Technical Appendix

Ceiling and Portable Fans

1. Introduction

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

The Mepsy ceiling and portable fan model includes all electric cooling or comfort fans typically used in homes and businesses, classified under Harmonized Commodity Description and Coding System (HS) code 841451.[1] The code includes fans placed or mounted on tables, floors, walls, windows, ceilings, or roofs, with a self-contained electric motor of an output not exceeding 125W. Other fan products, such as ventilation, kitchen hood, or industrial, are not included.

CLASP divided fans into two categories: larger ceiling fans and smaller portable or ceiling fans, which come in different designs and sizes (desk/table, wall, or floor/pedestal). Most portable and ceiling fans use an axial design, with fan blades surrounding a single motor pushing air in the direction of the motor axis, either in the vertical (ceiling fan) or horizontal (non-ceiling fan) plane. We did not consider newer tower or bladeless designs, due to their low expected shipments and stock.

2. Shipments and Stock

Euromonitor publishes portable and ceiling fan shipments in 210 countries from 2005 to 2024. 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 in a nearby similar country.[2] These were then reduced to the 162 countries, which are the countries included in Mepsy. Sales forecasts for the period from 2024 to 2030 were based on the compound annual growth rate (CAGR) for 2019-2024.

[1] “8414.51-Table, Floor, Wall, Window, Ceiling or Roof Fans, with a,” accessed January 14, 2025, https://www.htshub.com/us-hs/detail/841451.

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

The stock or number of fans in use in each country was estimated by accumulating shipments since 2005. Once they are shipped, fans enter service and remain in service until they fail beyond repair or are 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, the average lifetime varies based on the market study (Table 1).

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 refers to the Lawrence Berkeley National Laboratory (LBNL) study to determine a shape parameter (β) of 1.5 and a delay parameter (θ) of 0 for fans.[4]

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 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 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

[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/.

[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/.

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:

$$logit\left(\frac{\mu_c}{\alpha}\right) = \beta_0 + \beta_1 \times I_c + \beta_2 \times E_c + \beta_3 \times U_c + \beta_4 \times CDD_c$$

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. In the analysis, α is set at 2 for fans, 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.

After comparing multiple variables, we found that fan ownership is primarily influenced by factors including cooling demand measured by cooling degree days (CDDs)[10] and national electrification rate.[11] In countries where ownership data is missing, Mepsy estimates the missing data by relying on the correlation between ownership, CDD, and electrification rates. The relationship is represented by the following formula:

$$Fans\ Ownership = (0.07 + 1.5\ \times E_c +\ -5.28 * 10^{-4} \times CDD_c) \times Maximum\ Fans\ Ownership$$

This relationship is used to extrapolate ownership through 2050, based on projected CDD and electrification rates.[12] The household ownership rate is then multiplied by the projected number of households, as estimated by the United Nations, to calculate total stock. Additional details of this approach are provided in the 'Extending-Mepsy to 2050'.[13] From 2050 to 2060, Mepsy extrapolates appliance stock based on the Compound Annual Growth Rate (CAGR) calculated from the data between 2045 and 2050.

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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 "A Global Degree Days Database for Energy-Related Applications," accessed December 12, 2024, https://kapsarc.opendatasoft.com/explore/dataset/a-global-degree-days-database-for-energy-related-applications/information/.

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

12 In the model, we use linear interpolation to ensure data availability for the intervening years. A 100% cap was applied to electrification, meaning the rate will not increase once it reaches 100%. For cooling degree days,

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

3. Unit Energy Consumption, Usage, and Standards Scenarios

The **Business-as-usual UEC** was calculated for one key country in each region based on the service value and flow rate of the typical-sized fan in the market.

$$UEC_{Baseline} = \frac{\frac{\text{Service Value}}{\text{Flow Rate}}}{60} * Annual\ Hours\ of\ Use$$

In the formula, Service Value is expressed in m3/min/W and f Flow Rate in m3/min. Dividing the Service Value by the f Flow Rate provides the input power, which is multiplied by the annual hours of use to obtain the UEC.

CLASP did not have any data for Pakistan, China, Egypt, and Russia apart from MEPS requirements that had been recently updated, so these were used to estimate the business-as-usual service value. The fan size and flow rate were assumed equal to those in nearby regions (typically 48 or 52 in/1200 or 1300 mm for ceiling fans and 16 in/400 mm blade sweep for portable fans). Table 1 shows the base case performance parameters.

TABLE 1. BUSINESS AS USUAL PERFORMANCE PARAMETERS FOR KEY COUNTRIES IN EACH REGION

		CEILING FANS					NON-CEILING FANS				
REGION	COUNTRY	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)
South Asia	**India**	210	IS 374:2018, p. 6	3.1	BEE, Impact of Energy Efficiency Measures, 2018-2019, 2020, p. 80. "1200 mm fan, 65 W, service value is 3.1"	10					
South Asia	**Pakistan**	150	Assumed similar to other regions	2.9	Assumed equal to MEPS						
Southeast Asia	**Indonesia**	155	CLASP, Indonesia Fan Market Study and Policy Analysis, 2020, p. 58	2.6	CLASP, Indonesia Fan Market Study and Policy Analysis, 2020, p. 58	7	63	CLASP, Indonesia Fan Market Study and Policy Analysis, 2020, p. 57	1.0	CLASP, Indonesia Fan Market Study and Policy Analysis, 2020, p. 57, average of CLASP-recommended and Base Case (non-compliant) service values	5

		CEILING FANS					NON-CEILING FANS				
REGION	COUNTRY	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)
East Asia	**China**	150	Assumed similar to other regions	3.0	"According to the market research of Top10" Hu Bo and Zheng Feiyan, "Energy efficient fans:China", bigEE Appliance Guide, June 2015, p. 8.		56.21	Calculated based on average power value of 55 W. National Bureau of Statistics; industry statistics; average power of household appliances and annual utilization hours, referenced in Wang Qingyi, "2018 Energy Data," Energy Foundation China, p. 54. http://www.efchina.org/Reports-en/report-lceg-20200413-2-en	1.0	"According to the market research of Top10" Hu Bo and Zheng Feiyan, "Energy efficient fans:China", bigEE Appliance Guide, June 2015, p. 8. https://bigee.net/media/filer_public/2017/04/27/bigee_china_fans_1212.pdf	10

REGION	COUNTRY	CEILING FANS					NON-CEILING FANS				
		FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)
Europe	EU	150	Assumed similar to other regions	3.3	Average for ceiling fan Service Value, EU Air conditioners and comfort fans preparatory study, Task 7 report, p. 64		63	Based on Indonesian flow rate	0.8	Rough average for non-ceiling fan Service Value, EU Air conditioners and comfort fans preparatory study, Task 7 report, p. 64	10
Latin America	**Brazil**	104	Inmetro Product Registry Analysis	2.4			64	Analysis of Procel product registry as of December 2019	0.9	Analysis of Procel product registry as of December 2019	
North America	**United States**	119	Power at max speed multiplied by efficiency for 52-inch standard size fan across efficiency levels 0-3 US DOE, 2016-11 Final Rule TSD, pp. 5-35,5-38	2	Standard fan 0.65 D+ 38.03, where D is in inches and result in CFM/W, approx 0.028 m3/min/W). 10 CFR Part 430. 32(s)(2)(i)	13.8					

		CEILING FANS					NON-CEILING FANS				
REGION	COUNTRY	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)	FLOW RATE (M3/MIN)	SOURCE	BASE CASE SERVICE VALUE (M3/MIN/W)	SOURCE	LIFE-TIME (YR)
Sub-saharan Africa	**South Africa**						62	Average of flow rates in other regions	1.2	UEC of typical fan on the market divided by usage (to get wattage), then divided into flow rate to get service value	10
Middle East & North Africa	**Egypt**	150	Assumed similar to other regions	2.8	Assumed equal to MEPS		62	Average of flow rates in other regions	0.7	Assumed equal to MEPS	
Australia	**Australia**										
Russia	**Russian Federation**	150	Assumed similar to other regions	2.1	Assumed equal to MEPS		62	Average of flow rates in other regions	0.5	Assumed equal to MEPS	
Central Asia	**Iran**										

For countries lacking detailed data, CLASP estimated fan performance using a market-share-weighted average of key countries in each region, assuming these larger markets are representative of the region.

While the performance of fans within other countries in the region would stay constant, the usage hours could vary depending on the climate condition. Based on data from the key countries, CLASP developed a regression equation shown in Figure 1. We then used the equation to estimate the fan usage for all other countries based on the cooling degree days relative to 18.5 °C (65 °F).

FIGURE 1. THE REGRESSION EQUATION FOR ESTIMATING FAN OPERATING HOURS FROM COOLING DEGREE DAYS.

For the **UEC in the Global Benchmark (GB) and Net Zero Hero (NZH) scenarios**, Mepsy assumes all other indicators remain the same, while the service values for different fan technologies improve to a more efficient level, as listed in Table 2.

TABLE 2. SERVICE VALUES (M^3/MIN/W) OF CEILING AND NON-CEILING FANS UNDER GLOBAL BENCHMARK AND NET ZERO HERO SCENARIOS.

SERVICE VALUE	CEILING FAN (48-52 IN) (M^3/MIN/W)	NON-CEILING FAN (16 IN) (M^3/MIN/W)
Global Benchmark	4	1.08
Net Zero Hero	6	1.7
Source	Most recent India star rating system	GB: Malaysia standard NZH: Best-performing model in CLASP Indonesia fans market study

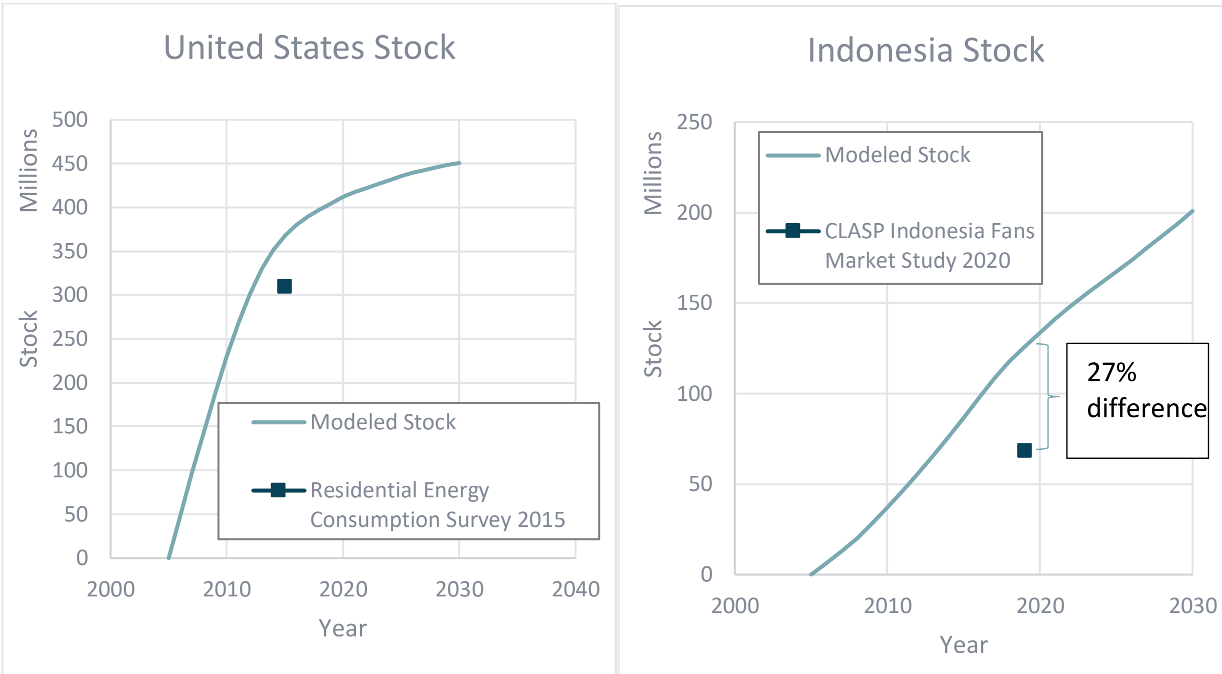
4. Model Outputs and Validation

To validate the model, CLASP compared the estimated stock of fans to published data for two key countries, the United States and Indonesia (Figure 2). The stock was calculated by adding annual shipments to the existing stock and replacing units as they retire. Since shipments began in 2005, the model's reliability improves after 2015, when earlier shipments would have started retiring. For this version, only Euromonitor data was used, but future iterations will incorporate additional data collected by CLASP.

Discrepancies between the modeled and published stock could stem from fans being used in commercial sectors. For instance, CLASP's study found that only 15% of fans in stock in 2019 were classified as "professional" or intended for commercial or industrial use.14

[14] "Indonesia-Fan-Market-Study-and-Policy-Analysis.Pdf," https://www.clasp.ngo/wp-content/uploads/2021/01/Indonesia-Fan-Market-Study-and-Policy-Analysis.pdf.

FIGURE 2. COMPARISON OF MODELED STOCK TO PUBLISHED ESTIMATES.



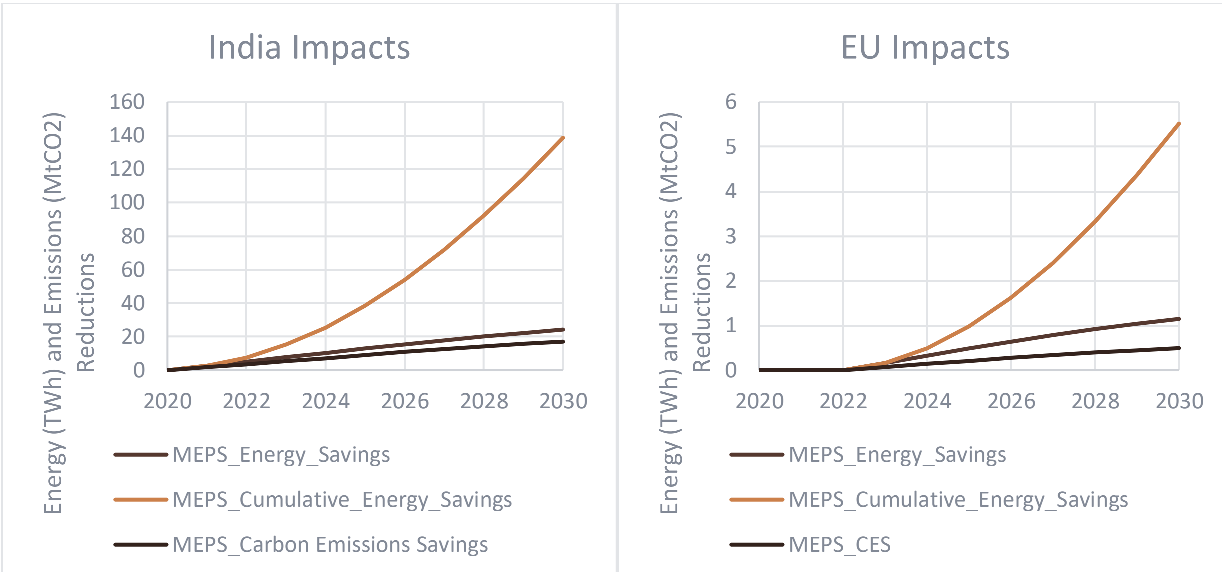
CLASP calculated the energy reduction potential of implementing specific MEPS for fans in India and the EU and compared the results to published data, as shown in Figure 3.

For India, CLASP evaluated the impact of a 4.0 m3/min/W MEPS requirement implemented in 2020. The model assumed a pre-MEPS average service value of 3.1 m3/min/W,[15] which translated to a UEC of 234 kWh/yr. In contrast, fans meeting the new MEPS level had a UEC of 181 kWh/yr. This would result in energy and emissions reductions of 24 TWh and 17 MtCO_2 annually in 2030 and 139 TWh and 97 MtCO_2 cumulatively between 2020 and 2030. This is much higher than CLASP's previous estimate that the policy would cumulatively "reduce energy and CO2 emissions by 35.9 BU [TWh], equivalent to 29 Mt CO_2 emissions reduction by 2030."16

For the EU, CLASP analyzed the impacts of MEPS requirements implemented in 2022: 4.0 m3/min/W for ceiling fans and 1.1 m3/min/W for non-ceiling fans. The model projected annual energy and emissions reductions of 1 TWh and 0.5 MtCO_2 in 2030 and 5.5 TWh and 2.4 MtCO_2 cumulatively between 2022 and 2030. The annual estimates align closely with the published savings of 1 TWh annually.[17]

[15] BEE, Impact of Energy Efficiency Measures, 2018-2019, 2020, p. 80. "1200 mm fan, 65 W, service value is 3.1"
[16] CLASP, "India Raises the Bar on Ceiling Fan Energy Efficiency", 2 August 2019, https://clasp.ngo/updates/2019/india-raises-the-bar-on-ceilingfan-energy-efficiency.
[17] EU Air conditioners and comfort fans preparatory study, Task 3 report, May 2018, p. 68.

FIGURE 3. MODELED IMPACTS OF PROJECTED MEPS IN INDIA AND THE EU



Glossary

Axial Design – A type of fan design where the blades surround a single motor, pushing air along the axis of the motor.

Ceiling Fan – A fan mounted on the ceiling, typically used for cooling or comfort in homes and businesses.

Cooling Degree Days (CDD) – A measure of how much (in degrees) and for how long (in days) the outside temperature was above a certain threshold, often used to estimate energy needs for cooling.

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

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

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

Global Benchmark (GB) Scenario – A low-ambition policy scenario based on efficiency levels recommended by organizations such as CLASP and United for Efficiency.

Household Ownership Rate – The proportion of households owning a particular appliance or product.

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

Net Zero Hero (NZH) Scenario – A high-ambition policy scenario, aligned with the targets outlined in the *Net Zero Heroes* report by CLASP, aiming to double the efficiency of key appliances to significantly reduce energy consumption.

Portable Fan – A fan that is designed to be moved and used in various locations, often smaller than ceiling fans and can be mounted on tables, floors, or walls.

Regression Analysis – A statistical method used to understand the relationship between variables, such as the correlation between appliance ownership and socio-economic factors.

Service Value – A measure of the effectiveness of a fan, typically in m^3/min/W, representing its performance in terms of airflow efficiency.

Stock – The number of appliances, such as fans or refrigerators, in use in a country, estimated by accumulating shipments since the product's introduction.

Unit Energy Consumption (UEC) – The amount of energy consumed by an appliance, typically measured in kWh/year, used to estimate the energy efficiency of a product in different scenarios.

Weibull Retirement Function – A model used to predict the failure and retirement rates of appliances like fans and refrigerators over time.

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