Technical Appendix

Television

1. Introduction

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

Televisions can be categorized based on size, resolution, and technology. The size is determined by the screen's diagonal length and its area. Resolution is defined by the number of lines of pixels: 1920x1080 is full high definition (FHD) and 3840 x 2160 is ultra-high definition (UHD). TV technologies are mainly composed of light emitting-diode (LED)-backlit liquid crystal displays (LCDs) although some older technologies such as plasma displays and cathode ray tube (CRT) TVs are still in use, they are no longer manufactured. Energy consumption tends to increase with size and resolution.[1] While these characteristics have been increasing in recent years, energy use has been decreasing due to the more efficient LED-LCD technology replacing CRT. Another important factor influencing TV energy consumption is display brightness, but this has not been modeled due to limited data.

2. Shipments and Stock

To calculate the stock of TVs, CLASP purchased estimates of global shipment data from Omdia (formerly a division of IHS Markit), which provided historical shipments and forecasts for 93 countries as well as eight regions from 2010 to 2024. CLASP extrapolated the shipments to 2030.

To estimate the shipments in countries not covered by Omdia, CLASP took the shipments in each region, deducted shipments for the countries that were provided, and divided the remainder between the countries based on the of the number of electrified households. This assumes that electrified households in the same region have the same ownership rate.

[1] Won Young Park et al., "Efficiency Improvement Opportunities in TVs: Implications for Market Transformation Programs," Energy Policy 59 (August 2013): 361–72, https://doi.org/10.1016/j.enpol.2013.03.048.

$$Shipments\ in\ Country\ i$$

$$= \frac{(Total\ Shipments\ in\ Region - \sum_{provided\ countries} Shipments) \times Electrified\ Households\ in\ Country\ i}{\sum_{all\ countries\ in\ region} Electrified\ Housholds}$$

Where:

$Total\ Shipments\ in\ Region$ is the total number of shipments in the region;

$\sum_{provided\ countries} Shipments)$ is the shipments already accounted for in the provided countries;

$lectrified\ Households\ in\ Country\ i$ is the number of electrified households in the specific country;

$\sum_{all\ countries\ in\ region} Electrified\ Housholds$ is the total number of electrified households in the region.

The stock or number of TVs in use in each country was estimated by accumulating shipments since 2005. Once shipped, the TV 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 $(Stock(y-1))$.[2]

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

Where:

$P\ (x)$ is the probability 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 (Mepsy assumes a lifetime of 7-14 years for TVs based on previous national market studies);

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

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

Mepsy refers to an LBNL study to determine a shape parameter (β) of 1.8 and a delay parameter (θ) of 1.0.[2]

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

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:[3]

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

CLASP used a two-step methodology to project ownership. We first collected the latest available ownership data from national surveys 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 including household income, urbanization, and electrification.[4] Therefore, CLASP utilizes beta regression analysis, which is well-suited for modeling continuous dependent variables constrained between 0 and 1.[5] 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.[6] 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 in a country (c) for a specific appliance;

α is the maximum observed ownership rate across all available data (for TVs, α is set at 5, according to Euromonitor data[7]);

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.

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[3] "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/.

[4] 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.

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

[6] 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.

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

For TV, 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.[8,9,10,11]

$$TV\ Ownership = (4.3 - 1.15\ \times 10^{-4} \times I_c - 2.95 \times E_c\ ) \times 5$$

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.[12] The household ownership rate is then multiplied by the future number of households, estimated by the United Nations, to calculate total stock.[13] 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

Unit energy consumption (UEC) is expressed in kWh per year, and factors in the TV's power consumption during on mode (actively watching) and standby mode (screen off but still turned on). Standby mode can be further divided into passive standby (no other functions except waiting for a turn-on signal from a switch or remote control) or network standby (maintaining an Internet connection). Some TVs can also download content over their network connection while in standby, but this has been omitted from the calculation because it occurs infrequently enough to be a negligible component of annual energy consumption.

The average time spent in the different modes varies by user and nominal values based on a national average, typically included in test methods or national standards. For example, the US test method assumes a daily operation of 5 hours in on mode and 19 hours in standby. In Australia, the test standard assumes 10 hours in on mode. While we recognize that TVs spend most of their time in standby mode (either passive or network),

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

[9] "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.

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

[11] "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.

[12] 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%.

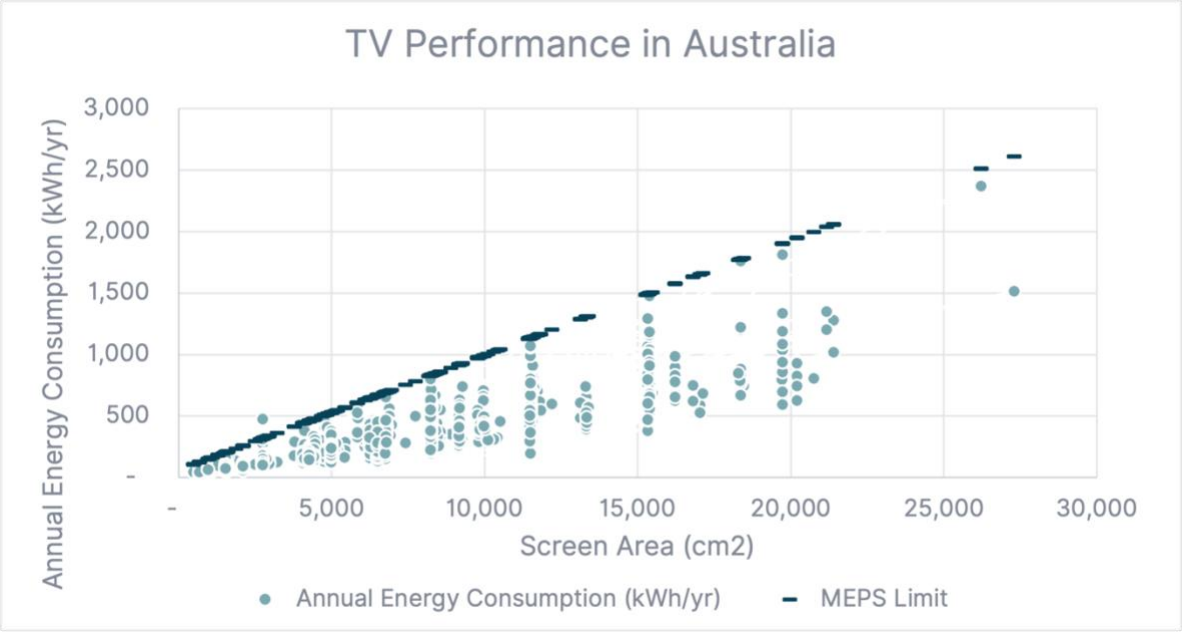
[13] "Mepsy Insights: 2050 Extension Model for Longer Forecasting," Zoho Campaigns, accessed January 10, 2025, https://zc.vg.

the power level in this mode is much lower, making on mode the main contributor to UEC. These differences in testing are reflective of the different usage in each key country and region and were incorporated into the analysis.

To estimate the base energy consumption of TVs in each country, CLASP researched market studies, surveys, and product databases. Due to the quick changes in technology and TV size, both of which impact UEC, CLASP attempted to use the most up-to-date data to estimate the efficiency of products currently in the market. While several countries have minimum energy performance standards (MEPS) in place for TVs, these were often out of date given the rate of change in TV technology and therefore were *not* used as an indicator of the average performance of TVs shipped.

Figure 1 for example, shows the UEC of TVs in Australia and New Zealand's product database and the applicable MEPS. For some of the models in the database, the MEPS level is four times higher than the actual consumption. (The only exception was India, where the MEPS was recently updated).

FIGURE 1.: ANNUAL ENERGY CONSUMPTION OF TVS IN AUSTRALIA IS MUCH BELOW THE MEPS LIMIT



CLASP therefore used product databases, surveys, and market studies to develop energy consumption trends and applied these values to the other countries in each region. In regions with multiple key countries, CLASP calculated a shipment-weighted average, assuming that the country with the highest shipments would be most representative of that region. In addition to the estimated shipments in each country, Omdia provided shipments by size and resolution for seven countries or regions: China, Japan, other Asia Pacific countries, Middle East and Africa, Latin America, North America, Western Europe,

and Eastern Europe. CLASP used these size breakdowns to weight the UECs in product databases for key countries in each region, thereby calculating a shipment-weighted, rather than model-weighted **Business-as-usual (BAU)** UEC.

Mepsy also includes two other scenarios, Global Benchmark scenario and **Net Zero Hero (NZH)** scenario. **Global Benchmark** scenario usually applies those efficiency levels recommended by CLASP and other organizations. For TVs, CLASP applied the recent EU Ecodesign MEPS requirements for on-mode electronic displays, which are given in the equation and table below.[14] CLASP also assumed that the standby power was 0.5 W in all countries.

$$On\ Mode\ Power = EEI \times \left(3 \times \left[90 \times tanh\left(0.02 + 0.004 \times (Area - 11)\right) + 4\right] + 3\right) - 1$$

Where:

Area is the screen area measured in square decimeters (cm^2).

TABLE 1: ENERGY EFFICIENCY INDEX (EEI) AND STANDBY POWER LIMITS FOR HD AND UHD SCENARIOS COMPARED TO GLOBAL BENCHMARK AND NET ZERO HERO STANDARDS

SCENARIOS	HIGH DEFINITION (HD) EEI (ENERGY EFFICIENCY INDEX)	ULTRA HIGH DEFINITION (UHD) EEI	STANDBY POWER LIMIT (WATTS)
Global Benchmark (EU Tier1 level in 2023 requirements)	0.9	1.1	0.5
Net Zero Hero (11-13% better than EU Tier 2 level in 2023 requirements)	0.65	0.8	0.5

CLASP calculated the shipment-weighted average area and proportion of HD and UHD for each area and weighted it by the expected number of hours in on mode to calculate the final **Global Benchmark** and **NZH** UECs. In cases where the BAU exceeded the GB level based on the EU requirements, we set the GB UEC values half-way between BAU and NZH.

[14] "Commission Regulation (EU) 2019/2021 of 1 October 2019 Laying down Ecodesign Requirements for Electronic Displays Pursuant to Directive 2009/125/EC of the European Parliament and of the Council, Amending Commission Regulation (EC) No 1275/2008 and Repealing Commission Regulation (EC) No 642/2009 (Text with EEA Relevance)Text with EEA Relevance" (2021), http://data.europa.eu/eli/reg/2019/2021/2021-05-01/eng.

GB UEC = BAU UEC, if BAU UEC $\leqslant$ GB UEC based on EU requirements

GB UEC = $\frac{BAU\ UEC+NZH\ UEC}{2}$, if BAU UEC $>$ GB UEC based on EU requirements

For the calculation of the weighted average area and proportion of HD and UHD:

$$Shipment-weighted\ average\ UEC = \sum_{i}\left(\frac{HD_i}{UHD_i} \times UEC_i \times Hours_{\ on-mode,i}\right)$$

Where:

$\frac{HD_i}{UHD_i}$ is the share of HD or UHD devices in that specific area i;

UEC_i is the UEC (energy consumption) for that specific area i;

$Hours_{\ on-mode,i}$ represents the expected hours that the devices are in use, weighted by their usage in each region.

Table 2 shows the base case, GB, and NZH UEC values for key countries and their regions.

TABLE 2. TV DATA AND ASSUMPTIONS IN KEY COUNTRIES FOR EACH REGION.

KEY COUNTRY	REGION	AVG LIFETIME (YR)	SOURCE	AVG USE (HR/DAY)	AVERAGE USAGE SOURCE	AVG AREA (CM^2)	BAU UEC (KWH/YR)	BASE-UEC (SOURCE)	BASE-UEC METHOD	GB UEC (KWH/YR)	NZH UEC (KWH/YR)
Australia	Asia Pacific	NA		10	Link	48	214	Link	Models grouped by their diagonal size and weighted by regional shipments of that size	185	156
New Zealand	Asia Pacific	NA		10	Link	48	220	Link	Models grouped by their diagonal size and weighted by regional shipments of that size	216	156
United States of America	North America	NA		3.9	Link	72	128	Link	See detailed method in the report	111	94
Singapore	Asia Pacific	NA		5	Link	48	111	Link	Models grouped by their diagonal size and weighted by regional shipments of that size	110	80

KEY COUNTRY	REGION	AVG LIFETIME (YR)	SOURCE	AVG USE (HR/DAY)	AVERAGE USAGE SOURCE	AVG AREA (CM^2)	BAU UEC (KWH/YR)	BASE-UEC (SOURCE)	BASE-UEC METHOD	GB UEC (KWH/YR)	NZH UEC (KWH/YR)
China	China	5	Link	2.87	Wang Qingyi, 2018 China Energy Statistics, Energy Foundation. According to the report, total annual usage is 1050 hrs, so daily use is 2.87 hrs	72	120		Based on the assumptions on household survey	96	70
Japan	Japan	5	Use Chinese data; assume more similar than rest of Asia Pacific.	2.87	Use Chinese data; assume more similar than rest of Asia Pacific.	53	120	Use Chinese data; assume more similar than rest of Asia Pacific.	Use Chinese data; assume more similar than rest of Asia Pacific.	74	54
India	Asia Pacific	7	Link	6	Link	48	117	MEPS requirement for average screen size		106	96

KEY COUNTRY	REGION	AVG LIFETIME (YR)	SOURCE	AVG USE (HR/DAY)	AVERAGE USAGE SOURCE	AVG AREA (CM^2)	BAU UEC (KWH/YR)	BASE-UEC (SOURCE)	BASE-UEC METHOD	GB UEC (KWH/YR)	NZH UEC (KWH/YR)
European Union	Eastern Europe	10	Link	4	Link	59	100	EU 2018 DB, n=738 models Divided DB into 3 screen size groups and took weighted average	Models grouped by their diagonal size and weighted by regional shipments of that size	100	80

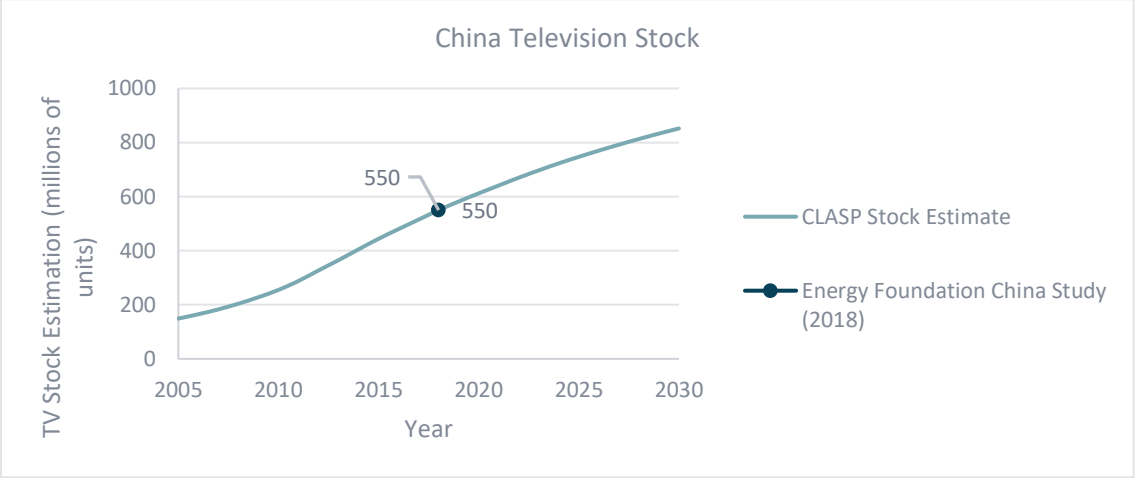
KEY COUNTRY	REGION	AVG LIFETIME (YR)	SOURCE	AVG USE (HR/DAY)	AVERAGE USAGE SOURCE	AVG AREA (CM^2)	BAU UEC (KWH/YR)	BASE-UEC (SOURCE)	BASE-UEC METHOD	GB UEC (KWH/YR)	NZH UEC (KWH/YR)
European Union	Western Europe	10	Link	4	Link	66	111	EU 2018 DB, n=738 models Divided DB into 3 screen size groups and took weighted average	Models grouped by their diagonal size and weighted by regional shipments of that size	100	80
Brazil	Latin America	NA		5	There is no report found on the average usage hour. We make an assumption that the average usage hour is 5 for now.	58	207		Each model grouped by its diagonal size and weighted by regional shipments of that size. On mode and standby weighted by usage hours	133	97

KEY COUNTRY	REGION	AVG LIFETIME (YR)	SOURCE	AVG USE (HR/DAY)	AVERAGE USAGE SOURCE	AVG AREA (CM^2)	BAU UEC (KWH/YR)	BASE-UEC (SOURCE)	BASE-UEC METHOD	GB UEC (KWH/YR)	NZH UEC (KWH/YR)
NA	Middle East and Africa	NA		NA		52	NA	121	No key country available; using shipment weighted average of countries in other regions	92	68

4. Model Outputs and Validation

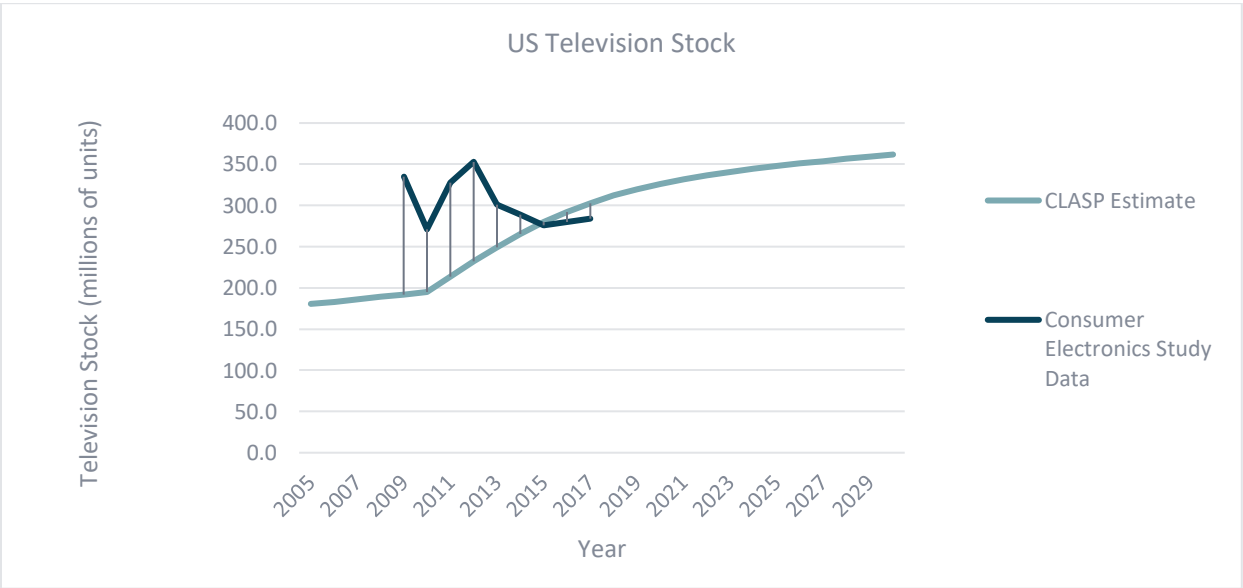
The initial comparisons of CLASP's model against published results are presented in Figure 2-5.

FIGURE 2. COMPARISON OF CLASP MODEL ESTIMATES OF TV STOCK IN CHINA AND PUBLISHED RESULTS FROM ANOTHER SOURCE



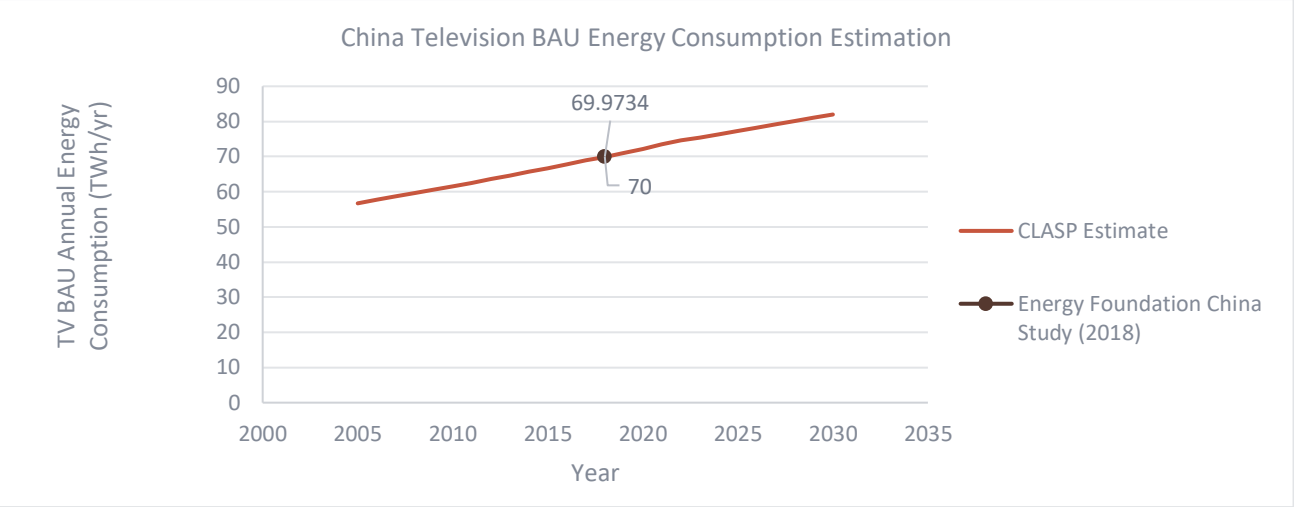
The 2018 stock for China in Mepsy closely aligns with the estimate provided by the Energy Foundation in China.

FIGURE 3. COMPARISON OF CLASP MODEL ESTIMATE OF NATIONAL ENERGY CONSUMPTION IN USA AND PUBLISHED RESULTS FROM OTHER SOURCE



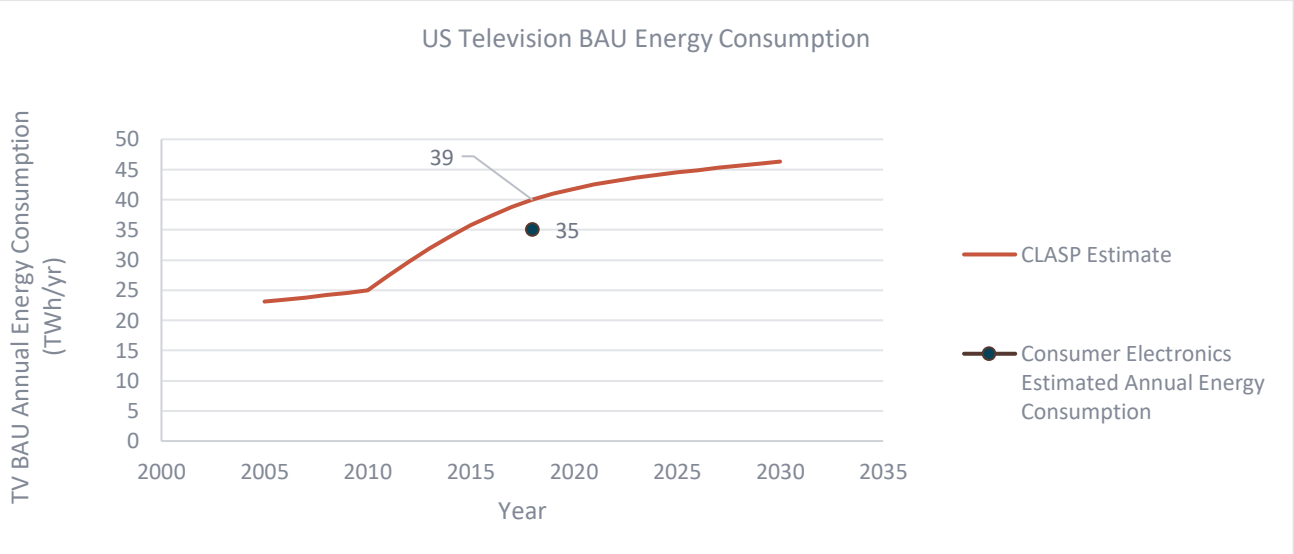
The estimated TV stock in the US differs no more than 28% from the latest consumer electronics study data from the US.

FIGURE 4. COMPARISON OF CLASP MODEL ESTIMATE OF NATIONAL ENERGY CONSUMPTION IN CHINA AND PUBLISHED RESULTS FROM OTHER SOURCE



The energy consumption for China in Mepsy closely aligns with the estimate from the Energy Foundation's study in China.

FIGURE 5. COMPARISON OF CLASP MODEL ESTIMATE OF NATIONAL ENERGY CONSUMPTION IN THE UNITED STATES AND PUBLISHED RESULTS FROM OTHER SOURCE



The CLASP modeled estimate is 11% higher than the published result.

Glossary

Area (Screen Area): The measurement of the TV screen's surface, typically in square decimeters (dm^2). This affects the TV's energy consumption, as larger screens generally consume more power.

Base Case Energy Consumption (Base-UEC): The estimated energy consumption of TVs under current market conditions, without any interventions, assuming business-as-usual scenarios (BAU).

Best Available Technology (BAT): The most energy-efficient and technologically advanced products available on the market, used as a benchmark for comparison.

Eco-design Minimum Energy Performance Standards (MEPS): Regulations that set the minimum energy efficiency standards for products like TVs. These standards are often updated to reflect technological advancements and environmental goals.

Energy Efficiency Index (EEI): A numerical value that quantifies the energy efficiency of a television. The lower the EEI, the more energy-efficient the TV is.

Energy Consumption Trends: The patterns or movements in the amount of energy consumed by TVs over time, typically based on data from surveys, market studies, or product databases.

Energy Foundation: An organization that collects and publishes energy-related data and reports, such as on energy use in TVs, typically focused on a specific region like China.

Extrapolation: The process of estimating future data based on existing data trends, used in this model to forecast future TV shipments and energy consumption.

Global Benchmark (GB): A standard or reference point for global TV energy efficiency, typically based on leading regulations or energy performance standards like those from the EU.

Lifetime (Average Lifetime): The expected operational lifespan of a TV, generally measured in years. This figure impacts the overall energy consumption over the life of the product.

Model-Weighted Business-As-Usual (BAU) unit energy consumption: The energy consumption estimate in a business-as-usual scenario, weighted by the number of units (shipments) of TVs in different regions and sizes.

MEPS UEC: The energy consumption level that a TV must meet to comply with the Minimum Energy Performance Standards (MEPS) in a given region or country.

Net Zero Hero (NZH): A hypothetical scenario or standard in which energy efficiency is maximized to reach a net-zero energy consumption target, typically reflecting the highest level of efficiency achievable.

On-Mode Power Consumption: The amount of energy a TV uses while it is in active use, i.e., when the screen is on and the user is watching television.

Shipment-Weighted Average: A method of calculating averages by giving more weight to regions or countries with higher shipments of TVs, providing a more accurate representation of global energy consumption.

Shipments: The number of TVs sold and distributed within a specific region or market. This data is crucial for calculating stock and energy consumption forecasts.

Size: The physical dimensions of a TV, often measured by the diagonal screen length. Larger TVs typically consume more energy due to their increased screen area.

Standby Mode Power Consumption: The power consumption of a TV when it is not in use but is still turned on, either in passive or network standby mode.

Standby Mode: The state a TV enters when it is turned off but still receiving power, either to maintain basic functions (passive standby) or an internet connection (network standby).

Stock: The total number of TVs in use in a specific country or region. This is influenced by past shipments and product lifetimes.

Unit Energy Consumption (UEC): The total energy consumed by a TV annually, typically measured in kilowatt-hours per year (kWh/year), which includes both on-mode and standby power usage.

TV Technology: Refers to the type of technology used to display images on the TV screen, such as LED-LCD, OLED, or older technologies like plasma or CRT (cathode ray tube).

Resolution: The clarity of the TV's image, defined by the number of pixels it displays. Common resolutions include Full HD (1920x1080 pixels) and Ultra HD (3840x2160 pixels), with higher resolutions generally leading to higher energy consumption.

Energy Consumption: The amount of electricity a TV uses, measured in kilowatt-hours (kWh), which is influenced by factors such as screen size, resolution, technology, and usage patterns.

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