clasp

Efficient Appliances for People & the Planet

Extending Mepsy Past 2030

17 MAY 2022

Introduction

The current, Version 1.1 Mepsy code and app analyzes impacts to 2030, same as the Policy and Analysis Modeling System (PAMS) upon which it was based. PAMS, developed in 2007, was able to provide 23 years of analysis despite its 2030 cutoff; however, today 2030 is only 8 years away.

Mepsy users and stakeholders have therefore requested extensions of Mepsy estimates to 2040 and 2050. Lifetimes of many appliances are longer than 9 years, meaning that Mepsy does not calculate the full benefit of appliance policies that occurs only upon full stock replacement. Moreover, many efficiency organizations are coordinating policy action by 2040 or 2050 and wish to evaluate impacts well into the future.

This paper reviews extending the Mepsy model for refrigerators by first reviewing how refrigerator ownership was forecasted in 2007-2010 in the PAMS model and associated research. It then evaluates whether the model still works with updated data and proposes an improvement using beta regression. Finally, it concludes with the resultant forecasts through 2050 and integration into the Mepsy model.

Forecasting Methodologies

In 2007, the PAMS tool was developed to calculate policy impacts to 2030. PAMS estimated the stock of appliances using a logistic regression model that factored in average household income, electrification, and urbanization (for refrigerators and washing machines) and days above 18.5°C/65°F (for air conditioners). Penetration data for training the model was obtained from national surveys (such as US Residential Energy Consumption Surveys (RECS) or the USAID Demographic and Health Surveys). The data sources and calculation procedures are described in the PAMS methodology as well as a follow-on journal article.[1,2]

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[1] McNeil, Michael A.; Letschert, Virginie, E.; Van Buskirk, Robert D.; "Methodology for the Policy Analysis Modeling System", 2007. Data from early 2000's.

[2] McNeil, Michael A.; Letschert, Virginie, E.; "Modeling diffusion of electrical appliances in the residential sector", *Energy and Buildings*, 42 (6), pp. 783-790, June 2010. https://www.sciencedirect.com/science/article/pii/S0378778809003119?via%3Dihub

Since appliances are typically shared within a household, the *household ownership* rate must be multiplied by the number of households to calculate total stock. Note that the household ownership rate can exceed 100% if a significant number of households owning more than one unit, as is common for TVs and refrigerators in some developed countries. This is in contrast to *penetration rate*, which is the percentage of households possessing at least one appliance, a number that by definition cannot exceed 100%. There is often confusion between these two numbers[3]; however, it appears that for developing countries with both penetration and ownership data, the two are very similar at least in the case of refrigerators, presumably due to low numbers of households owning more than one appliance, as can be seen below.

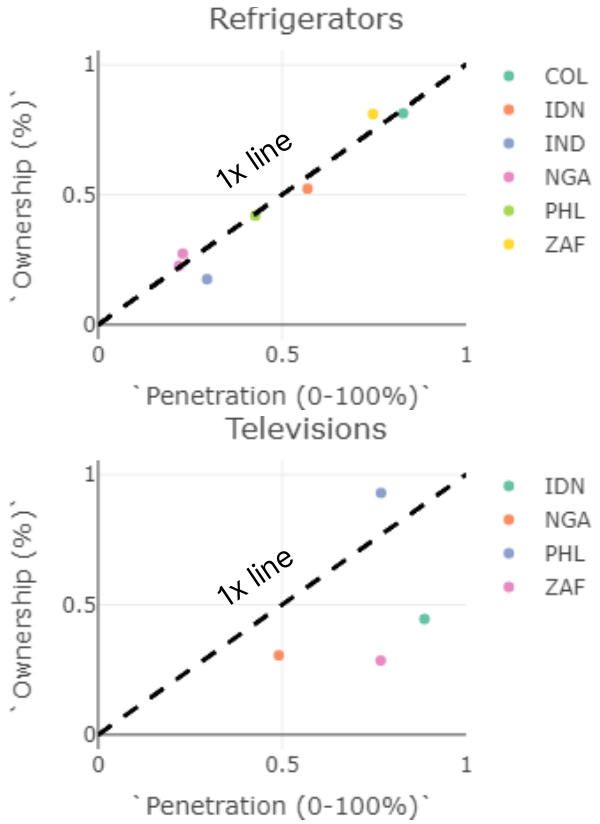


Figure 1. Comparison of penetration (% of households with at least one appliance) and ownership (number of appliances/number of households). Penetration data from USAID; ownership data from Euromonitor; plotted for years and countries where there was overlap in the data (various years 2015–2018).

Similarly, income is the per-household income, and is estimated as the purchasing power parity (PPP) adjusted national GDP divided by the number of households. In PAMS, it is expressed as monthly income in units of thousand dollars (i.e., divided by 12,000), based

[3] Cabeza, Louisa, F.; Űrge-Vorsatz, Diana; Palacios, Anabel; Űrge, Daniel; Serrano, Susana; Barreneche, Camila, "Trends in Penetration and Ownership of Household Appliances", *Renewable and Sustainable Energy Reviews*, 82 (3), pp. 4044-4059, February 2018.
https://www.sciencedirect.com/science/article/pii/S1364032117314454#

on GDP in 2000$. Finally, for consistency, electrification and urbanization percentages should also be per-household; however, these are often reported at the per-person level. There could potentially be a discrepancy (if rural, unelectrified households tend to be larger). However, there is little difference in the reported data for electrification:

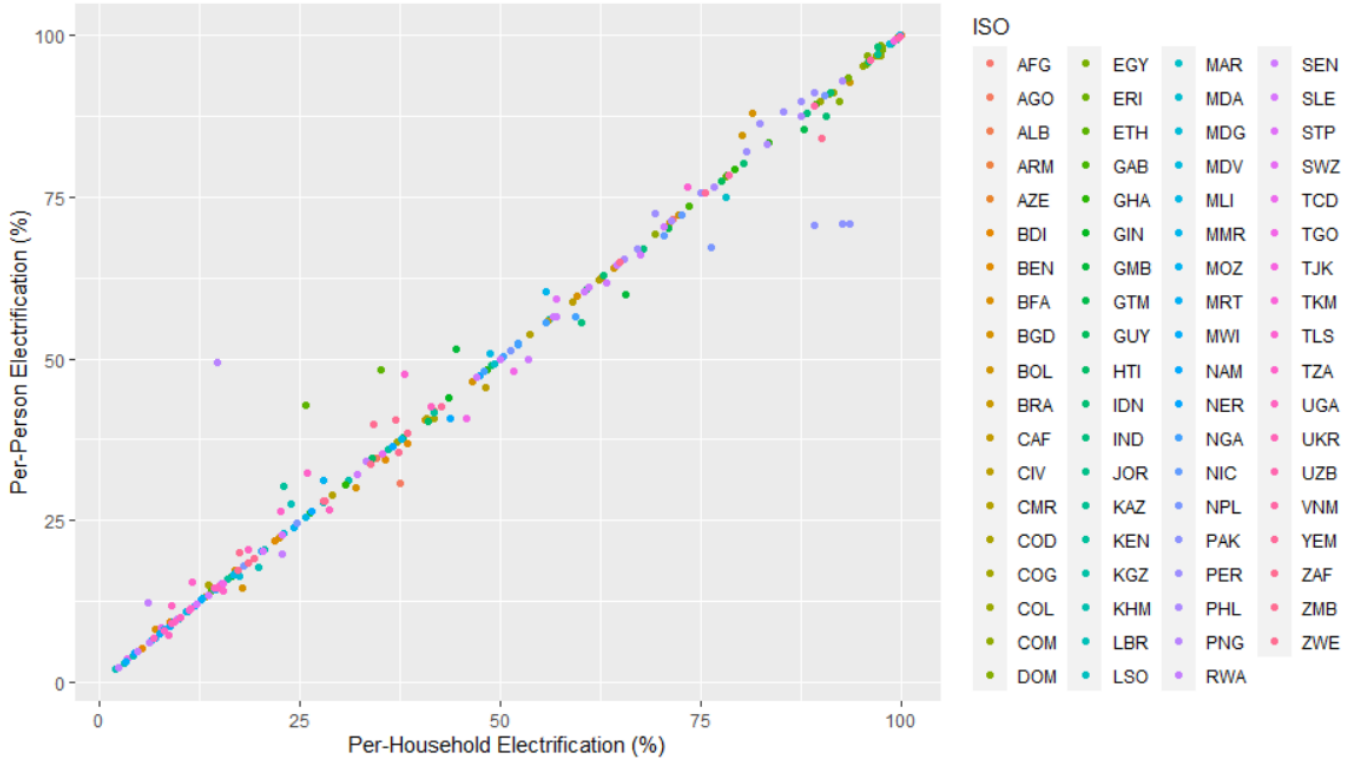


Figure 2. Comparison of electrification reported on a per-household level (USAID) versus per-person level (World Bank) for various countries and years where there is overlap (years various 1990-2019)

In both PAMS and the follow-on paper, the logistic fit equation takes the following form, with differing parameters in the two sources, due to the addition of newer or more data in the intervening 3 years and some minor methodological changes[4]:

$$Ownership = \frac{\alpha}{1 + \gamma e^{\beta_1 \cdot Income + \beta_2 \cdot Electrification + \beta_3 \cdot <Urbanization|CoolingDay\%>}}$$

or

$$\ln\left(\frac{\alpha}{Ownership} - 1\right) = \ln\gamma + \beta_1 \cdot Income + \beta_2 \cdot Electrification + \beta_3 \cdot < Urbanization|CoolingDay\% >$$

Where:

SYMBOL	VARIABLE	VALUE						
		REFRIG[1]	REFRIG[2]	AC[1]	AC[2]	WASHING MACHINE[1]	WASHING MACHINE[2]	TV[2]
α	Maximum Ownership	1.3	1.4	1	$0.994 - 1.17e^{-0.00298 \cdot CDD}$	1.04	1	3
$\ln\gamma$	Constant as used in model	4.502	4.84	8.078	4.843	6.999	8.91	3.701
β_1	Income Coefficient	-0.3776	-1.3×10^{-5}	-0.631	-6.9×10^{-5}	-0.4860	-3.5×10^{-5}	-2.5×10^{-5}
β_2	Electrification Coefficient	-3.2775	−3.59	-2.867	0	-7.1245	−8.98	−2.39
β_3	Urbanization Coefficient	-1.0787	−2.24	-1.973	0	1.2110	0	0

[4]Also, there was a change in units for income from thousands of dollars in PAMS to dollars in the paper and a reliance on cooling degree days (CDD) above 18.5°C, rather than proportion of days above 18.5°C, when modeling AC ownership.

Evaluation of Methodologies

In the paper, McNeil and Letschert reviewed the root-mean-square error between their modeled results and the initial data used to train the model, and found "an error of 1.6% for refrigerators, 3.5% for washing machines, 2.5% for televisions and 3.9% for air conditioners." This appears reasonably low given typical margin of error in surveys. For example, a 1000-respondent survey in a country of 300 million (e.g., the United States) provides a 3% error at the 95th percentile confidence level; reducing that down to 1% requires 5000 respondents.

To validate whether the PAMS-style linear regression model continues to perform well using today's data, and could therefore be suitable for forecasting to 2050, CLASP re-implemented the PAMS logistic regression model in R and tested it using the following updated data sources.

VARIABLE	SOURCE	YEAR	NOTES
Refrigerator Penetration	USAID Demographic and Health Surveys Households Possessing a Refrigerator (%)	Various (1990–2019)	Latest year available for each country used in analysis[5]
PPP GDP (2017$)	World Bank GDP, PPP (constant 2017 international $)	1990–2019	Indicator code NY.GDP.MKTP.PP.KD
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Combined with GDP to calculate household monthly income
Electrification	World Bank Access to Electricity (% of population)	Various (1990–2019)	Indicator code EG.ELC.ACCS.ZS
Urbanization	UN Population Division World Urbanization Prospects 2018 (% of population residing in urban areas)	1950–2050	

CLASP filled in missing data in the household size and urbanization dataset using linear interpolation in between available years, and then using linear extrapolation past the latest year available. For example, urbanization is provided every 5 years, so CLASP linearly interpolated during the 4 years in between. Meanwhile, household size is only provided during years that a survey was conducted, so CLASP again interpolated during the in-

[5] McNeil and Letschert write that keeping multiple years for each country would introduce errors through too many data points that are correlated to each other.

between years, then extrapolated beyond the years available assuming the households size remained constant.

According to the UN, "Estimated trends indicate that in most countries the average household size has declined over recent decades", however "this trend is not universal", with household size remaining unchanged across some countries in sub-Saharan Africa.[6]

Once CLASP had complete data for all the explanatory variables (monthly income, electrification, and urbanization) for the period 1990–2019, CLASP joined the data to the latest year of refrigerator penetration from the USAID surveys, using the ISO code of the country and the year of the survey as the keys. So in the case of Afghanistan, the latest survey year was 2015, so that was joined with data or interpolated or extrapolated estimates for 2015 from the household monthly income, electrification, and urbanization datasets.

The resulting data set with any incomplete rows discarded is shown below:

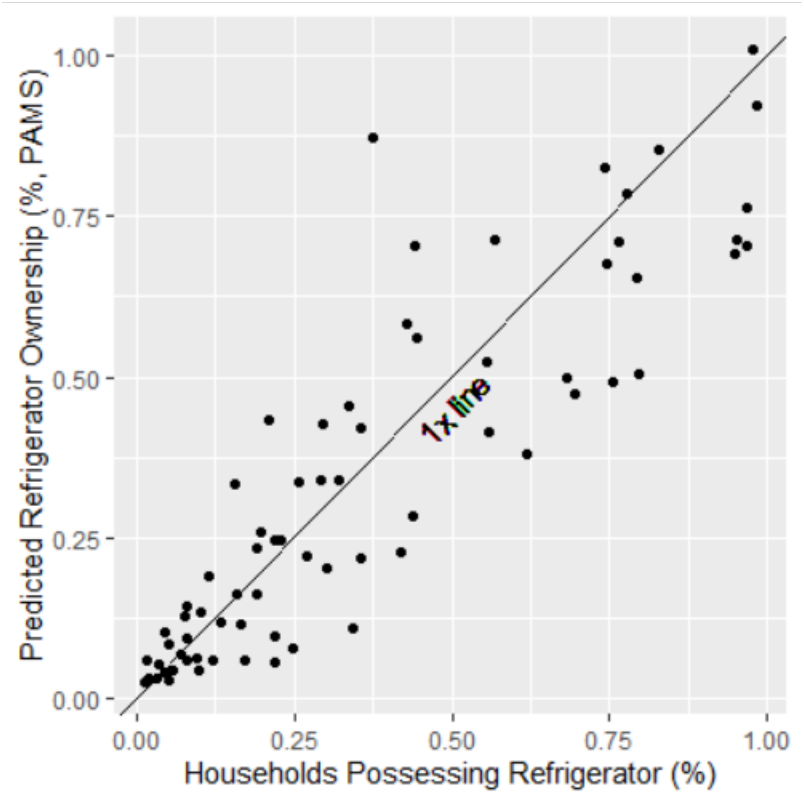
COUNTRY	ISO	YEAR	REFRIG. PENETRATION	HOUSEHOLD MONTHLY INCOME (2017$ PPP)	ELEC.	URBAN.
Afghanistan	AFG	2015	19%	$1,386	72%	25%
Albania	ALB	2008	95%	$3,097	100%	50%
Angola	AGO	2015	36%	$3,249	42%	63%
Armenia	ARM	2015	97%	$3,423	100%	63%
Azerbaijan	AZE	2006	77%	$3,266	100%	53%
Bangladesh	BGD	2017	29%	$1,550	82%	36%
Benin	BEN	2017	5%	$1,334	36%	47%
Bolivia	BOL	2008	34%	$2,085	80%	66%
Brazil	BRA	1996	78%	$3,857	94%	78%
Burkina Faso	BFA	2017	6%	$1,009	17%	29%
Burundi	BDI	2016	1%	$320	9%	12%
Cambodia	KHM	2014	8%	$1,292	56%	22%
Cameroon	CMR	2018	23%	$1,498	62%	56%
Central African Republic	CAF	1994	2%	$431	3%	37%
Chad	TCD	2014	2%	$893	8%	22%
Colombia	COL	2015	83%	$4,146	98%	80%

[6] United Nations Population Division, “Patterns and trends in household size and composition: Evidence from a United Nations dataset”, 2019, p. 8. https://www.un.org/en/development/desa/population/publications/pdf/ageing/household_size_and_composition_technical_report.pdf

COUNTRY	ISO	YEAR	REFRIG. PENETRATION	HOUSEHOLD MONTHLY INCOME (2017$ PPP)	ELEC.	URBAN.
Comoros	COM	2012	27%	$1,318	69%	28%
Congo	COG	2011	19%	$1,862	42%	64%
Congo Democratic Republic	COD	2013	5%	$430	14%	42%
Cote d'Ivoire	CIV	2011	11%	$1,466	56%	48%
Dominican Republic	DOM	2013	74%	$3,974	97%	77%
Egypt	EGY	2014	97%	$3,563	100%	43%
Eswatini	SWZ	2006	34%	$2,671	35%	22%
Ethiopia	ETH	2019	7%	$853	35%	21%
Gabon	GAB	2012	37%	$5,152	89%	87%
Gambia	GMB	2019	44%	$1,524	66%	62%
Ghana	GHA	2019	36%	$1,574	84%	57%
Guatemala	GTM	2014	44%	$3,072	88%	50%
Guinea	GIN	2018	17%	$1,300	44%	36%
Guyana	GUY	2009	62%	$2,989	78%	27%
Haiti	HTI	2016	14%	$1,062	41%	53%
India	IND	2015	30%	$2,077	88%	33%
Indonesia	IDN	2017	57%	$3,518	97%	55%
Jordan	JOR	2012	98%	$4,516	100%	88%
Kazakhstan	KAZ	1999	79%	$2,790	97%	56%
Kenya	KEN	2015	8%	$1,160	42%	26%
Kyrgyz Republic	KGZ	2012	80%	$1,490	100%	36%
Lesotho	LSO	2014	22%	$745	28%	26%
Liberia	LBR	2019	10%	$589	24%	52%
Madagascar	MDG	2016	4%	$646	23%	36%
Malawi	MWI	2017	5%	$390	13%	17%
Maldives	MDV	2016	98%	$7,870	100%	39%
Mali	MLI	2018	10%	$1,106	49%	42%
Moldova	MDA	2005	76%	$1,180	99%	43%
Morocco	MAR	2003	56%	$2,237	78%	54%
Mozambique	MOZ	2018	17%	$470	28%	36%
Myanmar	MMR	2015	16%	$1,501	56%	30%
Namibia	NAM	2013	42%	$3,473	47%	45%
Nepal	NPL	2016	16%	$1,025	91%	19%
Nicaragua	NIC	2001	26%	$1,775	73%	55%

COUNTRY	ISO	YEAR	REFRIG. PENETRATION	HOUSEHOLD MONTHLY INCOME (2017$ PPP)	ELEC.	URBAN.
Niger	NER	2012	3%	$536	14%	16%
Nigeria	NGA	2018	22%	$2,105	59%	50%
Pakistan	PAK	2017	55%	$2,590	93%	36%
Papua New Guinea	PNG	2016	10%	$1,912	15%	13%
Peru	PER	2012	44%	$3,493	89%	77%
Philippines	PHL	2017	43%	$2,863	93%	47%
Rwanda	RWA	2017	2%	$701	33%	17%
Sao Tome and Principe	STP	2008	30%	$1,037	57%	63%
Senegal	SEN	2019	32%	$2,450	70%	48%
Sierra Leone	SLE	2019	12%	$845	23%	42%
South Africa	ZAF	2016	75%	$3,557	90%	65%
Tajikistan	TJK	2017	69%	$1,542	99%	27%
Tanzania	TZA	2017	8%	$993	26%	33%
Timor-Leste	TLS	2016	20%	$1,469	73%	30%
Togo	TGO	2017	8%	$575	52%	41%
Uganda	UGA	2018	5%	$801	41%	24%
Ukraine	UKR	2007	95%	$2,638	100%	68%
Uzbekistan	UZB	1996	68%	$1,087	100%	44%
Vietnam	VNM	2005	21%	$1,383	96%	27%
Zambia	ZMB	2018	22%	$1,505	34%	44%
Zimbabwe	ZWE	2015	25%	$1,006	34%	32%

Using the 2007 PAMS model coefficients to estimate the refrigerator ownership (potentially higher than 100%) resulted in a root-mean-square error of 1.6 percentage points, equal to the results published by McNeil in Letschert in 2010. These estimates compared to the USAID data are illustrated below:



CLASP also re-calculated the logistic regression model coefficients using updated income, electrification, urbanization, and the USAID refrigeration penetration data shown above. CLASP also re-calculated the logistic model using refrigerator ownership data for 41 larger or wealthier countries from Euromonitor.[7] Finally, CLASP developed models for both datasets using beta regression with a logit link function (default choice in R betareg package). Several recent papers argue that beta regression is better suited to modeling realistic data between 0 and 100%, producing more evenly distributed errors than transforming data and then performing linear regression as above.[8] (Note that ownership data greater than 100% still has to be scaled down below 100% by dividing by the assumed maximum ownership rate.) The coefficients and percentage error of the two model types across the two datasets are shown below. The maximum refrigerator ownership was set

[7] Euromonitor International, "Penetration Rates: Consumer Appliances in All Countries", *Passport*, 2021. Accessed May 31, 2021. Sum of data for "Fridges" and "Fridge Freezers". Note that while the dataset is called "penetration", the data exceeds 100% so is here referred to as "ownership".

[8] Francisco Cribari-Neto and AchimZeileis, "Beta Regression in R", Accessed June 4, 2021. https://cran.r-project.org/web/packages/betareg/vignettes/betareg.pdf

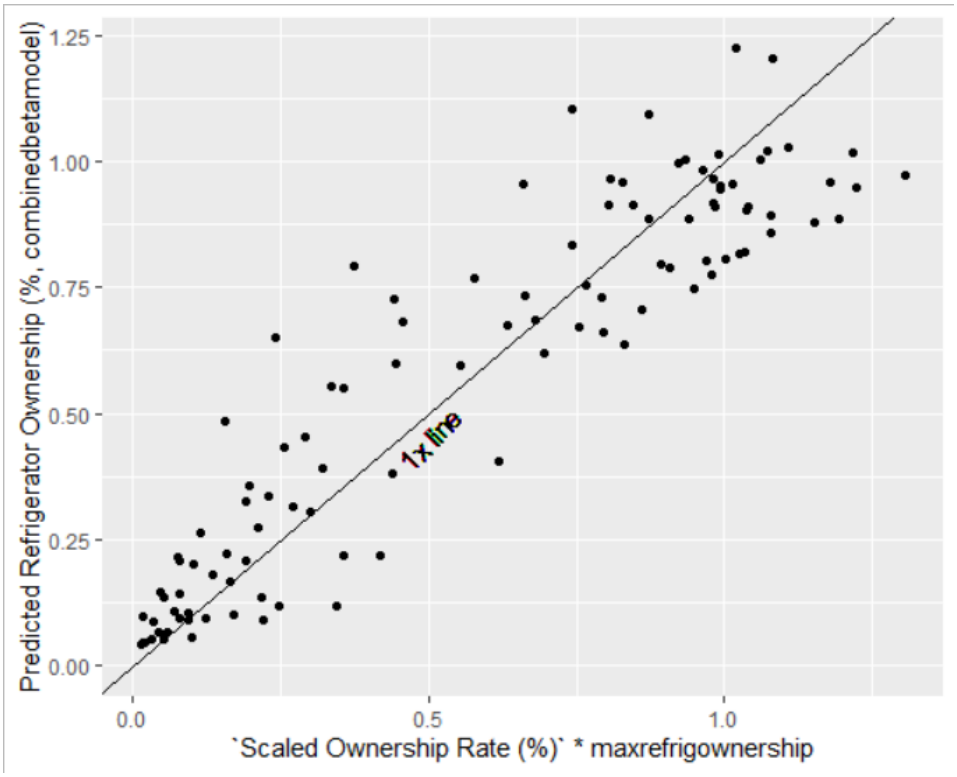
at 150% across all the models.

As can be seen, the beta regression model using the combined dataset seems to have the best performance, with the highest R^2, lowest error, and all variables significant (urbanization to 0.05, income and electrification to 0.001). This model was therefore selected as the basis for forecasting into the future, as further discussed in the next section.

		LOGISTIC REGRESSION MODEL			BETA REGRESSION MODEL		
SYM	VARIABLE	USAID DATA	EUROMON-ITOR DATA	COMBINED[9]	USAID DATA	EUROMON-ITOR DATA	COMBINED[9]
α	Maximum Ownership	1.5	1.5	1.5	1.5	1.5	1.5
	Constant (ln γ in logistic model)	4.317	4.896	4.317	-3.788	-4.417	-3.841
β_1	Income Coefficient[10]	-2.51×10^{-4}	-3.00×10^{-5}	-2.51×10^{-4}	1.97×10^{-4}	3.74×10^{-5}	8.47×10^{-5}
β_2	Electrification Coefficient	-0.029	-0.043	-0.029	0.027	0.038	0.008
β_3	Urbanization Coefficient	-0.009	-0.013	-0.009	0.007	0.012	0.031
	Multiple R^2/ Pseudo R^2	0.811	0.457	0.811	0.810	0.456	0.853
	RMS Error (percentage points)	1.6	2.7	1.8	1.6	2.7	1.5

[9] Euromonitor data retained for countries where both were available as it is more recent (2019) as well as a measure of ownership rather than penetration.

[10] Income is monthly household income, estimated as PPP-adjusted GDP, in 2017 international dollars, divided by number of households.



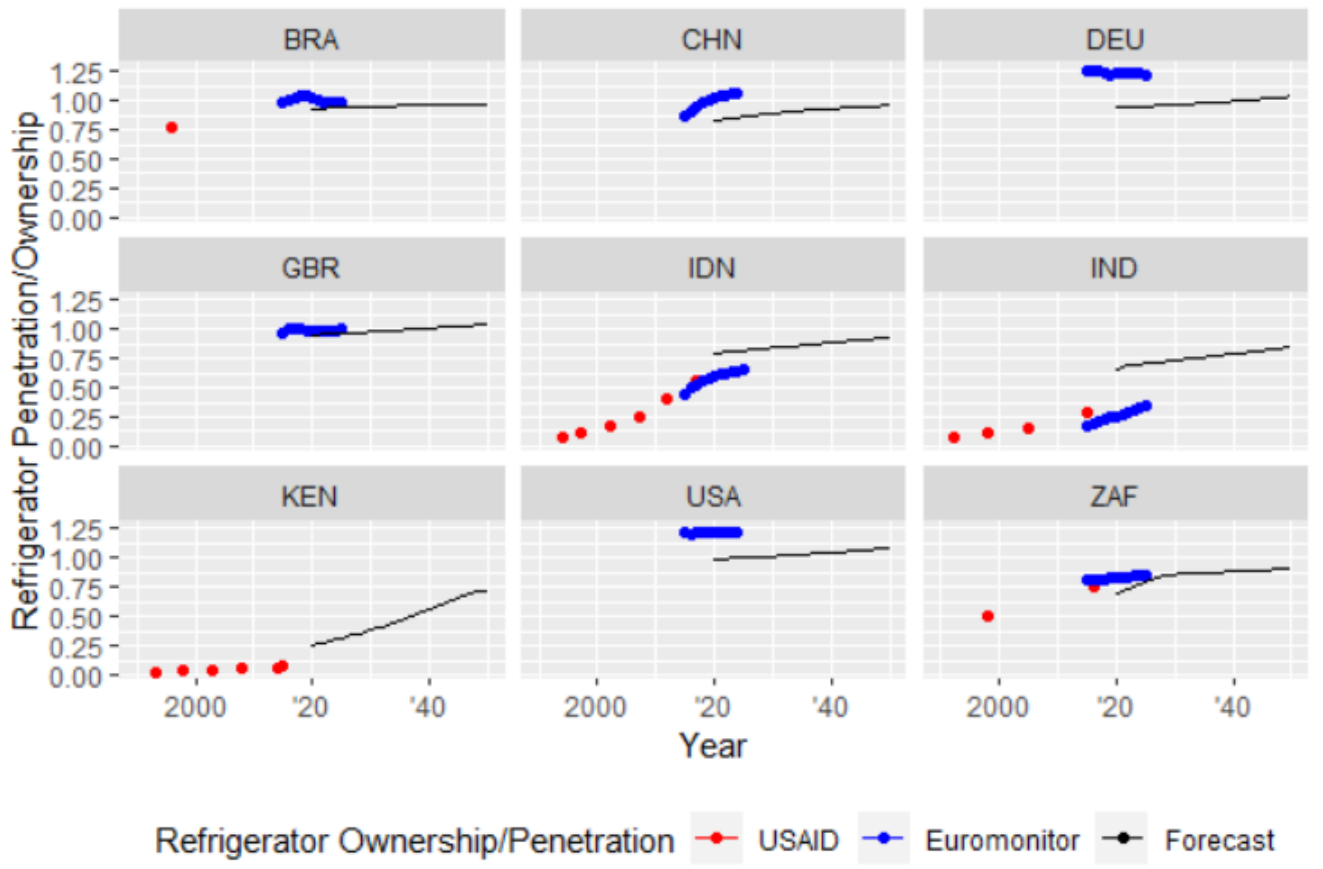
Forecasting: Refrigerators

For forecasting refrigerator ownership into the future, CLASP used the following data and assumptions:

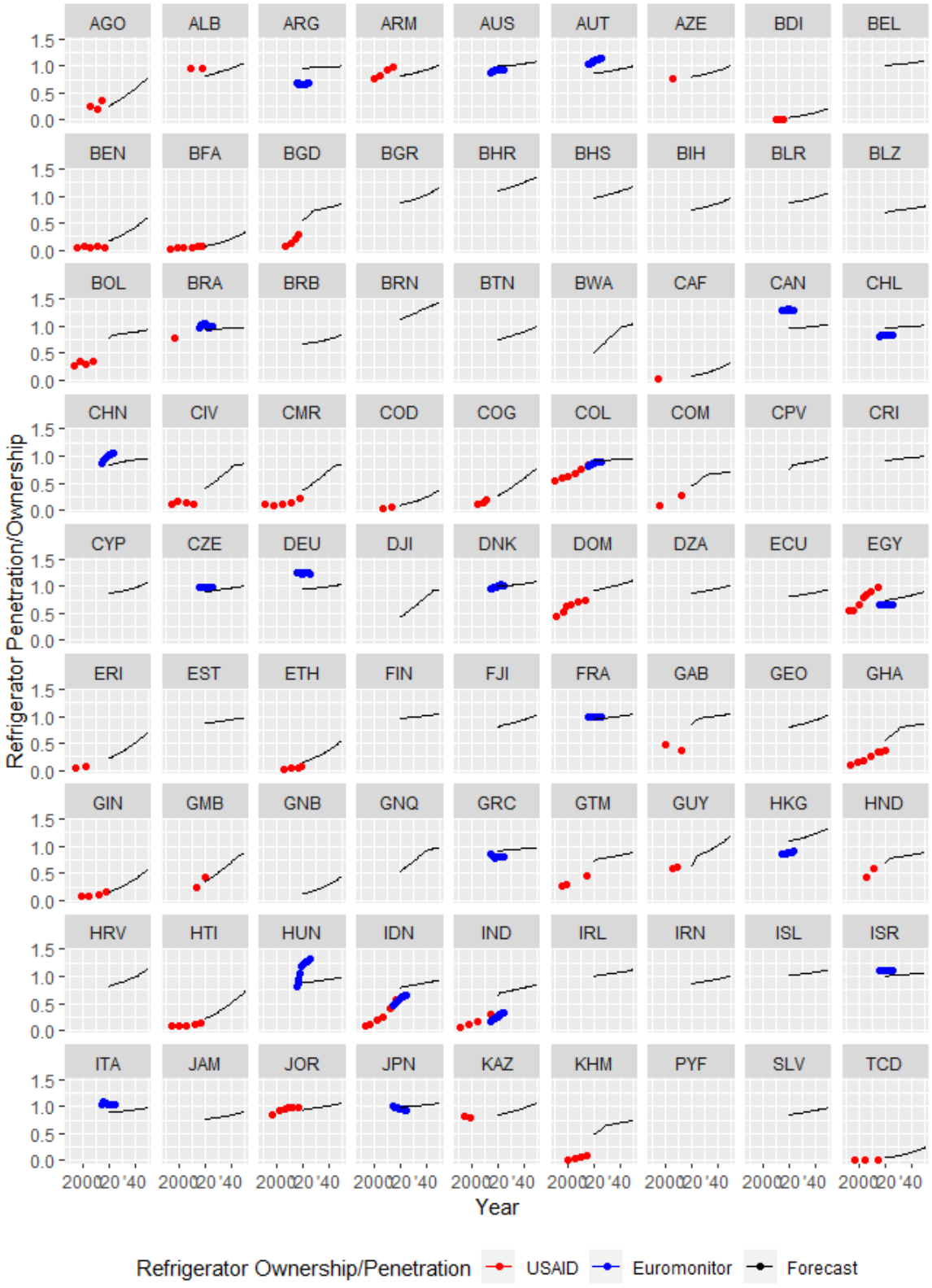
VARIABLE	SOURCE	YEAR	NOTES
Refrigerator Ownership	To be estimated	2020–2050	Using the beta regression model based on combined USAID and Euromonitor datasets, above
PPP GDP (2017$)	OECD Real GDP Long-term Forecast	2020–2060	PPP-adjusted and expressed in 2010 international dollars. Inflated to 2017$ by multiplying by 1.12. Provided for 46 countries; GDP for others estimated by applying average 5% growth rate, which is typical over 2015-2019. By comparison, average growth rate of the 46 countries provided (OECD and other larger, mostly developed economies) are expected to grow at 3%, decreasing to 2% by 2060

VARIABLE	SOURCE	YEAR	NOTES
			Combined with GDP to calculate household monthly income.
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Household size extrapolated using linear model using available country data. Result was an average growth rate with country-specific offsets. For countries without any data, regional average was used. Minimum was set at 2.0.
			Indicator code EG.ELC.ACCS.ZS
Electrification	World Bank Access to Electricity (% of population)	Various (1990–2019)	Electrification extrapolated using linear model using available country data 2015-2019. Result was an average growth rate with country-specific offsets. Maximum was set at 100%.
Urbanization	UN Population Division World Urbanization Prospects 2018 (% of population residing in urban areas)	1950–2050	

This created a new forecast dataset with the same variables as the historical dataset, allowing for prediction of refrigerator penetration through 2050 using the combined beta regression model developed earlier. The resultant refrigerator penetration and ownership showing both historical data and forecasts for some of the key countries where CLASP works are shown below.



And below are the same graphs for all 162 countries in Mepsy.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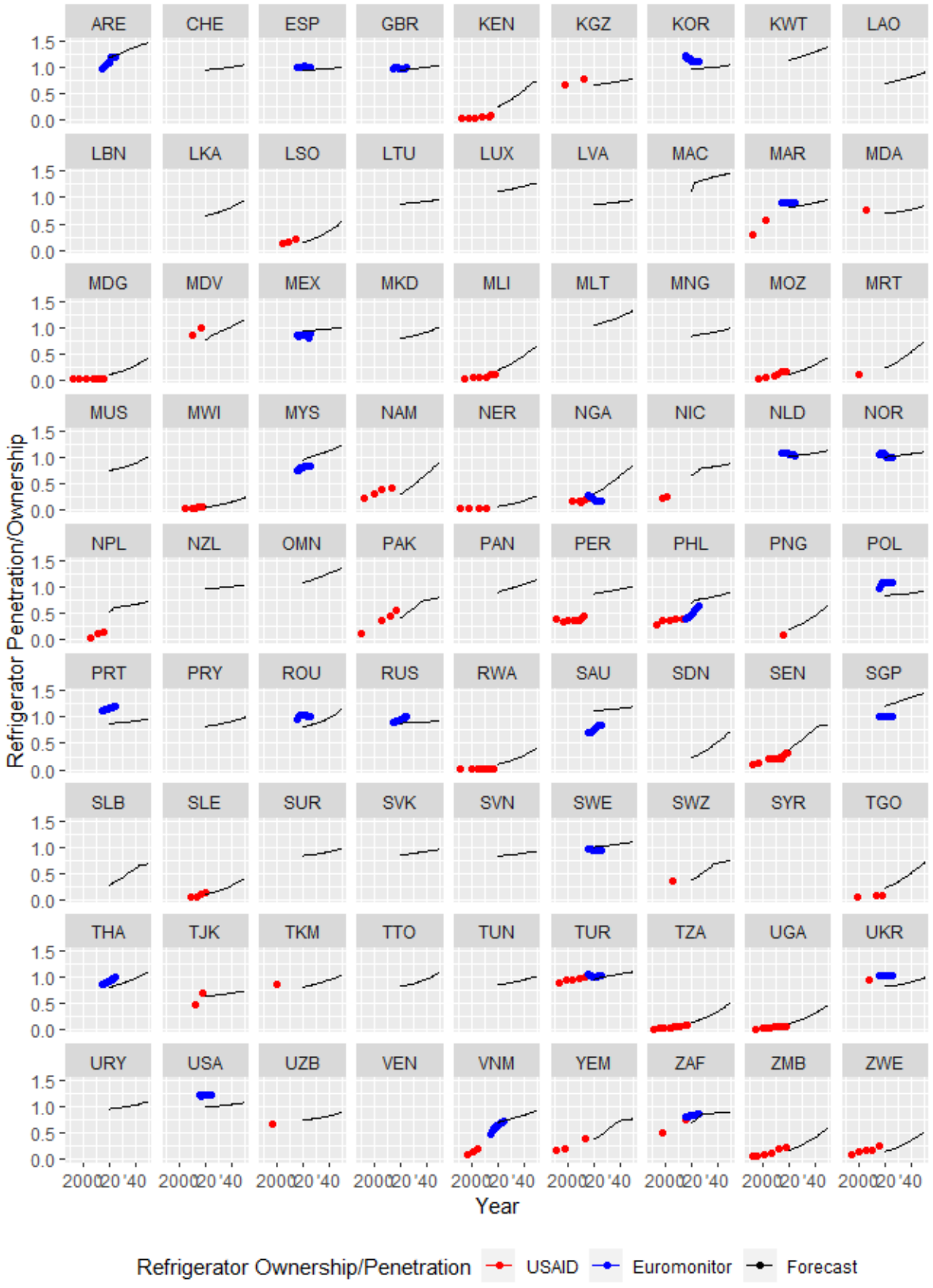
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Forecasting: Air Conditioners

CLASP used a similar approach to forecast air conditioners' stock. Firstly, CLASP related the latest year's AC ownership response to macroeconomic parameters, then utilized parameters' forecasts to estimate the AC ownership rate to 2050. Finally, CLASP used the ownership rate multiplied by national household numbers to calculate AC's total stock.

Even though the forecasting steps are similar to refrigerators, air conditioner modeling differs from other appliances. The ownership rate of the air conditioners depends not only on the price but also on the climate. In wealthy regions, like northern Europe, air conditioners' usage remains low, even though air conditioners are generally affordable. On the other hand, air conditioners might be the most desirable appliance in tropical developing countries, even though their costs to residents are still considered luxury items. Therefore, CLASP included climate variables (cooling degree days, CDD) in the regression model when forecasting the AC ownership to 2050.

Scaled AC Ownership by Climate Maximum Parameters

In the paper, McNeil and Letschert mentioned that when they used a regression over CDD and income, the model was complicated by the correlation between these two variables. That is because the warmest countries are among the poorest ones. Instead of adding CDD value directly to the regression equation, McNeil and Letschert demonstrated that the Climate Maximum parameter (calculated from CDD) could scale the AC ownership to improve the R2 of the regression. The Climate Maximum is calculated by the equation below:

$$\text{Climate Maximum (CDDc)} = 0.994 - 1.17e^{-0.00298 \cdot CDDc}$$ [11]

To calculate the $\text{Climate Maximum (CDDc)}$, CLASP collected cooling degree day data for each country. Because the CDD data collected were 24 hours basis values, CLASP firstly extracted and added up yearly CDD values (CDD_{YEAR}) for the latest five-year period from 2009 to 2013[12], then divided by 4 to turn the daily (24 hours) data into (6hour) daily basis, lastly divided by 5 to calculate the average 5-year CDD parameter from 2009 to 2013 for each country. The calculation is given by:

$$\text{CDDc} = \frac{\sum CDD_{YEAR}\,/4}{5}$$

Where CDD_{YEAR} is the annual number of coolness dates based on daily data.

Clasp scaled the AC ownership with the $\text{Climate Maximum (CDDc)}$, according to:

[11] The CDD value here were calculated based on daily average temperature.

[12] CLASP used 6-hour CDDs referenced to 18.3 °C for the years 2009–2013 (the five latest available) to take into account recent global warming.

$$\text{Scaled AC Ownership} = \frac{\text{AC Ownership}}{\text{Climate Maximum (CDDc)}}$$

After calculating the scaled AC ownership, CLASP used the following data resources to conduct the regression model:

VARIABLE	SOURCE	YEAR	NOTES[13]
AC Ownership[14]	Euromonitor, Appliance Ownership	Various (2015-2025)	Data of 2019 for each country used in the analysis
PPP GDP (2017$)	World Bank GDP, PPP (constant 2017 international $)	1990–2019	Indicator code NY.GDP.MKTP.PP.KD
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Combined with GDP to calculate monthly household income
Cooling Degree Days (CDD)	King Abdullah Petroleum Studies and Research Center (KAPSARC).	1964 - 2014	CDDs referenced to 18.3°C for the years 2009–2013 (the five latest available) to take into account recent global warming
Electrification	World Bank Access to Electricity (% of population)	Various (1990–2019)	Indicator code EG.ELC.ACCS.ZS
Urbanization	UN Population Division World Urbanization Prospects 2018 (% of population residing in urban areas)	1950–2050	

To reduce the redundant number of variables, CLASP used the Stepwise feature in R to construct a model with optimal performance with the fewest possible adders. As discussed

[13] CLASP used the same method as the one in refrigerator model to populate the missing data in the household size and urbanization dataset.

[14] The Euromonitor's AC (including window and split ACs) ownership (penetration) is formulated with the AC market stock (including shipment and retiring products) in each country, which means the use of multiple units in each household is taken into account.

in Baldesics and Malinowski's paper, the Stepwise process in R relies on Akaike Information Criterion (AIC) to improve upon Adjusted R2 by adding a penalty to each term in the model. So those less significant independent variables which add noise to data and make the models perform sub-optimally can be picked out and removed. In the AC ownership regression model, Stepwise selected Household Monthly Income as the only variable in the regression model.

The 41 countries'[15] latest year dataset with the Stepwise selected explanatory variables is listed below:

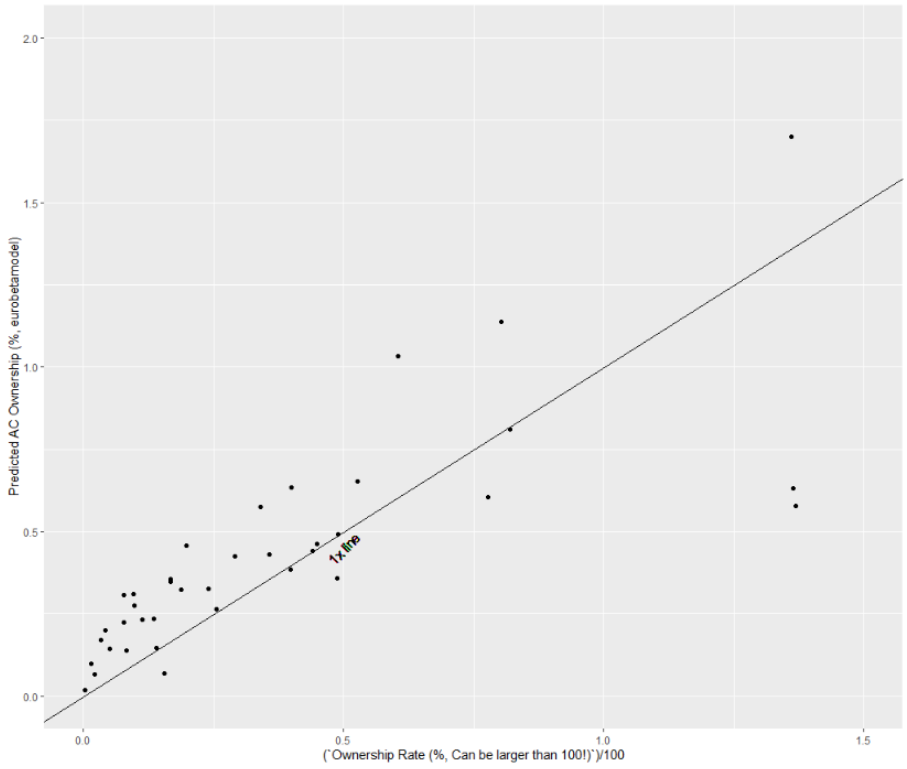
COUNTRY	ISO	AC OWNERSHIP	HOUSEHOLD MONTHLY INCOME (2017$ PPP)	CDDS (REFERENCED TO 18.3°C)	SCALED AC OWNERSHIP
Argentina	ARG	77.7%	$5,366.5	898.55	34.0%
Australia	AUS	136.4%	$8,937.1	739.25	63.1%
Austria	AUT	3.3%	$8,108.6	142.95	5.7%
Brazil	BRA	44.9%	$4,228.2	1671.1	18.2%
Canada	CAN	39.8%	$8,170.7	208.8	43.5%
Chile	CHL	7.7%	$6,059.2	198.55	8.9%
China[16]	CHN	109.0%	$4,027.0	856.05	48.3%
Colombia	COL	19.8%	$4,419.1	845.4	8.8%
Czechia	CZE	5.1%	$5,579.2	206.05	5.7%
Denmark	DNK	1.4%	$8,580.6	98.45	4.6%
Egypt	EGY	16.7%	$4,045.0	1863.65	6.8%
France	FRA	9.6%	$7,240.8	270.15	8.2%
Germany	DEU	0.2%	$7,782.5	185.8	0.2%
Greece	GRC	35.7%	$5,550.6	883.35	15.7%
Hungary	HUN	13.6%	$4,950.4	389.55	8.7%
India	IND	11.3%	$2,872.9	2841.85	4.5%
Indonesia	IDN	34.0%	$3,433.6	2632.9	13.7%
Italy	ITA	48.8%	$6,357.7	399.2	30.6%
Japan	JPN	175.7%	$7,458.6	639.3	85.7%
Malaysia	MYS	80.3%	$7,819.2	525.65	43.7%
Mexico	MEX	39.9%	$9,151.9	2298.95	32.4%
Morocco	MAR	9.8%	$5,975.8	1042.15	17.0%
Netherlands	NLD	2.1%	$3,240.5	1351.35	4.0%
Nigeria	NGA	16.8%	$8,781.5	80.7	11.3%
Philippines	PHL	29.2%	$1,494.7	2711.05	6.8%

[15] Euromonitor only has 41 countries AC ownership information for the latest year.

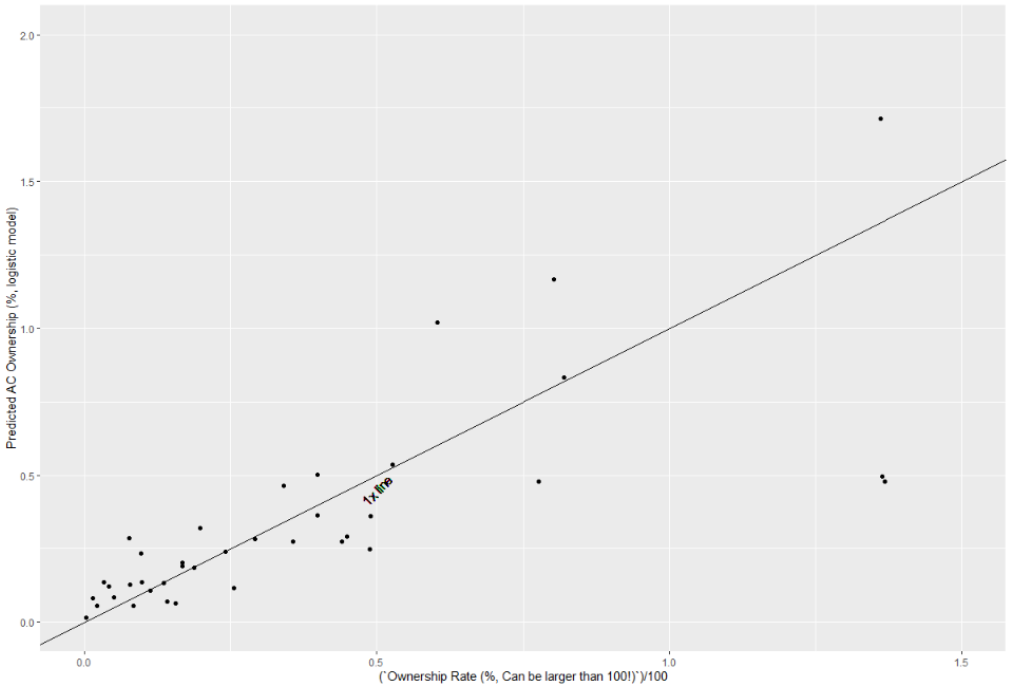
[16] Chinese AC ownership in 2019 is aligned with the national statistic survey http://www.stats.gov.cn/tjsj./ndsj/

COUNTRY	ISO	AC OWNERSHIP	HOUSEHOLD MONTHLY INCOME (2017$ PPP)	CDDS (REFERENCED TO 18.3°C)	SCALED AC OWNERSHIP
Poland	POL	4.2%	$3,401.3	3043.85	11.8%
Portugal	PRT	24.1%	$5,407.9	261.5	3.7%
Romania	ROU	7.8%	$6,093.2	312.4	18.1%
Russia	RUS	14.1%	$5,378.5	362.15	5.2%
Saudi Arabia	SAU	215.9%	$3,843.9	330.65	10.1%
South Africa	ZAF	18.7%	$16,317.5	3090.2	86.9%
South Korea	KOR	82.0%	$4,171.1	719.6	8.7%
Spain	ESP	52.7%	$7,175.7	682.5	25.1%
Sweden	SWE	15.6%	$8,394.6	78.6	91.3%
Thailand	THA	44.0%	$5,671.1	2392.7	17.7%
Turkey	TUR	25.6%	$7,883.4	713.65	12.0%
Ukraine	UKR	8.3%	$2,233.0	485.5	4.6%
United Arab Emirates	ARE	136.1%	$23,173.1	3619.35	54.8%
United Kingdom	GBR	0.3%	$7,020.8	62.7	5.1%
United States	USA	60.4%	$9,924.2	770.5	27.6%
Vietnam	VNM	49.0%	$3,205.5	2041.2	19.8%

CLASP calculated both beta and logistic regression model coefficients using the selected variables. In the beta regression model, the relationship between the variables is illustrated below:



The results of the logistic regression model are shown below:



As can be seen, the beta regression model has the best performance, with the highest R^2, lowest error, and the variables significant (income to 0.0001). Therefore, this model was selected as the basis for forecasting the future.

SYMBOL	VARIABLE	BETA MODEL	LOGISTIC MODEL
α	Maximum Ownership	2.5	2.5
	Constant (ln γ in logistic model)	-2.14	2.8
β_1	Income Coefficient[17]	1.50×10^{-4}	-1.99×10^{-4}
	Multiple R^2/Pseudo R^2	0.46	0.28
	RMS Error (percentage points)	5.3	5.5

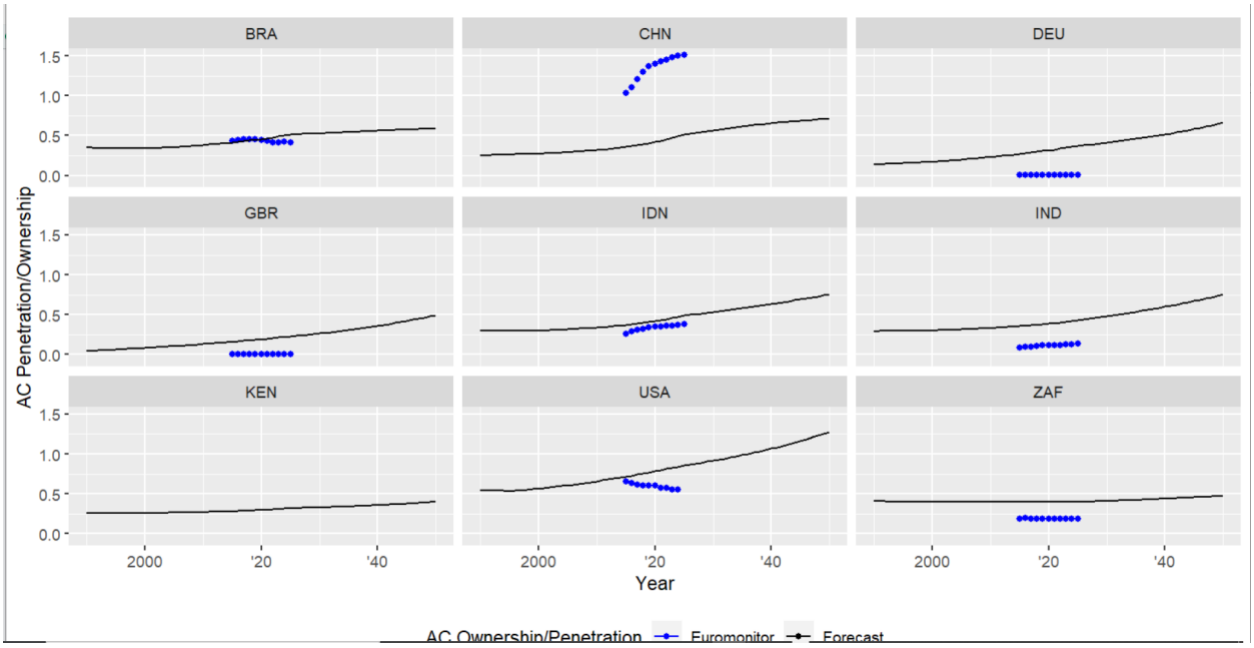
To project AC ownership through 2050, CLASP used the following data and assumptions:

VARIABLE	SOURCE	YEAR	NOTES
Scaled AC Ownership	To be estimated	2020–2050	Using the beta regression model based on the Euromonitor dataset. AC ownership was scaled by the maxacownership and climate max.
PPP GDP (2017$)	OECD Real GDP Long-term Forecast	2020–2060	PPP-adjusted and expressed in 2010 international dollars. Inflated to 2017$ by multiplying by 1.12. Provided for 46 countries. GDP for others is estimated by applying an average 5% growth rate, typically over 2015-2019. By comparison, the average growth rate of the 46 countries provided (OECD and other larger, most developed economies) are expected to grow at 3%, decreasing to 2% by 2060
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Combined with GDP to calculate monthly household income. Household size extrapolated by a linear model using available country data. Result was an average growth rate with country-specific offsets. For countries without any data, a regional average was used. The Minimum was set at 2.0.

[17] Income is monthly household income, estimated as PPP-adjusted GDP, in 2017 international dollars, divided by number of households.

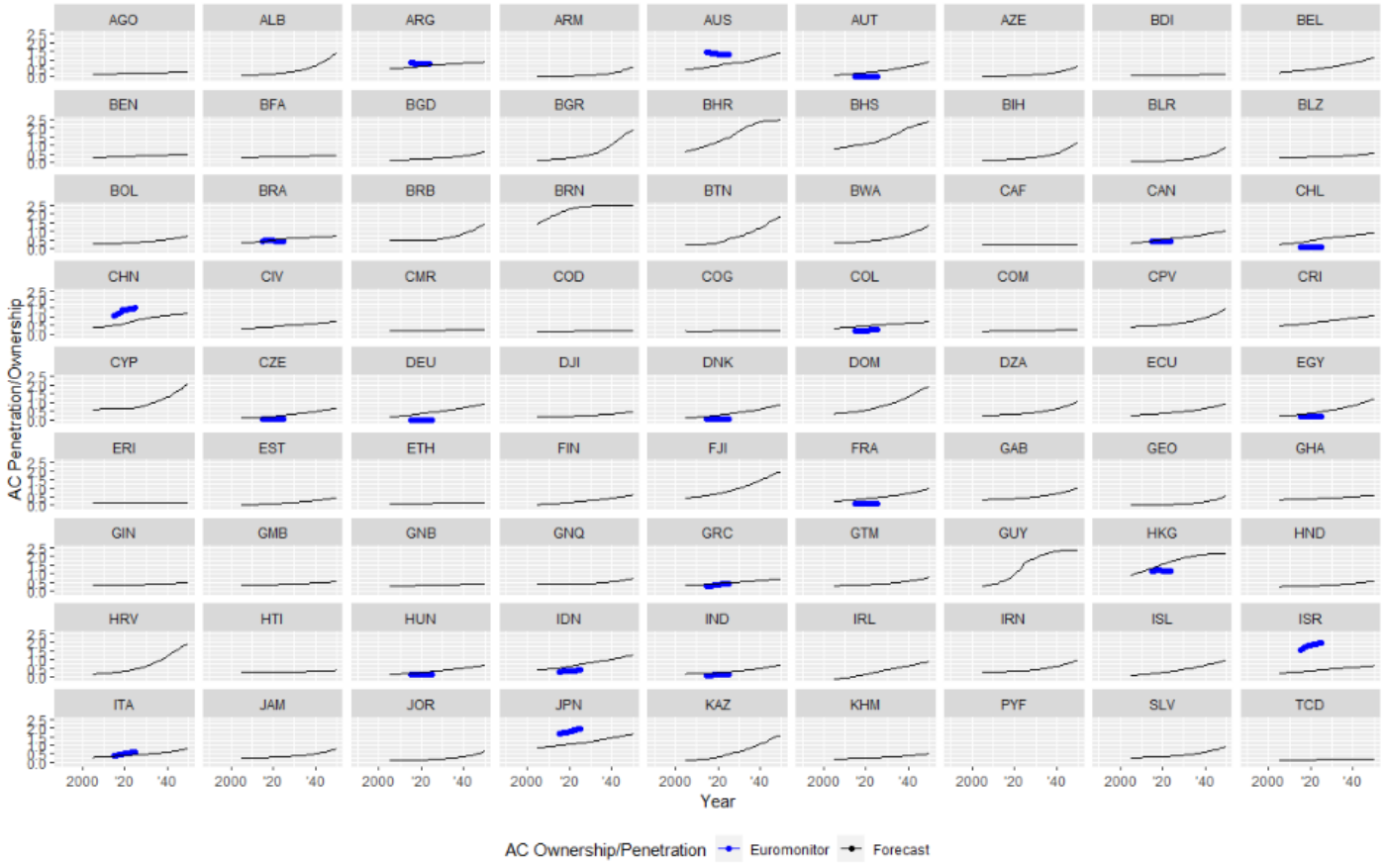
VARIABLE	SOURCE	YEAR	NOTES
Cooling Degree Days (CDD)	King Abdullah Petroleum Studies and Research Center (KAPSARC)	(1964-2013)	CDD was extrapolated by using a linear model with available country data from 1964 to 2013.

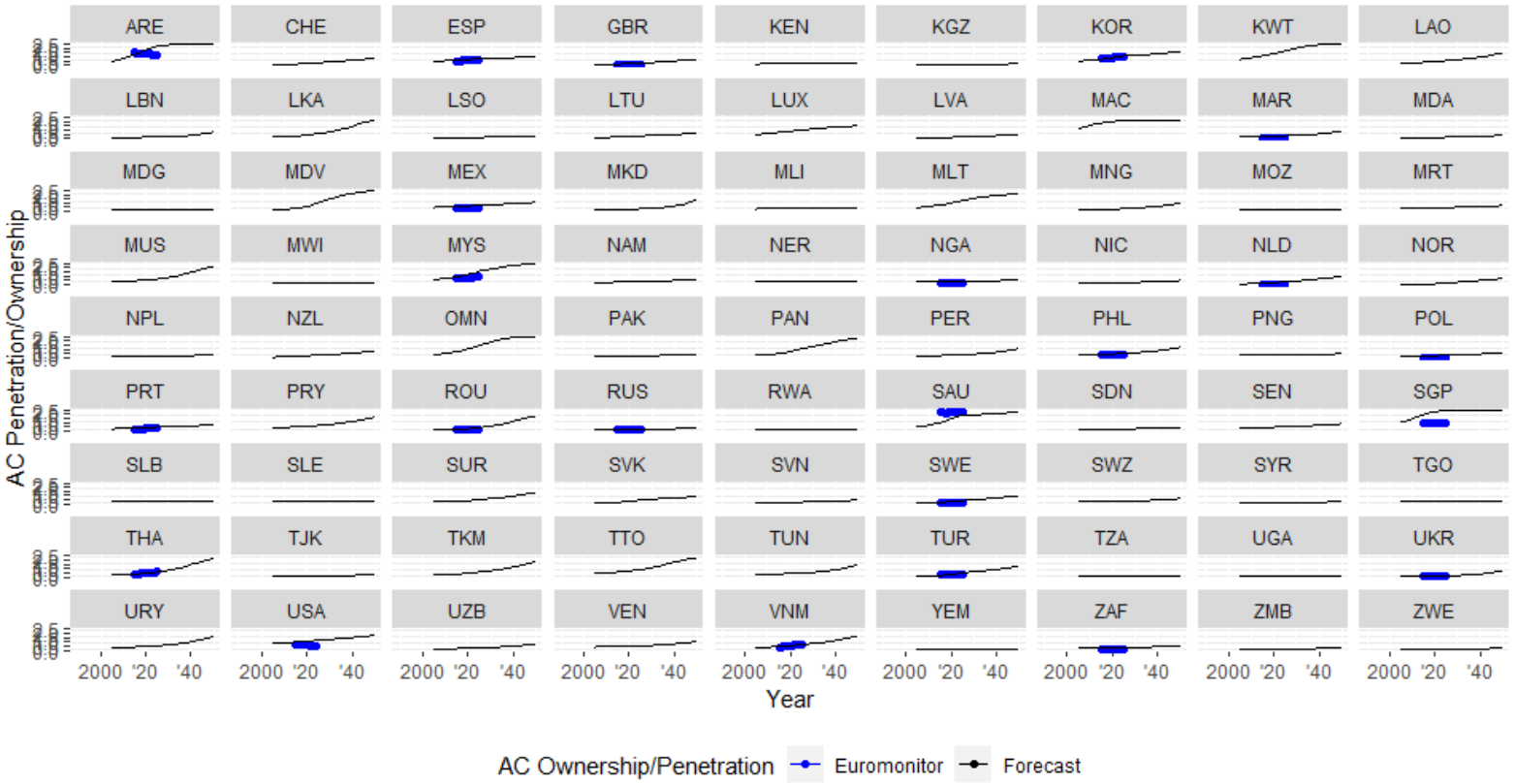
CLASP used the previous beta regression model[18] to predict AC ownership through 2050. The resultant of AC ownership showing both historical data and forecasts for some of the key countries where CLASP works are shown below.



[18] Even though the R^2 results of both beta and logistic regression are close, CLASP selected beta regression model to do the forecasting as it has a higher accuracy and more reasonable coefficient value for each variable.

And below are the same graphs for all 162 countries in Mepsy

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Forecasting: Fans

Unlike ACs, fans' price is relatively affordable to most people from different countries. Therefore, the fans' ownership highly depends on cooling degree days, which determine the length of the season in which fans are used and the number of hours per day they are necessary. Because data on the fan is very sparse, CLASP utilized available fans ownership data from the *Global Potential of Energy Efficiency Standards and Labeling Programs*[19]. The efficiency between ownership[20] and other variables were used to forecast fans' ownership for the other 153 countries to 2050.

The available nine countries' fans ownership data and resources are listed below:

COUNTRY	ISO	YEAR	FAN OWNERSHIP	RESOURCE
Brazil	BRA	2018	138%	Pesquisa de Possee e Habitos de Uso de Equipamentos Eletricos na Classe Residencial (PPH)
China	CHN	2002	152%	Statistical year book 2002
Ghana	GHA	1999	76%	LBNL
India	IND	1999	70%	NSSO
India	IND	2019	97%	
Indonesia	IDN	2019	130%	2020 Indonesia Residential End Use Survey
Japan	JPN	1998	154%	IEA
Panama	PAN	1990	38.6%	Centro Centroamericano de Población
Panama	PAN	2000	62.1%	Centro Centroamericano de Población
Panama	PAN	2001	72%	World Bank
Thailand	THA	2000	91%	2000 Census, National Statistic Office
United States	USA	2001	153%	RECS
United States	USA	2015	189%	RECS

[19] McNeil, Michael A.; Letschert, Virginie, E.; de la Rue du Can, Stephane; "Global Potential Energy Efficiency Standards and Labeling Programs", 2008.

[20] Clasp utilized the latest year ownership in the regression when there are more than one year ownership data for one country.

Data resources of two selected variables are listed below:

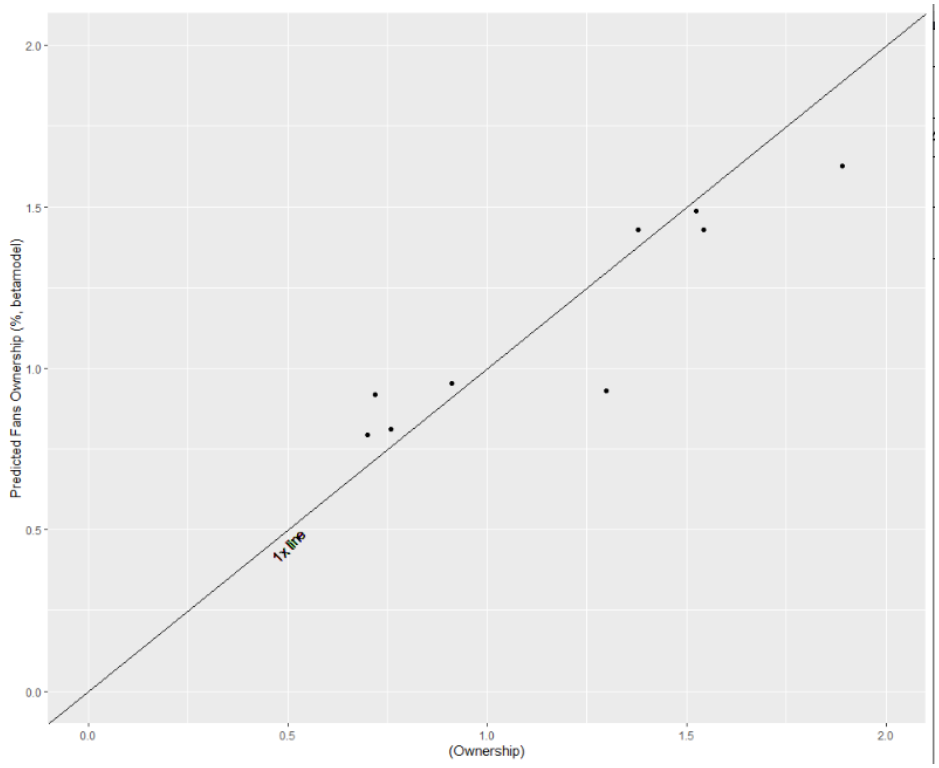
CLASP also used Stepwise in R to select the most significant variables from those used in the AC model. Electrification rate and CDD were selected. The data resources are listed below:

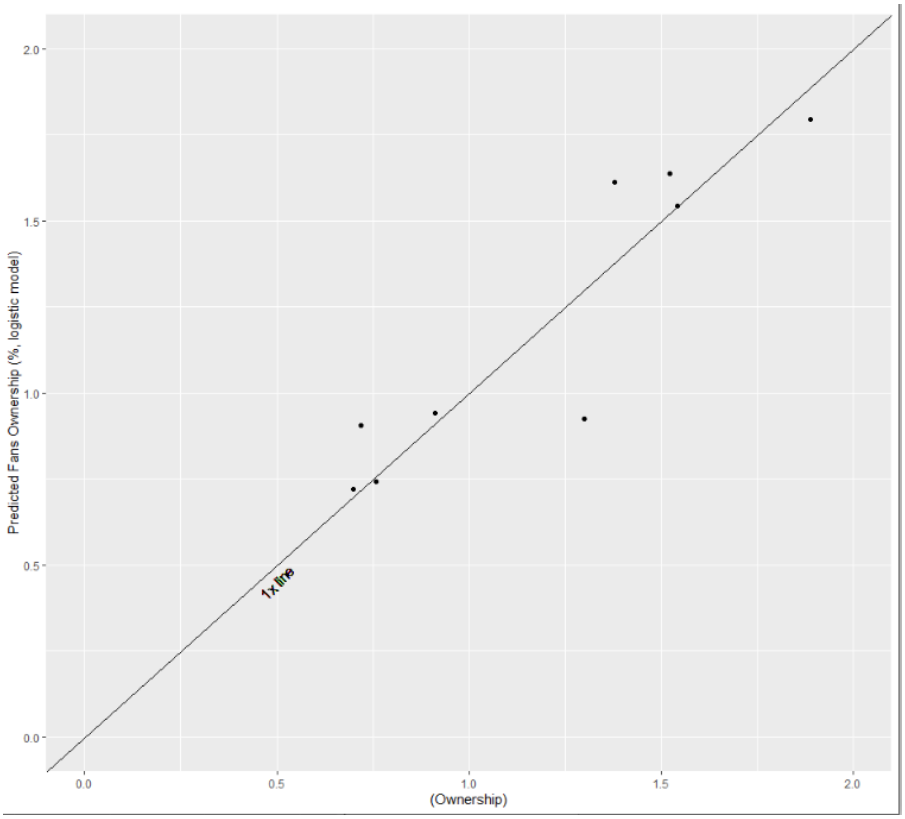
VARIABLE	SOURCE	YEAR	NOTES[21]
Cooling Degree Days (CDD)	King Abdullah Petroleum Studies and Research Center (KAPSARC).	1964 - 2014	CDDs referenced to 18.3 °C for the years 2009–2013 (the five latest available) to take into account recent global warming
Electrification	World Bank Access to Electricity (% of population)	Various (1990–2019)	Indicator code EG.ELC.ACCS.ZS

The beta and logistic regression coefficient results between variables are listed below:

SYMBOL	VARIABLE	BETA MODEL	LOGISTIC MODEL
α	Maximum Ownership	2	2
	Constant (ln γ in logistic model)	0.07	-0.76
β_1	CDD Coefficient	-5.28×10^{-4}	5.64×10^{-4}
β_2	Electrification Coefficient	1.5	-0.48
	Multiple R^2/Pseudo R^2	0.82	0.75
	RMS Error (percentage points)	5.7	5.5

The results of the beta and logistic regression model are shown below:



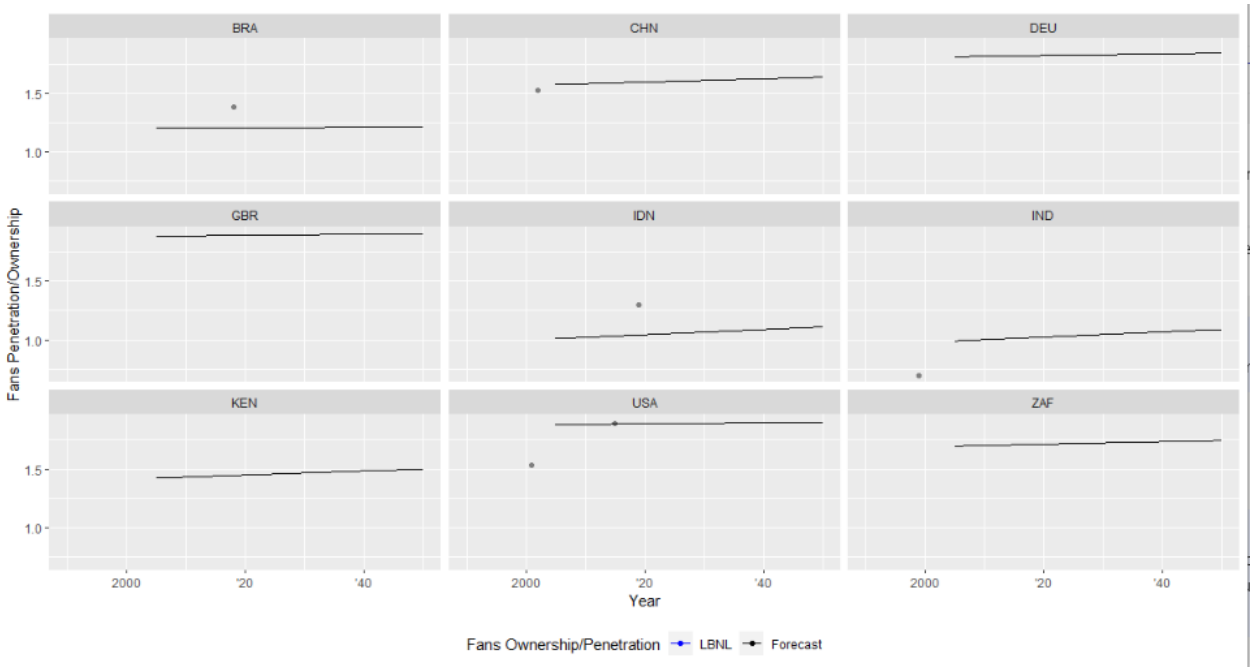


For forecasting fans ownership to 2050, CLASP then created a new forecast dataset with

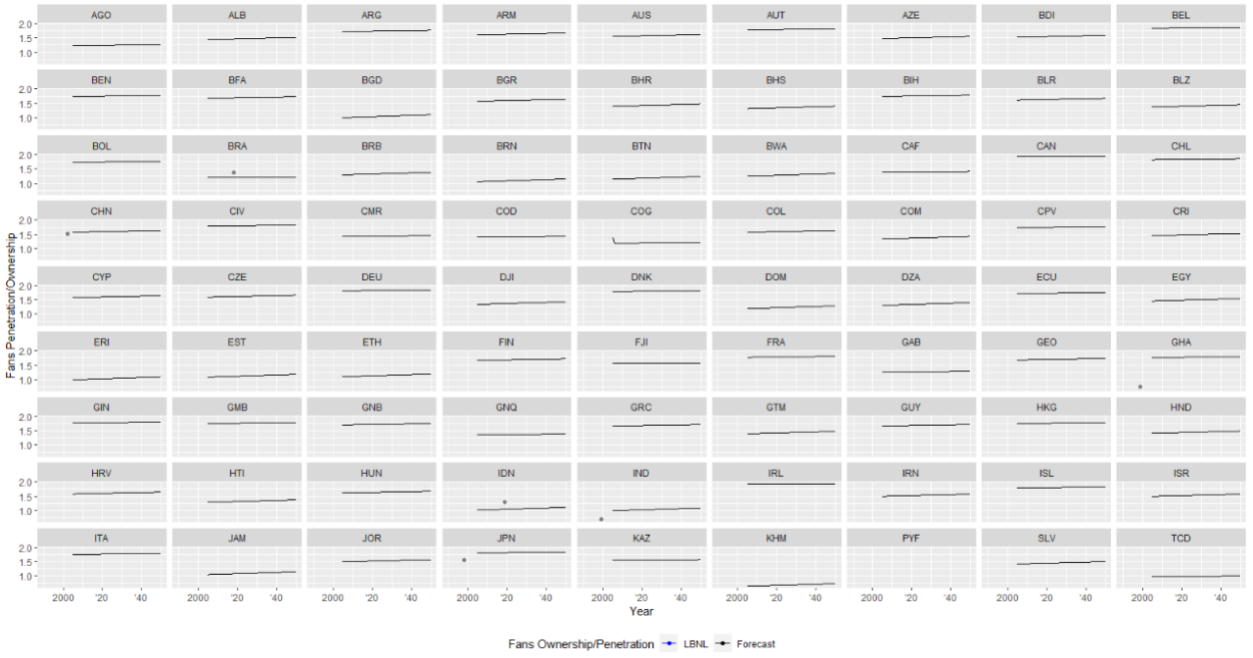
the same variables as the historical dataset in the beta model to predict fans ownership. The data and assumptions are listed below:

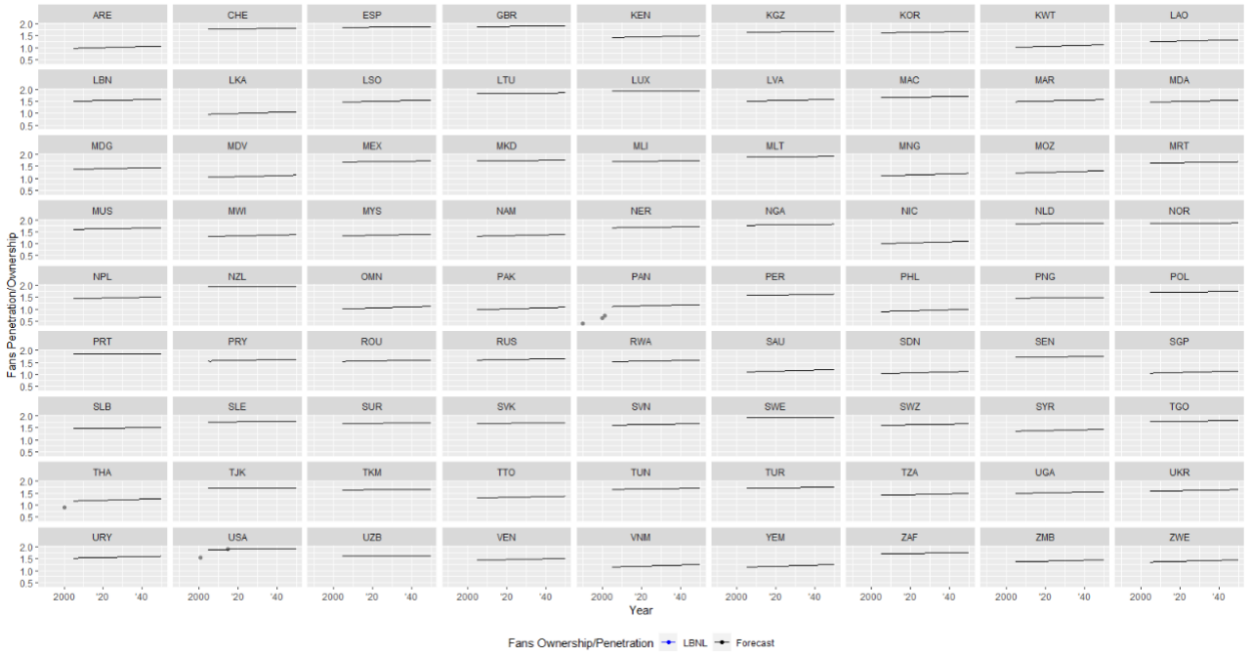
VARIABLE	SOURCE	YEAR	NOTES
Fans Ownership	To be estimated	2020–2050	Using the beta regression model based on different countries' national statistic survey data listed above
PPP GDP (2017$)	OECD Real GDP Long-term Forecast	2020–2060	PPP-adjusted and expressed in 2010 international dollars. Inflated to 2017$ by multiplying by 1.12. Provided for 46 countries; GDP for others estimated by applying an average 5% growth rate, which is typically over 2015-2019. By comparison, the average growth rate of the 46 countries provided (OECD and other larger, most developed economies) are expected to grow at 3%, decreasing to 2% by 2060
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Combined with GDP to calculate monthly household income. Household size was extrapolated using a linear model using available country data. The result was an average growth rate with country-specific offsets. For countries without any data, regional average was used. The Minimum was set at 2.0.
Electrification	World Bank Access to Electricity (% of population)	Various (1990–2019)	Indicator code EG.ELC.ACCS.ZS Electrification extrapolated using linear model using available country data 2015-2019. The result was an average growth rate with country-specific offsets. Maximum was set at 100%.

The results of fans ownership showing historical data and forecasts for some of the key countries where CLASP works are below:



All 162 countries' results are shown below:





Forecasting: TV

There is an order when it comes to households purchasing appliances. The poorest of electrified households will use electricity for lighting only, and the households of moderate-income may have more than one television. Therefore, the TV diffusion rate is closely following electrification rates and households' income. This conclusion has also been proved by the stepwise selection which shows the ownership of TV has a strong relationship with the household income and the access to electricity among all the other variables.

The resource of the variables selected for the regression model are listed below:

VARIABLE	SOURCE	YEAR	NOTES[22]
PPP GDP (2017$)	World Bank GDP, PPP (constant 2017 international $)	1990–2019	Indicator code NY.GDP.MKTP.PP.KD
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Combined with GDP to calculate monthly household income
Electrification	World Bank Access to Electricity (% of the population)	Various (1990–2019)	Indicator code EG.ELC.ACCS.ZS

The table below lists 131 countries' full data used in the regression.

[22] CLASP used the same method as the one in refrigerator model to populate the missing data in the household size and urbanization dataset.

COUNTRY	ISO	YEAR	TV OWNERSHIP[23]	MONTHLY INCOME	ELECTRIFICATION (%)
Albania	ALB	2007	77%	$ 1,621.24	100.00%
Algeria	DZA	2007	113%	$ 3,460.44	98.56%
Angola	AGO	2007	17%	$ 1,724.88	18.37%
Argentina	ARG	2007	118%	$ 4,285.41	96.08%
Armenia	ARM	2007	128%	$ 1,469.75	99.21%
Australia	AUS	2007	175%	$ 6,835.69	100.00%
Austria	AUT	2007	154%	$ 6,587.19	100.00%
Azerbaijan	AZE	2007	145%	$ 1,610.04	99.21%
Bahamas	BHS	2007	127%	$ 7,944.69	100.00%
Bahrain	BHR	2007	369%	$13,563.48	99.57%
Bangladesh	BGD	2007	37%	$ 1,135.09	43.51%
Barbados	BRB	2007	98%	$ 4,308.13	100.00%
Belarus	BLR	2007	95%	$ 1,519.97	100.00%
Belgium	BEL	2007	131%	$ 6,066.19	100.00%
Belize	BLZ	2007	93%	$ 2,386.61	84.39%
Benin	BEN	2007	37%	$ 826.46	26.13%
Bhutan	BTN	2007	18%	$ 766.73	43.18%
Bolivia	BOL	2007	85%	$ 1,662.03	77.32%
Bosnia and Herzegovina	BIH	2007	66%	$ 1,841.76	100.00%
Botswana	BWA	2007	32%	$ 4,903.79	36.55%
Brazil	BRA	2018	129%	$ 4,063.78	98.40%
Bulgaria	BGR	2007	117%	$ 2,031.25	100.00%
Burkina	BFA	2007	9%	$ 787.06	12.55%
Burundi	BDI	2007	16%	$ 263.71	5.30%
Côte d'Ivoire	CIV	2007	35%	$ 1,344.74	54.48%
Cambodia	KHM	2007	4%	$ 1,101.89	27.08%
Cameroon	CMR	2007	26%	$ 1,161.95	48.07%
Canada	CAN	2007	178%	$ 6,666.18	100.00%
Cape Verde	CPV	2007	52%	$ 2,583.02	48.05%
Central African Republic	CAF	2007	3%	$ 537.21	8.97%
Chad	TCD	2007	1%	$ 290.78	4.96%
Chile	CHL	2007	114%	$ 3,832.95	98.51%

[23] 131 countries' TV ownership data are coming from the report *World Telecommunication Indicators 2006* published by International Telecommunication Union (ITU) http://earthtrends.org/searchable_db/index.php?theme=4

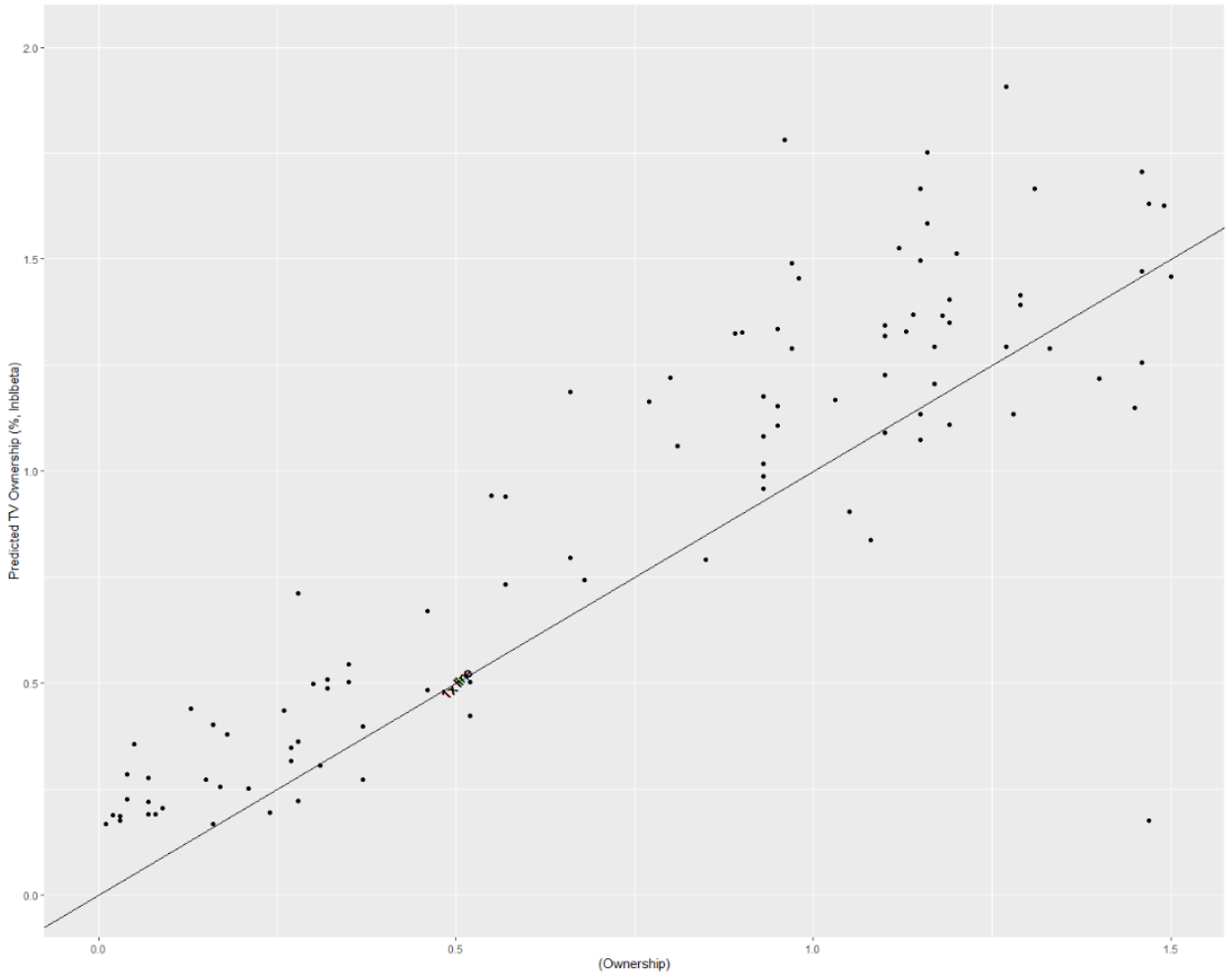
COUNTRY	ISO	YEAR	TV OWNERSHIP[23]	MONTHLY INCOME	ELECTRIFICATION (%)
China	CHN	2019	119%	$ 4,026.95	99.18%
Colombia	COL	2007	146%	$ 3,182.66	96.52%
Comoros	COM	2007	13%	$ 902.59	50.02%
Congo	COG	2007	7%	$ 632.06	27.76%
Congo, Dem. Rep. of the	COD	2007	2%	$ 391.27	10.13%
Costa Rica	CRI	2007	110%	$ 3,918.49	96.89%
Croatia	HRV	2007	95%	$ 3,260.17	100.00%
Cyprus	CYP	2007	179%	$ 6,868.81	100.00%
Czech Republic	CZE	2007	119%	$ 3,386.70	100.00%
Denmark	DNK	2007	197%	$ 6,420.78	100.00%
Djibouti	DJI	2007	35%	$ 1,053.13	60.17%
Dominican Republic	DOM	2007	93%	$ 3,297.74	91.78%
Ecuador	ECU	2007	110%	$ 1,762.92	95.25%
Egypt	EGY	2007	103%	$ 1,972.69	98.34%
El Salvador	SLV	2007	93%	$ 1,931.34	88.59%
Eritrea	ERI	2007	27%	$ 459.36	35.63%
Estonia	EST	2007	117%	$ 2,863.95	100.00%
Ethiopia	ETH	2007	4%	$ 457.43	18.98%
Fiji	FJI	2007	55%	$ 2,674.47	81.88%
Finland	FIN	2007	154%	$ 5,560.35	100.00%
France	FRA	2007	149%	$ 5,746.33	100.00%
French Polynesia	PYF	2007	121%	$14,015.91	100.00%
Gabon	GAB	2007	115%	$ 4,458.96	80.16%
Gambia	GMB	2007	16%	$ 1,579.80	41.67%
Georgia	GEO	2007	147%	$ 1,093.12	3.63%
Germany	DEU	2007	147%	$ 5,784.98	100.00%
Ghana	GHA	2007	32%	$ 1,247.36	53.61%
Greece	GRC	2007	146%	$ 4,451.89	100.00%
Guatemala	GTM	2007	105%	$ 2,596.82	79.97%
Guinea	GIN	2007	15%	$ 1,509.82	22.41%
Guinea-Bissau	GNB	2007	28%	$ 610.03	41.73%
Guyana	GUY	2007	57%	$ 2,838.19	80.92%
Haiti	HTI	2007	27%	$ 794.46	38.50%
Honduras	HND	2007	68%	$ 1,394.01	75.26%
Hong Kong, China (SAR)	HKG	2007	154%	$ 8,390.54	100.00%

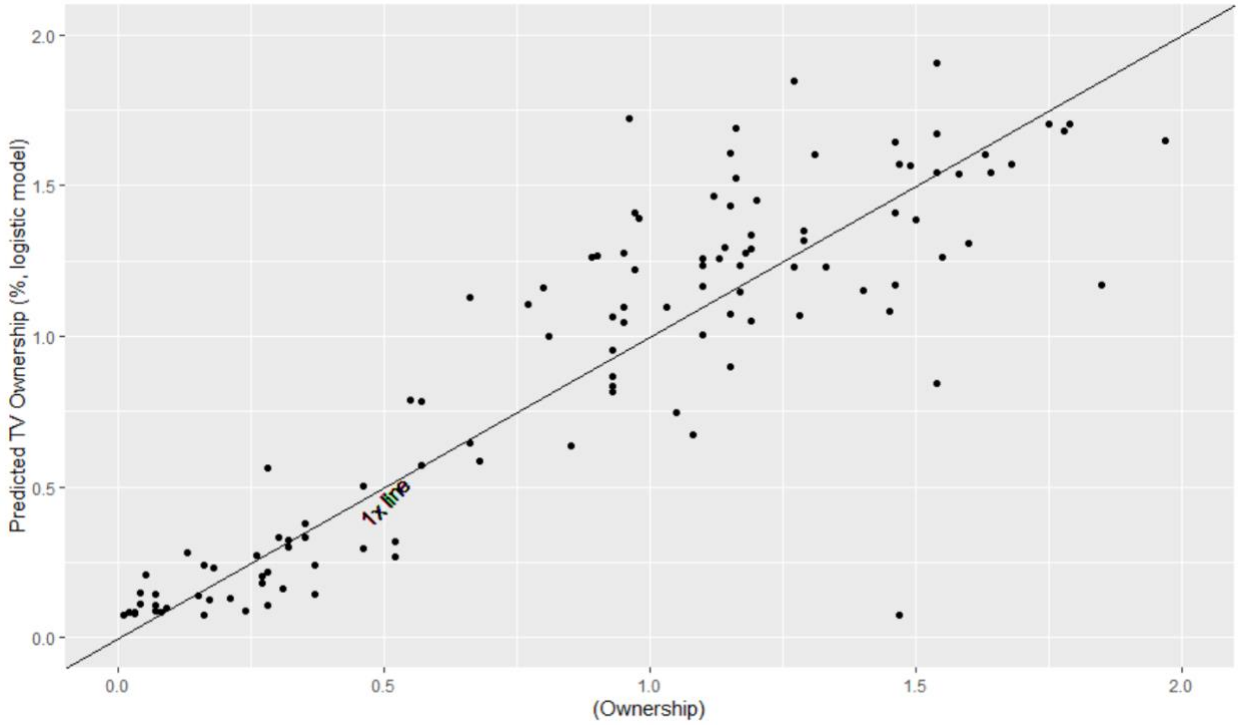
COUNTRY	ISO	YEAR	TV OWNERSHIP[23]	MONTHLY INCOME	ELECTRIFICATION (%)
Hungary	HUN	2010	160%	$ 3,577.04	100.00%
Iceland	ISL	2007	96%	$ 6,981.71	100.00%
India	IND	2007	46%	$ 1,573.65	68.70%
Indonesia	IDN	2020	110%	$ 3,648.02	97.10%
Iran	IRN	2007	97%	$ 3,124.31	98.48%
Ireland	IRL	2007	148%	$ 9,601.86	100.00%
Israel	ISR	2007	116%	$ 6,742.81	100.00%
Italy	ITA	2007	116%	$ 5,410.71	100.00%
Jamaica	JAM	2007	154%	$ 1,620.20	88.60%
Japan	JPN	2007	210%	$ 6,453.50	100.00%
Jordan	JOR	2007	155%	$ 3,364.92	99.05%
Kazakhstan	KAZ	2007	140%	$ 2,272.69	99.33%
Kenya	KEN	2007	21%	$ 627.84	23.24%
Korea, Rep. of	KOR	2007	120%	$ 4,804.31	100.00%
Kuwait	KWT	2007	377%	$14,114.11	100.00%
Kyrgyzstan	KGZ	2007	95%	$ 1,076.69	99.78%
Lao People's Dem. Rep.	LAO	2007	30%	$ 1,247.19	54.52%
Latvia	LVA	2007	212%	$ 2,351.39	100.00%
Lebanon	LBN	2007	209%	$ 2,678.44	96.37%
Lesotho	LSO	2007	24%	$ 1,049.56	8.48%
Lithuania	LTU	2007	133%	$ 2,834.28	100.00%
Luxembourg	LUX	2007	148%	$13,403.36	100.00%
Macao	MAC	2007	137%	$11,893.97	100.00%
Madagascar	MDG	2007	7%	$ 399.19	17.75%
Malawi	MWI	2007	3%	$ 292.97	7.54%
Malaysia	MYS	2007	97%	$ 5,048.14	97.76%
Maldives	MDV	2007	93%	$ 3,056.87	88.05%
Mali	MLI	2007	28%	$ 750.74	16.36%
Malta	MLT	2007	163%	$ 6,068.02	100.00%
Mauritania	MRT	2007	31%	$ 1,468.66	28.50%
Mauritius	MUS	2007	129%	$ 4,100.98	99.28%
Mexico	MEX	2007	150%	$ 4,615.12	98.56%
Moldova	MDA	2007	81%	$ 531.26	100.00%
Moldova, Rep. of	MKD	2007	80%	$ 2,180.87	100.00%
Mongolia	MNG	2007	28%	$ 955.54	75.19%
Morocco	MAR	2007	108%	$ 2,279.86	77.19%
Mozambique	MOZ	2007	7%	$ 387.92	10.92%
Namibia	NAM	2007	46%	$ 3,198.86	42.71%

COUNTRY	ISO	YEAR	TV OWNERSHIP[23]	MONTHLY INCOME	ELECTRIFICATION (%)
Nepal	NPL	2007	5%	$ 894.70	39.12%
Netherlands	NLD	2007	146%	$ 6,384.71	100.00%
New Zealand	NZL	2007	130%	$ 5,807.69	100.00%
Nicaragua	NIC	2007	66%	$ 1,403.50	78.96%
Niger	NER	2007	8%	$ 562.04	9.86%
Nigeria	NGA	2007	52%	$ 800.85	48.48%
Norway	NOR	2007	247%	$ 7,986.93	100.00%
Oman	OMN	2007	450%	$10,125.27	95.64%
Pakistan	PAK	2007	57%	$ 1,506.52	73.81%
Poland	POL	2007	90%	$ 3,174.38	100.00%
Portugal	PRT	2007	115%	$ 4,667.76	100.00%
Romania	ROU	2007	185%	$ 2,259.18	100.00%
Russian Federation	RUS	2007	110%	$ 2,230.21	100.00%
Slovakia	SVK	2007	89%	$ 3,149.24	100.00%
Slovenia	SVN	2007	112%	$ 4,915.44	100.00%
South Africa	ZAF	2007	93%	$ 4,286.73	77.85%
Spain	ESP	2007	158%	$ 5,535.85	100.00%
Sweden	SWE	2007	164%	$ 5,561.12	100.00%
Switzerland	CHE	2007	115%	$ 6,074.72	100.00%
Tajikistan	TJK	2007	230%	$ 676.99	98.89%
Turkmenistan	TKM	2007	127%	$ 2,919.35	99.71%
Ukraine	UKR	2007	115%	$ 1,312.10	100.00%
United Kingdom	GBR	2007	233%	$ 5,562.80	100.00%
United States	USA	2015	230%	$ 9,261.08	100.00%
Uzbekistan	UZB	2007	119%	$ 1,121.51	99.71%

The beta and logistic regression coefficient results between variables are listed below. Even though the logistic model has a higher Multiple R^2, (which usually means the model can better explain the relationship between the variables), CLASP used beta model results to forecast the TV ownership to 2050 since beta model has a lower error rate of the model results.

SYMBOL	VARIABLE	BETA MODEL	LOGISTIC MODEL
α	Maximum Ownership	5	5
	Constant (ln γ in logistic model)	-3.5	4.3
β_2	Monthly Income Coefficient	1.12×10^{-4}	-1.15×10^{-4}
β_3	Electrification Coefficient	2.13	-2.95
	Multiple R^2/Pseudo R^2	0.75	0.76
	RMS Error (percentage points)	3.9	4.9



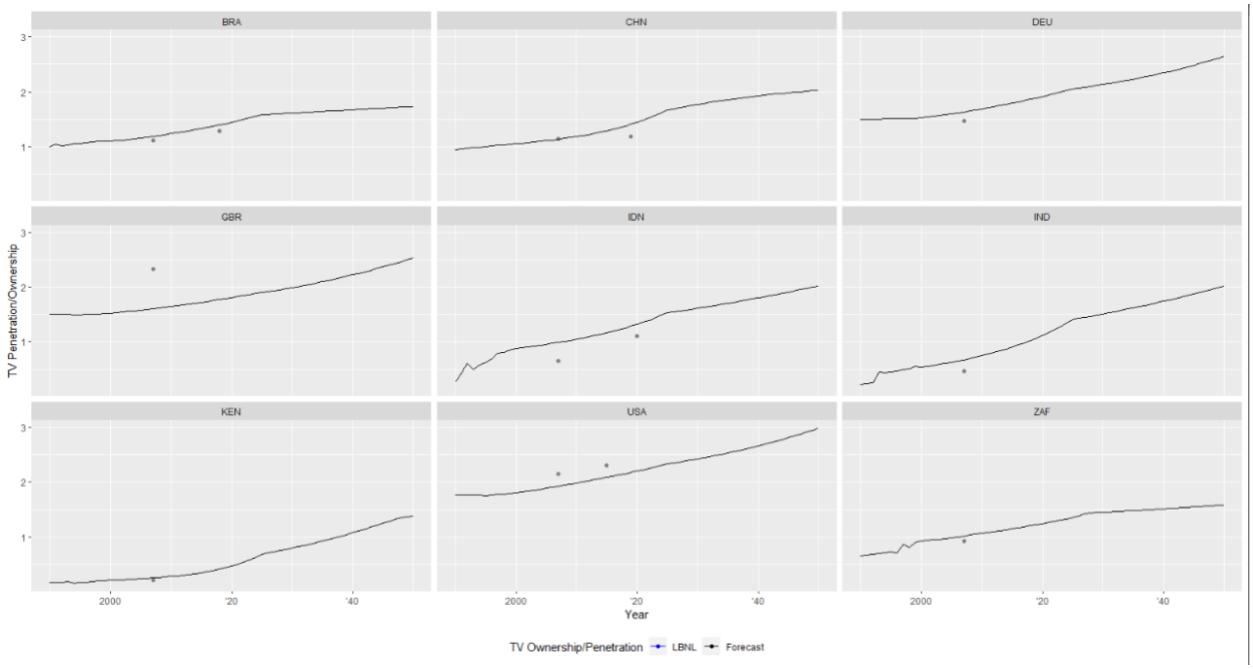


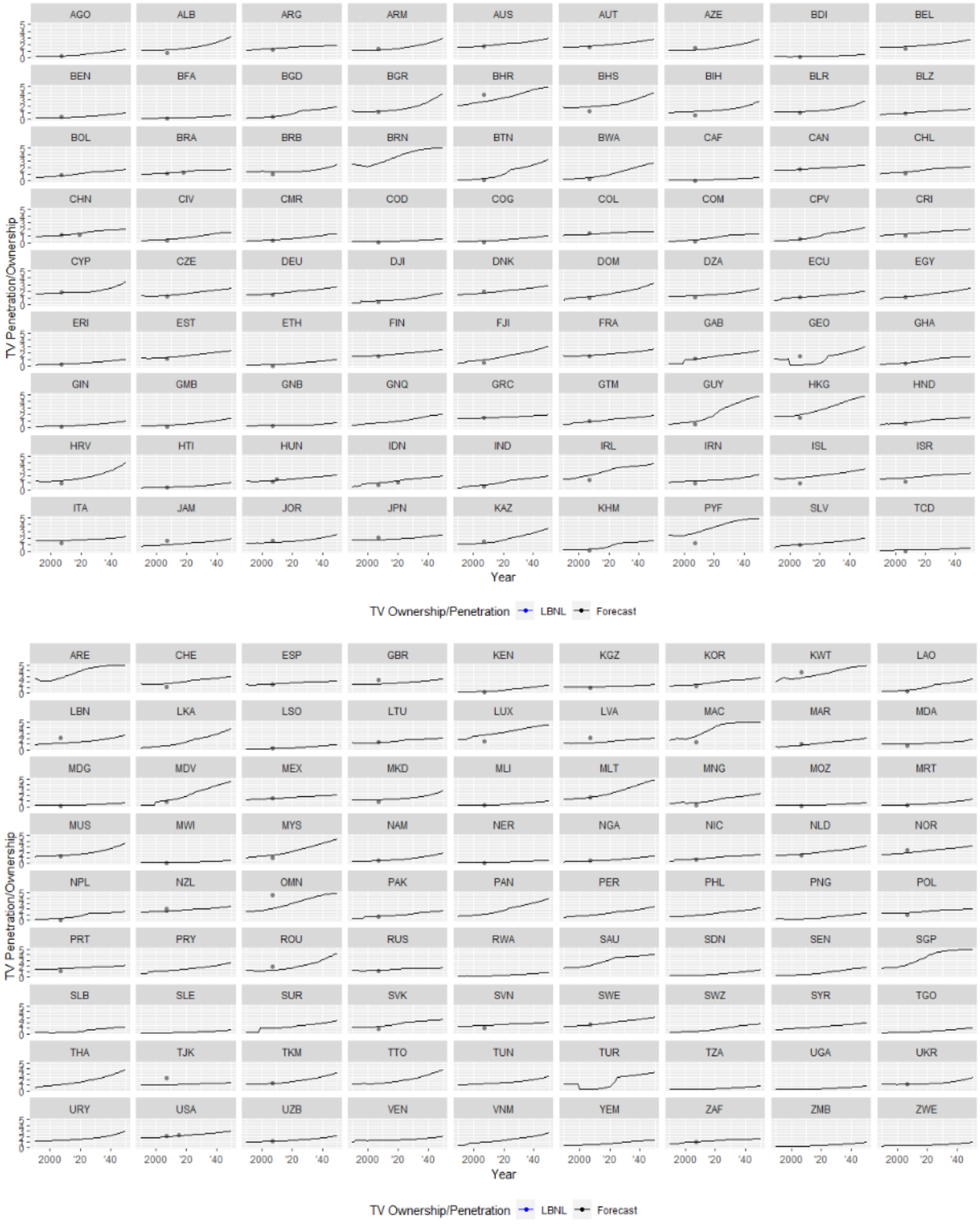
CLASP used the following data and assumptions to forecast TV ownership in the future to build a new forecast dataset.

VARIABLE	SOURCE	YEAR	NOTES
Fans Ownership	To be estimated	2020–2050	Using the beta regression model based on different countries' national statistic survey data listed above
PPP GDP (2017$)	OECD Real GDP Long-term Forecast	2020–2060	PPP-adjusted and expressed in 2010 international dollars. Inflated to 2017$ by multiplying by 1.12. Provided for 46 countries; GDP for others estimated by applying an average 5% growth rate, which is typically over 2015-2019. By comparison, the average growth rate of the 46 countries provided (OECD and other larger, most developed economies) is expected to grow at 3%, decreasing to 2% by 2060

VARIABLE	SOURCE	YEAR	NOTES
			Combined with GDP to calculate monthly household income.
Household Size	UN Population Division Household Size and Composition 2019	Various (1960–2018)	Household size was extrapolated using a linear model using available country data. The result was an average growth rate with country-specific offsets. For countries without any data, a regional average was used. The Minimum was set at 2.0.
			Indicator code EG.ELC.ACCS.ZS
Electrification	World Bank Access to Electricity (% of population)	Various (1990–2019)	Electrification extrapolated using linear model using available country data 2015-2019. The result was an average growth rate with country-specific offsets. Maximum was set at 100%.

CLASP estimated TV ownership for 162 countries in Mepsy. The results are shown below:




AGO ALB ARG ARM AUS AUT AZE BDI BEL
BEN BFA BGD BGR BHR BHS BIH BLR BLZ
BOL BRA BRB BRN BTN BWA CAF CAN CHL
CHN CIV CMR COD COG COL COM CPV CRI
CYP CZE DEU DJI DNK DOM DZA ECU EGY
ERI EST ETH FIN FJI FRA GAB GEO GHA
GIN GMB GNB GNQ GRC GTM GUY HKG HND
HRV HTI HUN IDN IND IRL IRN ISL ISR
ITA JAM JOR JPN KAZ KHM PYF SLV TCD
TV Penetration/Ownership
2000 '20 '40
Year
TV Ownership/Penetration LBNL Forecast

ARE CHE ESP GBR KEN KGZ KOR KWT LAO
LBN LKA LSO LTU LUX LVA MAC MAR MDA
MDG MDV MEX MKD MLI MLT MNG MOZ MRT
MUS MWI MYS NAM NER NGA NIC NLD NOR
NPL NZL OMN PAK PAN PER PHL PNG POL
PRT PRY ROU RUS RWA SAU SDN SEN SGP
SLB SLE SUR SVK SVN SWE SWZ SYR TGO
THA TJK TKM TTO TUN TUR TZA UGA UKR
URY USA UZB VEN VNM YEM ZAF ZMB ZWE
TV Penetration/Ownership
2000 '20 '40
Year
TV Ownership/Penetration LBNL Forecast

Forecasting: Motors

The variables utilized in the extension model for motors are different from other home appliances. Meanwhile, Clasp has acquired the latest motors' sales data from Omdia to prepare the current Mepsy model from 2005 to 2030. Therefore, Mepsy based the motors' stock projections through 2050 on multivariate regression modeling, which relates the latest year of sales response to macroeconomic parameters (including GPD, employment in Industry, warehouse building stocks, etc.).

To conduct the regression model, CLASP used the following updated data resources.

VARIABLE	SOURCE	YEAR[24]	NOTE
Motor Sales	Omdia, Motor Sales	Various (2015-2024)	
PPP GDP (2017$)	World Bank GDP, PPP (constant 2017 international $)	1990–2019	Indicator code NY.GDP.MKTP.PP.KD
Industry (including construction), value added (annual % growth)	World Bank Industry value-added GDP,	1960-2020	Combined with GDP to calculate the national Industrial GDP
Employment in Industry	World Bank Employment in Industry	1960 - 2020	Indicator code SL.IND.EMPL.ZS
Warehouse Building Stock	Guidehouse	2018 - 2030	
Export Goods/Service	World Bank, Exports of goods and services (US $)	1960 - 2020	Indicator code NE.EXP.GNFS.CD

Since the beta regression model is only suited to realistic model data between 0% and 100%, sales number are all bigger than 1 unit. Therefore, the linear regression model is used for forecasting motor sales to 2050.

Due to the high variance of the sales value of different countries, CLASP divided 162 countries into four separate groups based on their sales number in 2019 to build different regression models.

[24] Data for year 2019 were used in the regression model

The group of 13 countries had large motor sales of over 600,000 units in 2019.

COUNTRY	ISO	SALES IN 2019 (THOUSAND) UNITS
China	CHN	6591.98
United States	USA	3814.24
Germany	DEU	3742.41
Italy	ITA	1709.78
India	IND	1410.61
France	FRA	1378.88
Russian Federation	RUS	1132.43
United Kingdom	GBR	937.26
Brazil	BRA	916.03
Spain	ESP	830.77
Japan	JPN	813.20
Korea, Rep. of	KOR	807.49
Turkey	TUR	681.49

The group of 32 countries had medium motor sales between 99,000 to 60,000 units in 2019.

COUNTRY	ISO	SALES IN 2019 (THOUSAND) UNITS
Thailand	THA	462.98577
Canada	CAN	432.3996
Saudi Arabia	SAU	411.5083
Mexico	MEX	409.90405
Austria	AUT	407.24678
Netherlands	NLD	393.69516
Poland	POL	318.26564
Switzerland	CHE	296.95329
Sweden	SWE	289.15386
Greece	GRC	266.86474
Nigeria	NGA	261.46404
Indonesia	IDN	244.8156
Iran, Islamic Rep. of	IRN	231.1109
Belgium	BEL	229.35913
Norway	NOR	219.70429
United Arab Emirates	ARE	218.5508
South Africa	ZAF	205.0492
Israel	ISR	205.03553
Australia	AUS	201.18262
Denmark	DNK	189.60411

Egypt	EGY	176.89306
Hong Kong, China (SAR)	HKG	168.22683
Finland	FIN	146.39887
Portugal	PRT	141.63923
Venezuela	VEN	136.47953
Romania	ROU	134.40703
Czech Republic	CZE	132.47851
Ireland	IRL	128.8636
Argentina	ARG	127.22851
Kazakhstan	KAZ	120.02051
Ukraine	UKR	102.44618
Algeria	DZA	99.182737

The group of 43 countries has small motor sales between 20,000 to 99,000 units in 2019.

COUNTRY	ISO	SALES IN 2019 (THOUSAND) UNITS
Colombia	COL	91.617294
Colombia	COL	91.617294
Hungary	HUN	86.51367
Philippines	PHL	82.421533
Singapore	SGP	81.386224
Chile	CHL	79.87956
Malaysia	MYS	79.776052
Kuwait	KWT	69.934011
Morocco	MAR	69.27243
Bangladesh	BGD	66.185466
Peru	PER	64.184757
Pakistan	PAK	60.859207
Viet Nam	VNM	57.293545
Slovakia	SVK	56.660443
Ethiopia	ETH	56.075768
Kenya	KEN	55.723019
Angola	AGO	55.216759
Belarus	BLR	42.023065
Oman	OMN	39.950198
Ghana	GHA	39.082823
Uzbekistan	UZB	38.586119
New Zealand	NZL	37.174114
Tanzania, U. Rep. of	TZA	36.861813
Bulgaria	BGR	36.508252

Côte d'Ivoire	CIV	34.303385
Croatia	HRV	32.471041
Azerbaijan	AZE	32.008478
Cyprus	CYP	31.238276
Luxembourg	LUX	30.793723
Ecuador	ECU	30.398022
Lithuania	LTU	29.140802
Slovenia	SVN	28.884348
Lebanon	LBN	27.694703
Congo	COG	27.609498
Turkmenistan	TKM	27.15434
Dominican Republic	DOM	25.165196
Macau	MAC	24.753598
Jordan	JOR	22.700672
Tunisia	TUN	22.637231
Cameroon	CMR	22.615501
Guatemala	GTM	21.704561
Syrian Arab Republic	SYR	20.968084
Uganda	UGA	20.063856
Bahrain	BHR	20.017924

The group of 74 countries had tiny motor sales lower than 20,000 units in 2019.

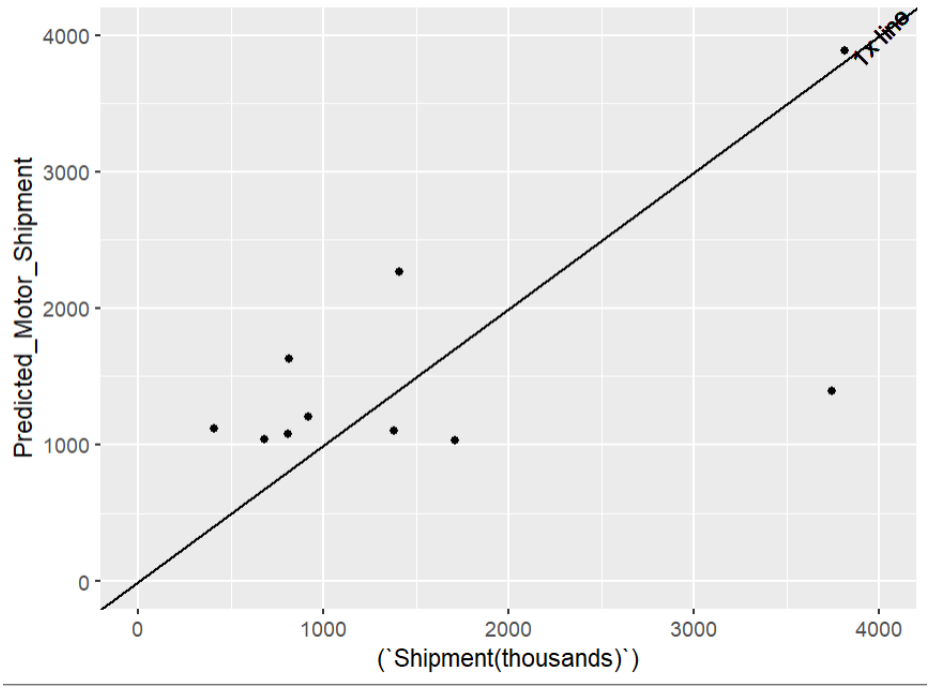
COUNTRY	ISO	SALES IN 2019 (THOUSAND) UNITS
Panama	PAN	18.900727
Malta	MLT	18.803202
Sri Lanka	LKA	18.376367
Latvia	LVA	18.336687
Costa Rica	CRI	17.47842
Estonia	EST	16.869281
Uruguay	URY	15.857722
Yemen	YEM	14.318421
Senegal	SEN	13.757063
Zambia	ZMB	13.457533
Iceland	ISL	13.175641
Zimbabwe	ZWE	12.510002
Georgia	GEO	11.820198
Bolivia	BOL	11.570989
Sudan	SDN	11.028883
Paraguay	PRY	10.79289

Bosnia and Herzegovina	BIH	10.774949
Botswana	BWA	10.701106
Mali	MLI	10.216611
Gabon	GAB	9.7193907
Burkina Faso	BFA	9.1871801
Armenia	ARM	9.1085747
Mozambique	MOZ	8.713608
Benin	BEN	8.3965217
Mauritius	MUS	8.273839
Madagascar	MDG	8.217512
Albania	ALB	8.2113803
Moldova, Rep. of	MDA	7.9644959
Guinea	GIN	7.9294978
El Salvador	SLV	7.6458298
Niger	NER	7.543162
Namibia	NAM	7.2154761
Honduras	HND	7.1005321
Macedonia, TFYR	MKD	6.8229804
Trinidad and Tobago	TTO	6.8189506
Nepal	NPL	6.7025999
Chad	TCD	6.6019147
Equatorial Guinea	GNQ	6.4337729
Congo, Dem. Rep. of the	COD	6.3134712
Cambodia	KHM	5.9256254
Rwanda	RWA	5.9061412
Kyrgyzstan	KGZ	5.6323154
Papua New Guinea	PNG	5.4619378
Tajikistan	TJK	5.4071507
Jamaica	JAM	4.6566734
Malawi	MWI	4.4732785
Mauritania	MRT	4.4307134
Lao People's Dem. Rep.	LAO	3.9754075
Bahamas	BHS	3.6292923
Nicaragua	NIC	3.5426882
Togo	TGO	3.1857246
Mongolia	MNG	3.0302196
Brunei Darussalam	BRN	2.9463474
Swaziland	SWZ	2.5704144
Haiti	HTI	2.4047158
Sierra Leone	SLE	2.2997251
Djibouti	DJI	1.9363656

Burundi	BDI	1.7576017
Barbados	BRB	1.4738429
Lesotho	LSO	1.4353741
Central African Republic	CAF	1.2954788
Maldives	MDV	1.2532353
Guyana	GUY	1.2111157
Fiji	FJI	1.2108648
Eritrea	ERI	1.2048629
Cape Verde	CPV	1.156344
Suriname	SUR	1.1275933
Gambia	GMB	1.0291324
Guinea-Bissau	GNB	0.7820746
French Polynesia	PYF	0.7541273
Comoros	COM	0.691835
Bhutan	BTN	0.5351938
Belize	BLZ	0.5318209
Solomon Islands	SLB	0.3117256
Comoros	COM	0.691835
Bhutan	BTN	0.5351938
Belize	BLZ	0.5318209
Solomon Islands	SLB	0.3117256

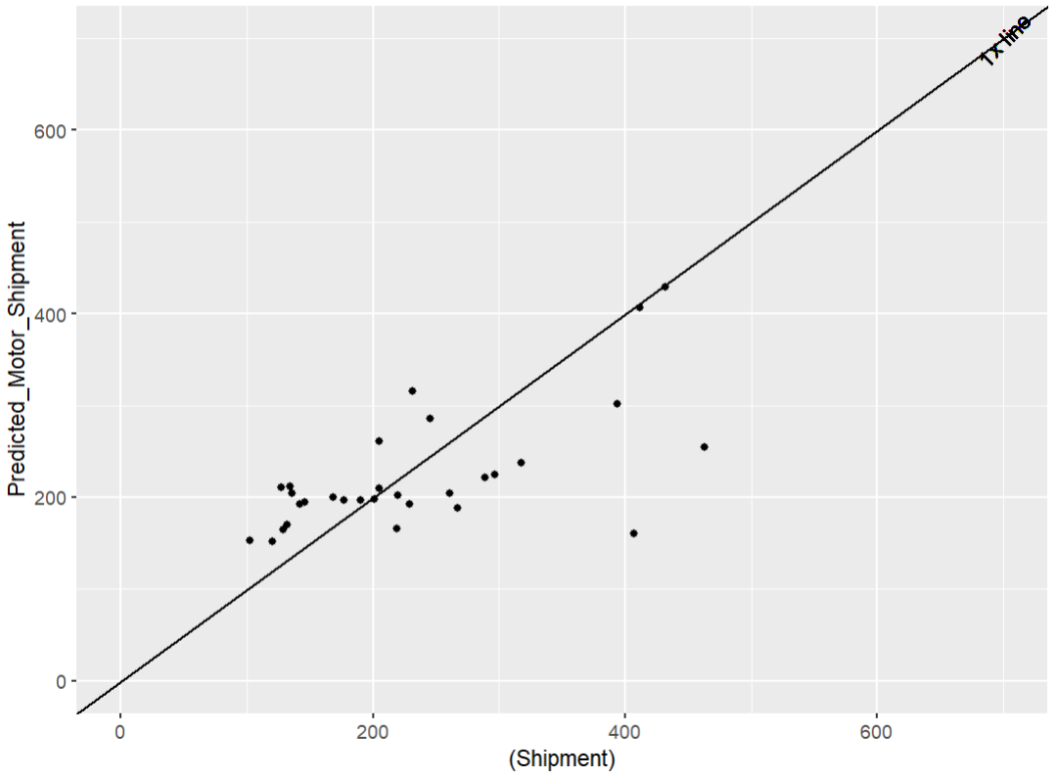
The coefficient results between variables for four groups of countries are listed below. For the countries that had sales of over 600,000 units:

SYMBOL	VARIABLE	LINEAR REGRESSION MODEL
	Constant (ln γ in logistic model)	-2.03
β_1	Industrial sector GDP	5.79×10^{-4}
β_2	Warehouse Building Stock	-1.73×10^{-5}
	Multiple R^2/Pseudo R^2	0.91
	RMS Error (percentage points)	3.9



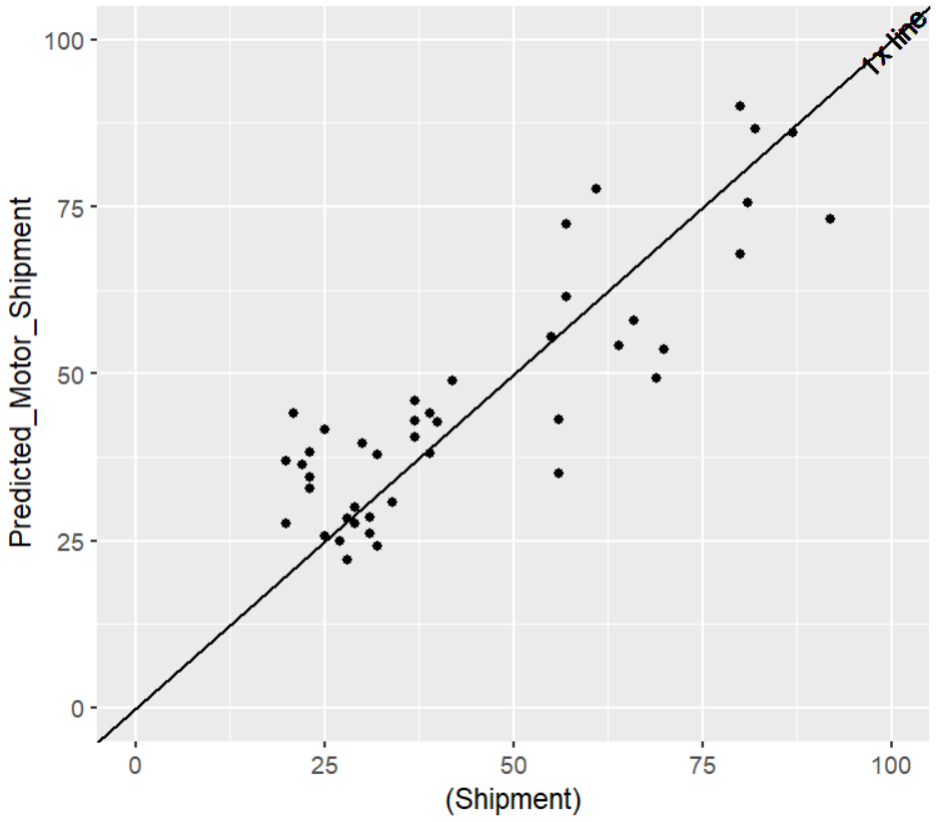
For the countries that had sales between 99,000 to 600,000 units:

SYMBOL	VARIABLE	LINEAR REGRESSION MODEL
	Constant (ln γ in logistic model)	1.64
β_1	Industrial sector GDP	-4.74×10^{-1}
β_2	Export Goods Value	4.93×10^{-11}
	Multiple R^2/Pseudo R^2	0.42
	RMS Error (percentage points)	2.1



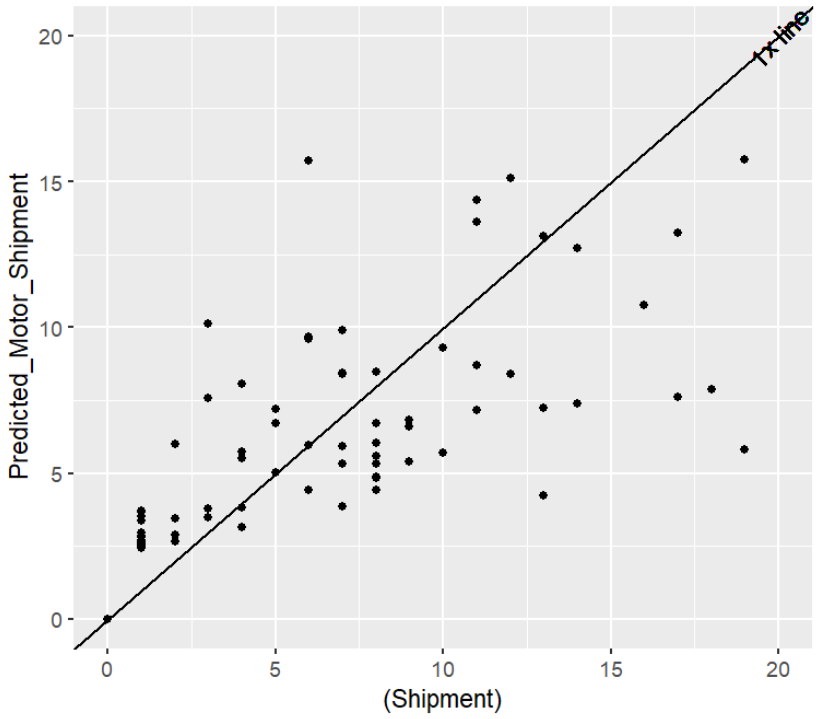
The countries had sales between 20,000 to 99,000 units:

SYMBOL	VARIABLE	LINEAR REGRESSION MODEL
	Constant (ln γ in logistic model)	3.23
β_1	Industrial sector GDP	0.19
β_2	Employment in Industry	-7.47
β_3	Warehouse Building Stock	-9.41
β_4	Export Goods Value	2.5×10^{-11}
	Multiple R^2/Pseudo R^2	0.72
	RMS Error (percentage points)	1.8



For the countries had sales below 20,000 units:

SYMBOL	VARIABLE	LINEAR REGRESSION MODEL
	Constant (ln γ in logistic model)	2.36
β_1	Industrial sector GDP	0.19
	Multiple R^2/Pseudo R^2	0.51
	RMS Error (percentage points)	2.5

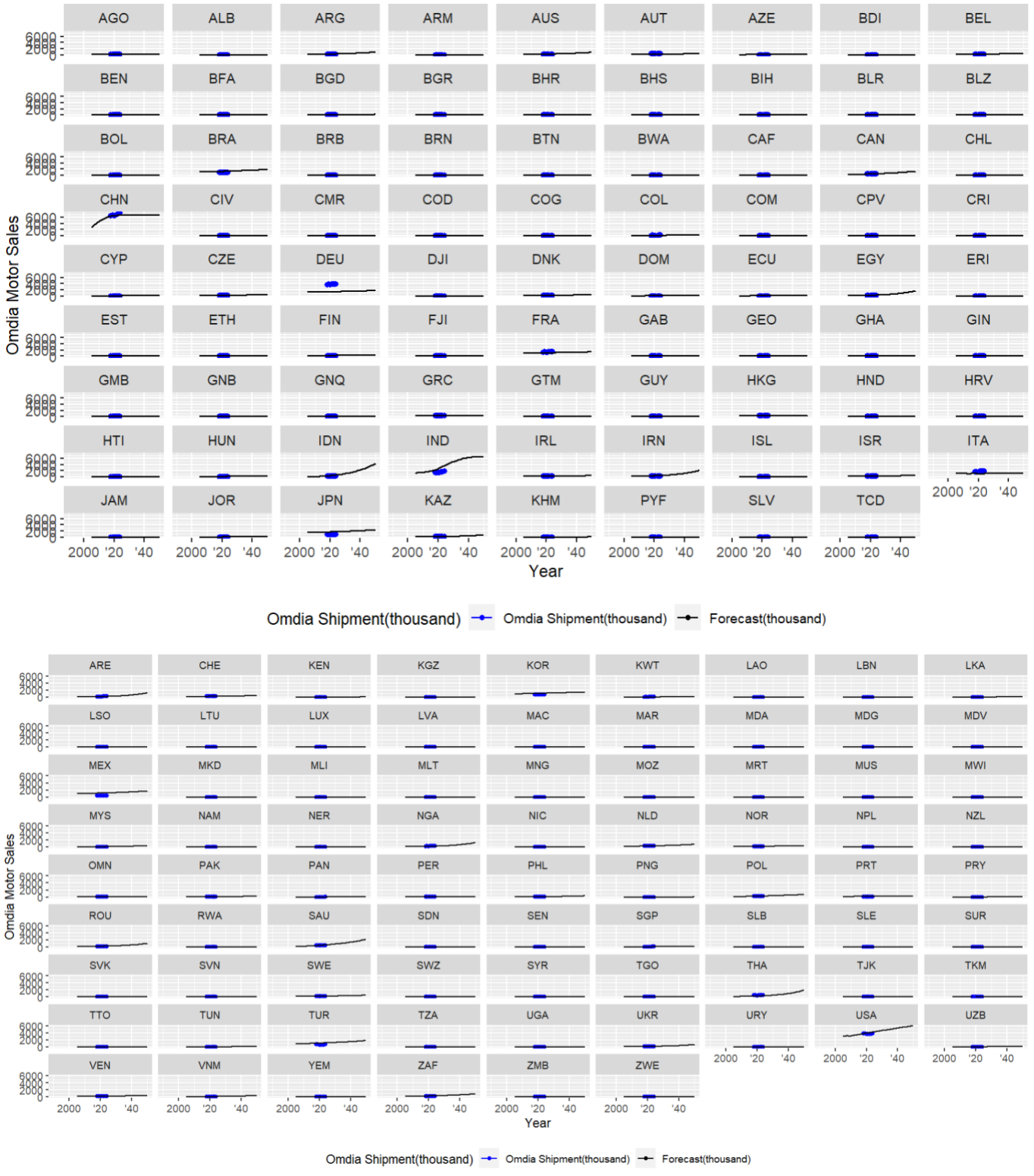


To project motors sales through 2050, CLASP used the following data and assumptions:

VARIABLE	SOURCE	YEAR	NOTES
Motor Sales	Omdia, Motor Sales	Various (2005 -2050)	Using the beta regression model based on the Omdia sales dataset.
PPP GDP (2017$)	OECD Real GDP Long-term Forecast	2020–2060	PPP-adjusted and expressed in 2010 international dollars. Inflated to 2017$ by multiplying by 1.12. Provided for 46 countries; GDP for others estimated by applying average 5% growth rate, which is typical over 2015-2019. By comparison, average growth rate of the 46 countries provided (OECD and other larger, mostly developed economies) are expected to grow at 3%, decreasing to 2% by 2060.

VARIABLE	SOURCE	YEAR	NOTES
Industry (including construction), value added (annual % growth)	World Bank Industry value-added GDP,	1960-2020	Combined with GDP to calculate national Industrial GDP Extrapolated by using a linear model with available country data from 2020 to 2050.
Employment in Industry	World Bank Employment in Industry	1960 - 2020	Employment percentage in Industry was extrapolated by using a linear model with available country data from 2020 to 2050.
Warehouse Building Stock	Guidehouse	2018 - 2030	Extrapolated by using a linear model with available country data from 2030 to 2050.
Export Goods/Services Value	World Bank, Exports of goods and services (US $)	1960 - 2020	Export value was extrapolated by using a linear model with available country data from 2020 to 2050.

The compiled results of motor sales showing historical data and forecasts for 162 countries are shown below:


AGO ALB ARG ARM AUS AUT AZE BDI BEL
BEN BFA BGD BGR BHR BHS BIH BLR BLZ
BOL BRA BRB BRN BTN BWA CAF CAN CHL
CHN CIV CMR COD COG COL COM CPV CRI
CYP CZE DEU DJI DNK DOM ECU EGY ERI
EST ETH FIN FJI FRA GAB GEO GHA GIN
GMB GNB GNQ GRC GTM GUY HKG HND HRV
HTI HUN IDN IND IRL IRN ISL ISR ITA
JAM JOR JPN KAZ KHM PYF SLV TCD
Omdia Motor Sales
0 2000 4000 6000
2000 '20 '40
Year
Omdia Shipment(thousand)
Omdia Shipment(thousand)
Forecast(thousand)

ARE CHE KEN KGZ KOR KWT LAO LBN LKA
LSO LTU LUX LVA MAC MAR MDA MDG MDV
MEX MKD MLI MLT MNG MOZ MRT MUS MWI
MYS NAM NER NGA NIC NLD NOR NPL NZL
OMN PAK PAN PER PHL PNG POL PRT PRY
ROU RWA SAU SDN SEN SGP SLB SLE SUR
SVK SVN SWE SWZ SYR TGO THA TJK TKM
TTO TUN TUR TZA UGA UKR URY USA UZB
VEN VNM YEM ZAF ZMB ZWE
Omdia Motor Sales
0 2000 4000 6000
2000 '20 '40
Year
Omdia Shipment(thousand)
Omdia Shipment(thousand)
Forecast(thousand)