic Republic of)	0	Souther n Asia	1.2	1.04	0	4.8	4.8	0	0
Ireland	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Israel	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Italy	EU	Souther n Europe	1.2	1.2	0	4.8	4.8	0	0
Jamaica	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Japan	0	Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Jordan	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Kazakhstan	0	Central Asia	1.2	1.2	0	4.8	4.8	0	0
Kenya	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Kuwait	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0

Kyrgyzstan	0	Central Asia	1.2	1.2	0	4.8	4.8	0	0
Lao People's Democratic Republic	0	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Latvia	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Lebanon	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Lesotho	sAfrica	Southern Africa	1.2	1.2	0	4.8	4.8	0	0
Lithuania	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Luxembourg	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0
Macau	0	Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Madagascar	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Malawi	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Malaysia	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Maldives	0	Southern Asia	1.2	1.04	0	4.8	4.8	0	0
Mali	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Malta	EU	Southern Europe	1.2	1.2	0	4.8	4.8	0	0
Mauritania	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Mauritius	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Mexico	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Mongolia	0	Eastern Asia	1.2	1.2	0	4.8	4.8	0	0

Morocco	0	Northern Africa	1.2	1.2	0	4.8	4.8	0	0
Mozambique	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Namibia	sAfrica	Souther n Africa	1.2	1.2	0	4.8	4.8	0	0
Nepal	0	Souther n Asia	1.2	1.04	0	4.8	4.8	0	0
Netherlands	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0
New Zealand	0	Australia and New Zealand	1.2	1.2	0	3.36	3.36	0	0
Nicaragua	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Niger	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Nigeria	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
North Macedonia	EU	Souther n Europe	1.2	1.2	0	4.8	4.8	0	0
Norway	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Oman	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Pakistan	0	Souther n Asia	4.31	4.31	0	6.56	6.56	0	0
Panama	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Papua New Guinea	0	Melanesi a	1.2	1.2	0	4.8	4.8	0	0
Paraguay	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Peru	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Philippines	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0

Poland	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Portugal	EU	Southern Europe	1.2	1.2	0	4.8	4.8	0	0
Republic of Korea	0	Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Republic of Moldova	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Romania	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Russia	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Rwanda	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Saudi Arabia	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Senegal	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Sierra Leone	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Singapore	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Slovakia	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
Slovenia	EU	Southern Europe	1.2	1.2	0	4.8	4.8	0	0
Solomon Islands	0	Melanesia	1.2	1.2	0	4.8	4.8	0	0
South Africa	sAfrica	Southern Africa	1.2	1.2	0	4.8	4.8	0	0
Spain	EU	Southern Europe	1.2	1.2	0	4.8	4.8	0	0
Sri Lanka	0	Southern Asia	1.2	1.04	0	4.8	4.8	0	0
Sudan	0	Northern Africa	1.2	1.2	0	4.8	4.8	0	0

Suriname	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Sweden	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
Switzerland	EU	Western Europe	1.2	1.2	0	4.8	4.8	0	0
Syrian Arab Republic	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Tajikistan	0	Central Asia	1.2	1.2	0	4.8	4.8	0	0
Thailand	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Togo	sAfrica	Western Africa	1.2	1.2	0	4.8	4.8	0	0
Trinidad and Tobago	0	Central America	1.2	1.2	0	4.8	4.8	0	0
Tunisia	0	Northern Africa	1.2	1.2	0	4.8	4.8	0	0
Turkey	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Turkmenistan	0	Central Asia	1.2	1.2	0	4.8	4.8	0	0
Uganda	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Ukraine	EU	Eastern Europe	1.2	1.2	0	4.8	4.8	0	0
United Arab Emirates	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
United Kingdom of Great Britain and Northern Ireland	EU	Northern Europe	1.2	1.2	0	4.8	4.8	0	0
United Republic of Tanzania	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0

United States of America	0	Northern America	1.2	1.2	0	3.54	3.54	0	0
Uruguay	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Uzbekistan	0	Central Asia	1.2	1.2	0	4.8	4.8	0	0
Venezuela, Bolivarian Republic of	South America	South America	1.2	1.2	0	4.8	4.8	0	0
Viet Nam	ASEAN	South-Eastern Asia	1.2	1.2	0	4.8	4.8	0	0
Yemen	0	Western Asia	1.2	1.2	0	4.8	4.8	0	0
Zambia	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0
Zimbabwe	sAfrica	Eastern Africa	1.2	1.2	0	4.8	4.8	0	0

To determine the differences in total energy consumption for various scenarios, efficiency levels were determined for the following scenarios:

- **Business-as-Usual**: Current estimated efficiencies for water heater types were taken from Liu's research as the baseline efficiency in China.[4]
- **Global Benchmark**: In this scenario, the tool assumes that heat pumps replace 100% of electric storage water heaters, and all gas water heaters are condensing by 2050.
- **Net Zero Hero**: Deployment of high-efficiency technologies causes a shift of the projected demand for Gas/Electric storage units to Heat Pump and Gas Instantaneous to Electric Instantaneous.

TABLE 4. EFFICIENCIES BY TECHNOLOGY USED TO ESTIMATE TOTAL ENERGY CONSUMPTION.

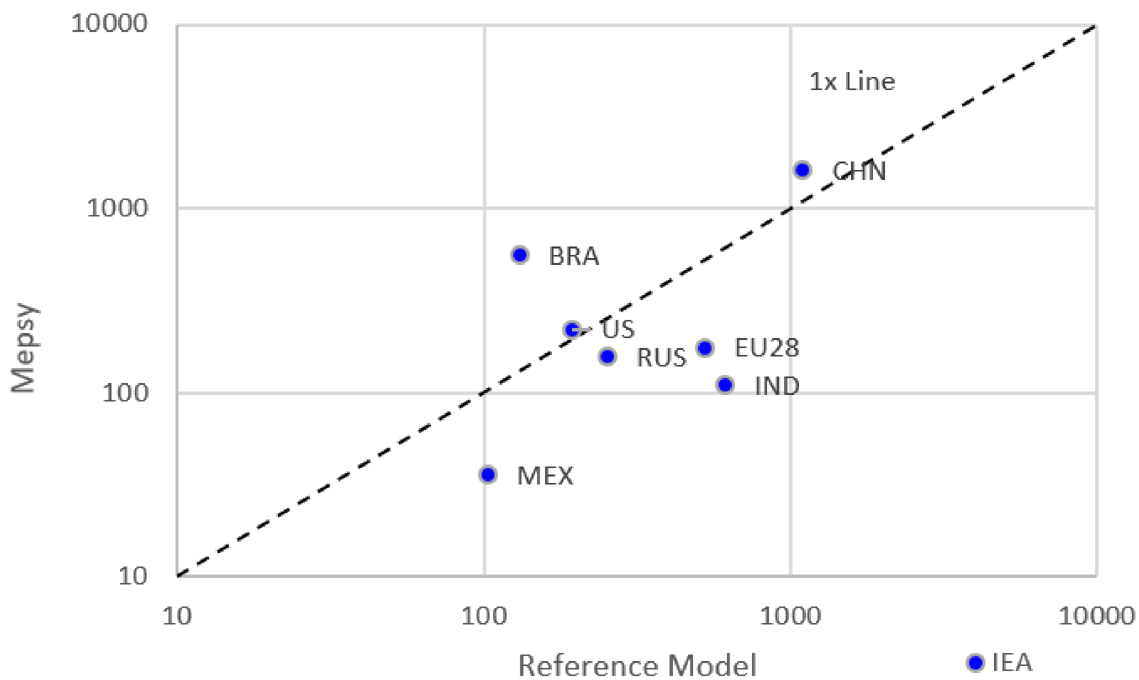
WATER HEATER TECHNOLOGY	COEFFICIENT OF PERFORMANCE (BAU)	COEFFICIENT OF PERFORMANCE (GB)	COEFFICIENT OF PERFORMANCE (NZH)
Electric Heat Pump	225%	237%	237%
Electric Storage	98%	98%	237%
Electric Instantaneous	98%	98%	98%
Gas Stor Cond	96%	96%	96%
Gas Stor NC	87.5%	96%	96%
Gas Inst Cond	96%	96%	96%
Gas Inst NC	87.5%	96%	96%

[4] Wei Liu et al., "Environmental Life Cycle Assessment and Techno-Economic Analysis of Domestic Hot Water Systems in China," Energy Conversion and Management 199 (November 1, 2019): 111943, https://doi.org/10.1016/j.enconman.2019.111943.

4. Model Outputs and Validation

The Unit Energy Consumption (UEC) for each product category, along with stock estimates in each country, was used to calculate the total energy consumption per country per year in tera watt hour. The results were compared with the IEA's Energy Technology Perspectives 2017[5] estimates for appliance energy production in Figure 1.

FIGURE 1. COMPARISON OF MEPSY RESULTS WITH IEA ETP 2017 ESTIMATES FOR APPLIANCE ENERGY CONSUMPTION



RESULTS VALIDATION FOR CHINA

To verify the results of the calculation, estimates of energy usage in China for ASHP, electric, and gas water heaters were compared to Wei Liu's estimates[6] as shown in Table 5.

[5] "Energy Technology Perspectives 2017," n.d.

TABLE 5. COMPARISON OF UNIT ENERGY CONSUMPTION (UEC) OF WATER HEATERS IN MEPSY AND LIU'S ESTIMATE

	ELECTRIC HEAT PUMP	ELECTRIC STORAGE	ELECTRIC INSTANT	GAS STORAGE COND	GAS STORAGE NC	GAS INSTANT COND	GAS INSTANT NC
Mepsy (kwh/year)	1202	2193	1755	3544	3718	1792	1966
Wei Liu's estimation (kwh/year)	918	2404					2104[7]

While population per region weighs Liu's energy usage estimates, they don't consider the impact of energy efficiency grade adoption (EEG). For example, Table 6 shows the Unit Energy Consumption (UEC) for electric storage water heaters from Liu's paper, which were weighted by population in each region, but not weighted by EEG.[3]

TABLE 6. ELECTRICITY CONSUMPTION OF ELECTRIC DHW SYSTEMS.

REGION	ELECTRICITY CONSUMPTION（KWH/YR）				
	EEG 1	EEG 2	EEG 3	EEG 4	EEG 5
1	1395.3	1531.5	1697.0	1846.8	2093.0
2	1940.0	2129.2	2359.4	2567.6	2910.0
3	1945.0	2134.8	2365.6	2574.3	2917.5
4	2104.9	2310.2	2560.0	2785.9	3157.3
5	2216.1	2432.3	2695.2	2933.1	3324.1

In 2020, the estimated total energy consumption from all water heaters was 1146 TWh/year while the electric water heaters' was 547 TWh/year. Another research paper finds that China consumed 96.4 TWh/year for residential electric water heaters in 2019, about six times less than our electric estimate. The discrepancy is likely due to a significant difference in usage estimation. In the report, the electric water heaters assumed consumption is 2500W and estimated usage is about 190 hours/year, which implies many users unplug their heaters when not in use.[8,9]

7 Although Liu et al does not clarify the type of gas water heater, CLASP assumed they referred to gas instantaneous non-condensing as that is the predominant gas water heater type in China.

8 Chen Renwei, "Energy Data 2020," Page, accessed January 17, 2025, https://www.efchina.org/Reports-en/report-lceg-20210430-3-en.

9 A 2014 CLASP survey found that 38% of households unplugged water heaters when not in use, so implementing this in our model has the potential to lower electricity consumption, which is currently 303.4 TWh/year for electric heaters.

TABLE 7. BASELINE UNIT ENERGY CONSUMPTION CALCULATIONS OF 7 PRODUCT CATEGORIES IN CHINA

WATER HEATER TECHNOLOGY	COEFFICIENT OF PERFORMANCE (COP)	SOURCE	STANDING LOSS (KWH/DAY)	SOURCE
Electric Heat Pump	225%	Baseline efficiencies for Region 3 (Hot Summer/Cold Winter) from Liu Et Al, Except in the case of Electric Heaters[10]	1.2	IEA 4E Benchmarking Report for domestic gas and electric, storage, instantaneous and heat pump water heaters [11]
Electric Storage	98%		1.2	
Electric Instantaneous	98%		0	
Gas Stor Cond	96%		4.8	
Gas Stor NC	87.5%		4.8	
Gas Inst Cond	96%		0	
Gas Inst NC	87.5%		0	

Liu's baseline Coefficient of Performance (COP) in region 3 was significantly lower than anticipated for electric water heaters presumably because the rate was a combination of the COP and standing loss. Since Liu's value for standing loss was not available, the team utilized standing loss rates from the 2017 IEA 4E's benchmarking document.[7] The assumed COP of 98% for electric water heaters, in combination with the new standing loss values, provided an estimated per unit energy consumption similar to that of a water heater running at Liu's suggested 82% with no standing loss.[3]

The original standing loss rates are in watts. For the model, the electric heaters are assumed to run continuously for 24 hours with the water heaters left plugged at all times.

RESULTS VALIDATION FOR USA

In the US water heater distribution is skewed more heavily towards storage-type units, totaling at 149,107,768 unit.

TABLE 8. 2020 WATER HEATER STOCK BY PRODUCT TYPE IN THE US

HEAT PUMP	ELECTRIC STORAGE	ELECTRIC INST	GAS STORAGE CONDENSING	GAS STORAGE NON CONDENSING	GAS INST CONDENSING	GAS INST NON CONDENSING	TOTAL
73,273	72,762,558	9,542,389	4,208,180	48,992,199	1,175,920	12,353,249	149,107,769

[11] "Water_Heaters_-_FINAL_Benchmarking_Report_-_IEA_4E_-_v2.0.Pdf," accessed December 16, 2024, https://www.iea-4e.org/wp-content/uploads/2020/08/Water_Heaters_-_FINAL_Benchmarking_Report_-_IEA_4E_-_v2.0.pdf.

The total is more than the EIA's reported number of homes at 118.2 million homes.[12] In the same report, the total energy and gas consumption in 2015 was found to be 472 TWh, with 173TWh coming from electric heaters, and the remaining 299 TWh coming from burning gas. In 2015, our estimated total US energy consumption from water heating was about 422 TWh (11% less than EIA), with a split between electric and gas of 203 TWh and 218 TWh respectively.

One possible reason to explain the difference is that the actual lifetime of water heaters in the US is longer than the current lifetime assumptions from Liu and Berkley's research.[3] An increased lifetime for these products would increase the stock estimations from current shipment data and would proportionally increase energy consumption.

[12] "Space Heating and Water Heating Account for Nearly Two Thirds of U.S. Home Energy Use - U.S. Energy Information Administration (EIA)," accessed December 16, 2024, https://www.eia.gov/todayinenergy/detail.php?id=37433.

Glossary

ASHRAE: The American Society of Heating, Refrigerating, and Air-Conditioning Engineers, an international technical society that publishes standards for heating, ventilation, and air conditioning (HVAC) systems.

BAU (Business-as-usual) Scenario: A scenario that assumes no changes in lighting or appliance policies between 2020 and 2030, reflecting current trends without additional interventions.

BSRIA (Building Services Research and Information Association): An organization that provides technical expertise, research, and information related to building services, including water heating systems.

CAGR (Compound Annual Growth Rate): The annual growth rate of a value over a specified period of time, assuming the rate of growth is constant.

COP (Coefficient of Performance): A measure of the efficiency of heating or cooling systems, representing the ratio of useful heating or cooling output to the energy input.

EIA (Energy Information Administration): A U.S. government agency responsible for providing independent statistics and analysis on energy.

Energy Consumption (E): The total amount of energy used, measured typically in kilowatt-hours (kWh), over a specified time period (e.g., annually).

Energy Technology Perspectives (ETP): A report by the International Energy Agency (IEA) that provides long-term energy scenarios, including energy efficiency and technology adoption.

EEG (Energy Efficiency Grade): Classification of appliances or systems based on their energy efficiency, often denoted from **EEG 1** (least efficient) to **EEG 5** (most efficient).

Gas Instant Heater (Condensing & Non-Condensing): A type of gas water heater where condensing models recover heat from exhaust gases, while non-condensing models do not.

Gas Storage Heater (Condensing & Non-Condensing): Gas-powered water heaters that store water and provide heat on demand, with condensing models being more energy-efficient.

Gas Storage Heater: A type of water heater that stores heated water for future use, typically powered by natural gas.

Gas Instant Heater: A type of water heater that heats water instantly as it flows through the system, typically powered by natural gas.

GB (Global Benchmark) 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

IEA 4E: The International Energy Agency's Efficient Electrical End-Use Equipment program, which benchmarks the energy performance of electrical equipment, including water heaters..

GB (Global Benchmark) 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

P_standby (Standby Power Consumption): The amount of energy consumed by a water heater while it is on standby, maintaining the temperature of the water even when it is not being used.

Shipments: The number of units of a specific product category sold or shipped in a given period.

Standby Energy Consumption: Energy consumed by the water heater while maintaining the water temperature when it is not actively heating or in use.

Standing Losses: The energy consumed by a water heater to maintain the water temperature even when it is not actively being used, often due to heat loss from the tank or pipes.

Stock Estimates: The number of units of a product category that are currently in use or installed in households.

UEC (Unit Energy Consumption): A measure of the total energy consumed by an appliance or system, usually expressed on an annual basis.

WC (Water Consumption): The volume of hot water used per household per day, typically measured in liters.

ΔT (Temperature Difference): The difference in temperature between the desired temperature of the heated water (T_Final) and the cold-water inlet temperature (T_Initial)

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