Inequalities in global residential cooling energy use to 2050

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ABSTRACT

The interplay of a warming climate and socio-demographic transformations will increase global heat exposure. Assessing future use and impacts of energy-intensive appliances for indoor thermal adaptation is therefore a crucial policy goal. Here we train statistical models on multi-country household survey data (n = 480,555) to generate global gridded projections of residential air-conditioning (AC) uptake and use. Our results indicate that the share of households owning AC could grow from 26% to a scenario median of 38% by 2050, implying a doubling of residential AC electricity consumption, to 925 TWh/yr. This growth will be highly unequal both within and across countries and income groups, with significant regressive impacts. Up to 4.5 billion heat-exposed people may lack AC access in 2050. Outcomes will largely depend on socio-economic development and climate change pathways. Our gridded projections can support the modelling of the impacts of residential AC on decarbonization pathways and health outcomes.

Keywords

Climate change adaptation; air conditioning; electricity consumption; shared socioeconomic pathways; gridded dataset; inequality

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The impacts of anthropogenic climate change are increasingly felt[1,2] and the growing heat exposure is one of the most widely perceived outcomes[3,4]. As a result, the uptake of autonomous means of adaptation to heat such as air conditioning (AC) is growing quickly[5,6] around the world, with important repercussions on energy demand and electricity systems stability and planning[7,8], but also household expenditure and welfare[9], environmental pollution, including feedback emission of greenhouse gases and climate policy[10]. According to the IEA's *The Future of Cooling* report[11], already today air cooling appliances account for nearly 20% of the total global electricity used in buildings, which in turn represent about 30% of global final energy consumption and 27% of total energy sector emissions[12]. Moreover, about two thirds of the 1.6 billion AC units installed globally are in residential buildings, accounting for about half of the total 1,200 TW of installed cooling output capacity.

Against this backdrop, documenting and projecting future access to appliances for cooling and the related energy use and environmental implications within and across countries and world regions is a timely and policy-relevant goal. Previous studies have used different techniques, including empirical regression models[5,13–16] and bottom-up engineering approaches[17,18], to analyse the decision of purchasing and utilising air conditioning in different contexts and at different scales. For instance, at the cities level[19,20], country level[21–23], multi-country level[5,14,24], or globally[13,15].

Yet, these studies are either context-specific or - when global - carried out at a coarse resolution, not allowing for within-country inequality assessments or vulnerability analysis, or only focusing on the extensive margin of AC (i.e. the asset ownership), therefore not characterising its intensive margin (the intensity and change in use, and thus electricity consumption). However, adaptation is a context-specific phenomenon, as it depends on the interaction of local climate, such as heat exposure, and socio-economic characteristics[25]. Therefore, in order to generate a picture of the heterogeneous future of AC around the world and its implications for energy consumption, it is necessary to account for a set of different local and context-specific drivers.

Here we assemble a global database of household level microdata covering a large number of sub-national administrative units from 25 countries, representing 62% of the world's population and accounting for 73% of the global electricity consumption (see Figure 1B and Table SI-1 for an account of the regions included in our database). We train two-stage (extensive and intensive margin) statistical models (Figure 1A) on our multi-country dataset, which includes a rich set of household characteristics. We benchmark different model specifications (see Tables SI-4-SI-5) to show why our preferred prediction framework is a random forests (RF) machine learning (ML) model, which uses regression tree algorithms to implement flexible non-parametric estimations (see Methods).

We generate global gridded projections of future AC uptake and induced residential electricity consumption under an array of socio-economic and climate change scenarios (see Table SI-3 for a description of the assumed future evolution of drivers in each scenario) based on robust statistical modelling techniques (Figure 1C). We then analyse the results to draw implications for energy use, cooling poverty, and CO_2 emissions. Our results can inform decision makers at the intersection of public health, infrastructure planning, and energy and climate policy. The output datasets are made publicly available and they can serve for carrying out vulnerability assessments or as input data into energy and integrated assessment models.

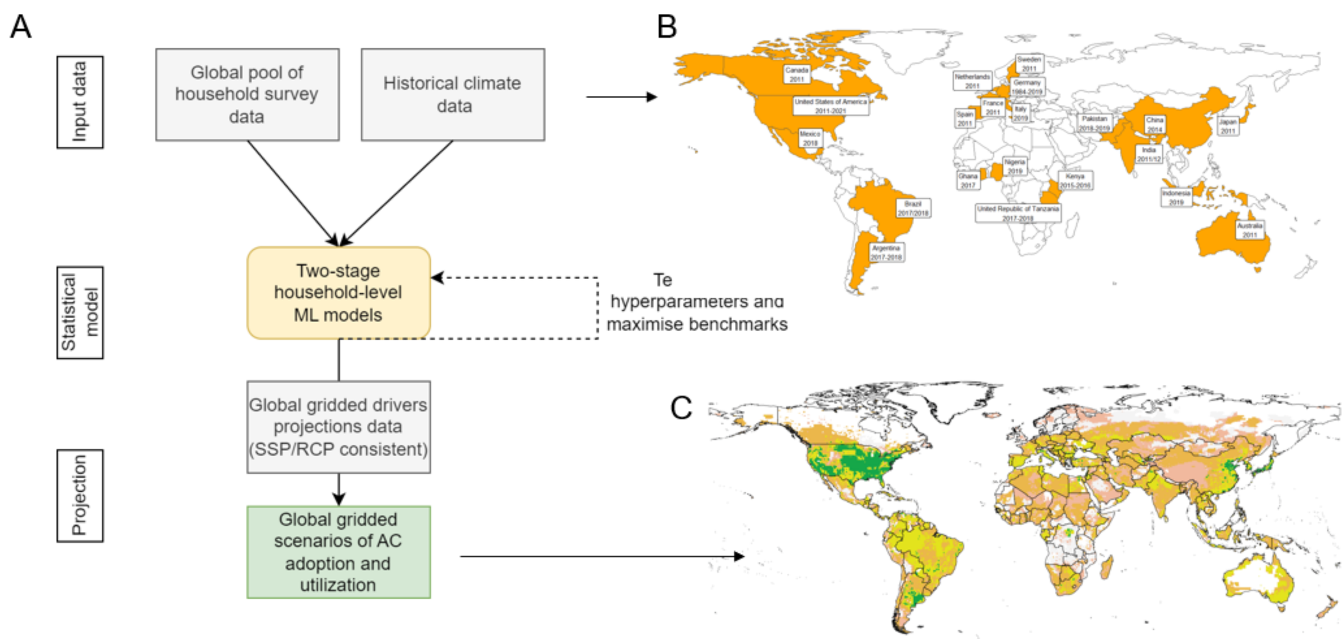

Figure 1. Methodological framework of the analysis presented in this paper. (A) Flowchart of the analysis; (B) Countries covered in the household survey global pool database; (C) Representative example of output gridded projections.

Results

Soaring residential cooling energy demand and greenhouse gas emissions

Figure 2 presents maps of the gridded model-based projections of AC penetration and induced residential electricity consumption - per capita and total per grid-cell - in year 2020 and in year 2050 under SSPs 2(45) and 5(85) (refer to Figures SI-10 in the SI for SSPs 1(26)-3(70)). The results illustrate the highly heterogeneous growth in AC penetration rates across and within regions and countries: emerging hotspots of household AC ownership are clearly visible in Latin America, North Africa, Southern Africa, as well as South and South-East Asia. As a result of surging AC penetration, a warmer climate, income and population growth, existing hotspots of high residential AC electricity consumption will enlarge (such as as North America and and Japan) and new hotspots will emerge, e.g. Eastern China, Northern India, Indonesia, as well as Central Europe, Egypt and the Middle East.

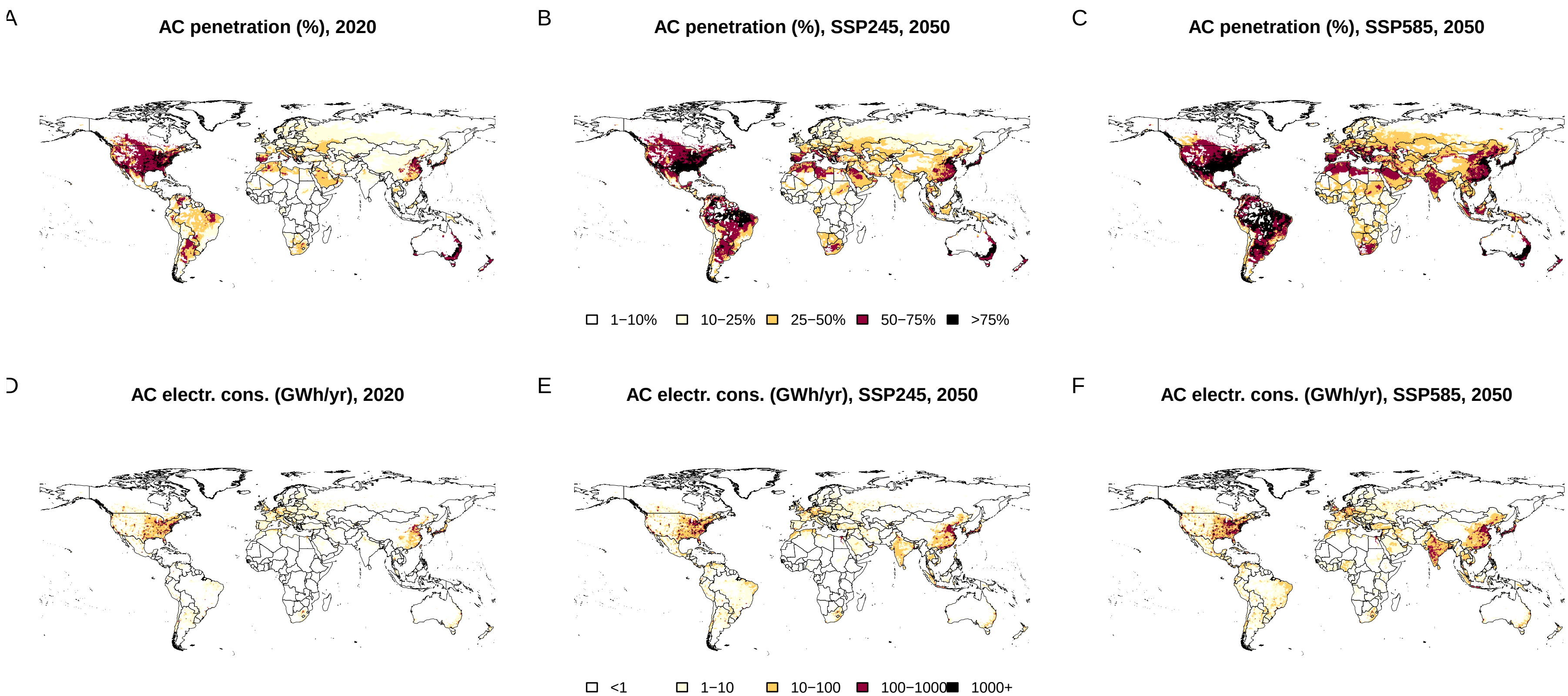

Figure 2. Global gridded projections for residential air conditioning. Maps of AC ownership (% of households) (A,B,C) and (D,E,F) residential sector AC electricity consumption, SSP scenarios 2(45) and 5(85) in 2020 and 2050, CMIP6 GCMs enemble median (exluding 'hot models'[26]).

These gridded projections are obtained by pooling multi-country household survey data from 25 countries (n = 480,555) to train two-stage tree-based classification and regression models of AC adoption and its impact on residential electricity consumption. The climate variables and household characteristics used in the RF model are summarised in Tables SI-1, while the Methods section describes in detail the model selection and validation procedures, yielding to high confidence predictions both within and out of the training sample. Using these global models, we predict (see Methods for projection drivers data and approach) AC ownership and the AC-induced electricity consumption on a regular global grid with a spatial resolution of 0.5 arc-degrees and project their future evolution based on assumptions underlying SSP scenarios 1(26), 2(45), 3(70), and 5(85) (see Methods and Table SI-3).

Global and regional statistics derived from the gridded projections, presented in Figure 3, reveal that in the baseline SSP2(45) scenario the global projected AC penetration (% of households equipped with AC) may grow from the current 26% to 35%. This translates into a growth from 500 million to an estimated 800 million households owning AC by 2050. In turn, this AC availability growth in SSP2(45) would translate into a surge in the global residential AC electricity consumption (Figure 3, panel B) from 500 to 900 TWh/yr. in 2050. Such growth is inclusive of the evolution of an array of socio-economic, demographic, and climate divers (see Table SI-3).

Yet, as seen from the regional trends in Figure 2 and from Table SI-6 in the SI (presenting a country-level summary of projected AC ownership and AC energy consumption), substantial heterogeneity is and will be characterising AC availability and energy consumption. South Asia and Sub-Saharan Africa will experience a very rapid growth in the penetration of AC, though starting from very low levels and reaching 40% and 20% by 2050, respectively. The highest levels of AC prevalence will be observed, after the North America region, in the Middle East and North Africa, East and South Asia, and Latin America (Figure 3, Panel A). Yet, the largest energy consumption for AC will be in North America and East Asia & Pacific (Figure 3, Panel B).

Besides regional heterogeneity, our results also demonstrate the large scenario uncertainty affecting AC uptake and energy use projections. SSPs 1(26) and 2(45) lead to similar results in most regions, demonstrating how different climate change and socio-economic growth interactions can generate similar impact scenarios. On the other hand, SSPs 3(70) and 5(85) show radically different outcomes irrespective of similar implied radiative forcing. Being SSP3(70) a scenario of regional rivalry, economic stagnation, and high population growth, it results in low AC uptake in the developing world, while SSP5(85) implies strong, fossil-fuel driven economic growth resulting in very high warming and also high cooling energy consumption.

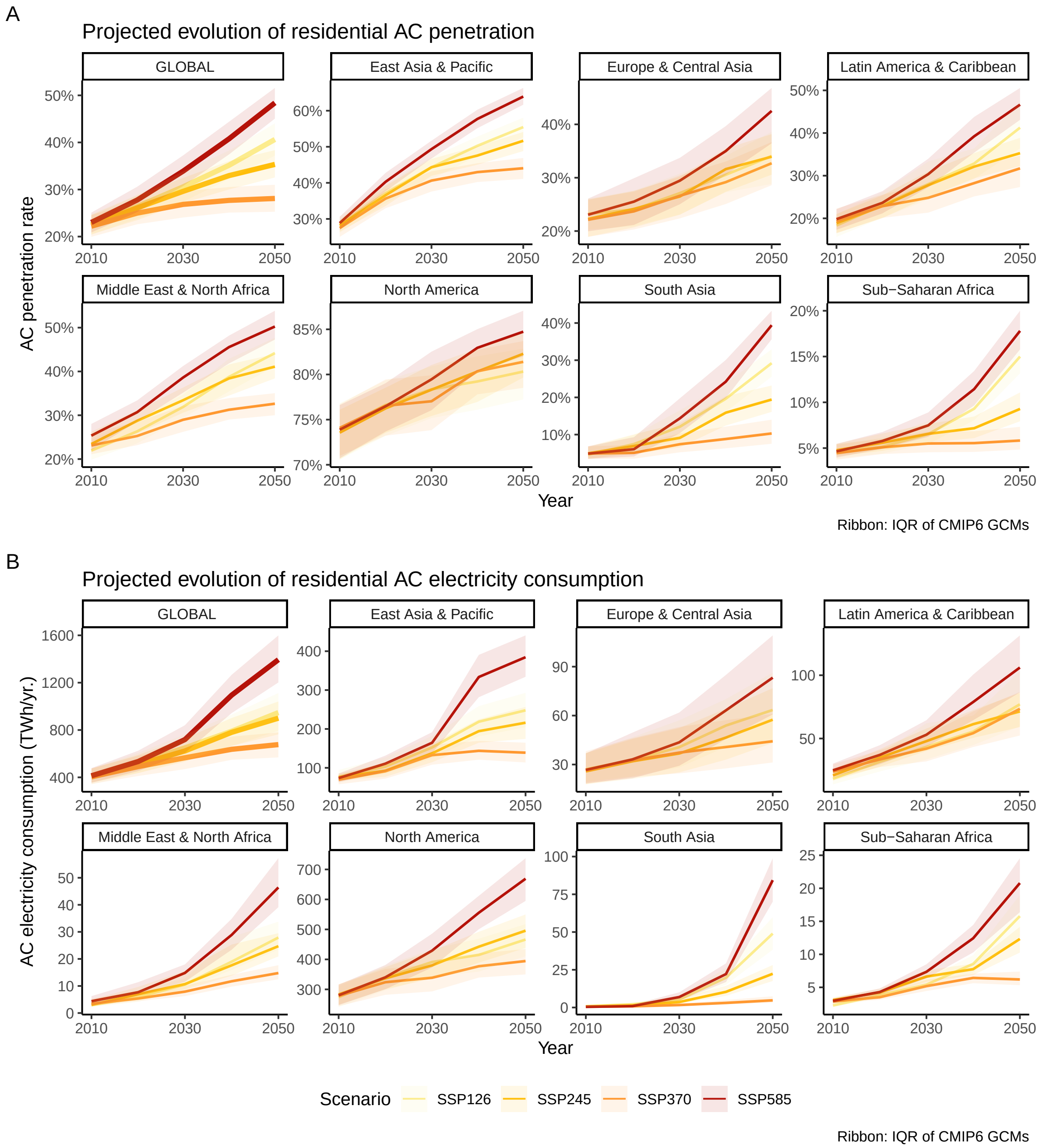

Figure 3. Regional aggregated trajectories of residential air conditioning. (A) Projected global household adoption of air conditioning in 2050, SSPs 1(26), 2(45), 3(70), and 5(85). (B) Global AC-induced residential electricity consumption in 2050, SSPs 1(26), 2(45), 3(70), and 5(85). Selected countries. The ribbon represents the CMIP6 GCMs IQR whilst the solid line depicts the model ensemble median (excluding 'hot models'[26]).

To assess the consequences of increased AC energy use, we then estimate CO_2 emissions in response to future projected AC utilisation. Depending on the global power sector decarbonisation pathway that is represented in the different SSP scenarios, the use of AC electricity might drive a feedback effect on the global warming dynamics by emitting additional greenhouse gases into the atmosphere. To quantify such potential emissions, we combine our projection dataset with country (where available) or regional-level power sector emission factors of different SSP scenarios from the IPCC AR6 Database[27]. Such emission factors are multiplied by the estimated AC-induced electricity demand for cooling in each country.

Table 1 shows aggregate regional CO_2 electricity emissions from the residential use of AC, totalling 313 Mt in 2020 and - according to our projections - ranging between 261-781 Mt in 2050, with the lion shares taken by the Americas and Asia. For reference in 2021 the emissions by the United States electric power sector were 1,551 Mt. We estimate that future global AC electricity may emit up to about half of the current total electricity emissions by the US[28]. In SSP1(26), a scenario of high decarbonisation, we observe a reduction of emissions irrespective of a robust growth in AC energy use. To complement the region-level results, Table SI-7 in the SI presents emission implications for all countries in the world.

Table 1. Estimated CO_2 emissions from electricity use for cooling in the residential sector in 2020 and 2050, by region. Note: the main numbers refer to projections calculated with the CMIP6 GCMs enemble median (exluding 'hot models'[26]), whilst the number in parentheses describe the IQR of CMIP6 GCMs.

	Region	2020	SSP126 (2050)	SSP245 (2050)	SSP370 (2050)	SSP585 (2050)
1	East Asia & Pacific	75.1 (62.3 - 90.5)	102.8 (84.9 - 121.5)	159.4 (128.7 - 189.4)	101.4 (83 - 120.2)	242.9 (211.1 - 278.4)
2	Europe & Central Asia	16.1 (10.7 - 23)	16.5 (11.7 - 22.4)	27.8 (20.9 - 37.2)	24.1 (17 - 33.2)	49.2 (35.8 - 64.5)
3	Latin America & Caribbean	15.7 (12.5 - 18.8)	14.9 (11.5 - 20)	29.3 (24.2 - 35.2)	29.1 (20.7 - 34.3)	54.6 (44.5 - 67.7)
4	Middle East & North Africa	3.6 (2.6 - 5)	8.6 (7.3 - 10.4)	12.6 (10.7 - 15.1)	9.2 (7.8 - 11.1)	26 (21.9 - 32.1)
5	North America	196.7 (175.7 - 218.7)	89.4 (78.8 - 99.2)	251.4 (222.2 - 278.8)	236.4 (209.7 - 260.5)	333.9 (296.9 - 368.1)
6	South Asia	1.3 (0.8 - 2.1)	23 (18 - 28.1)	16.9 (13.3 - 21.3)	3.5 (2.3 - 5.4)	58.8 (48.8 - 68.9)
7	Sub-Saharan Africa	4.1 (3.5 - 4.7)	5.9 (4.7 - 7)	9.9 (8.2 - 11.4)	4.7 (4.1 - 5.6)	15.2 (12 - 17.9)
8	Total	312.7 (268.1 - 362.8)	261.1 (216.9 - 308.7)	507.3 (428.1 - 588.3)	408.4 (344.6 - 470.3)	780.6 (671 - 897.7)

Inequitable AC access and utilisation worldwide: patterns and projections

Whilst growing AC penetration and related electricity use will be observed in all world regions, Figure 3 demonstrates that the strongest increase will be witnessed in East Asia an Pacific, in the Middle East and North Africa, and in South Asia. Europe, Latin America, North America will witness lower growth rates, also because of already higher current AC prevalence rate. Crucially, sub-Saharan Africa will remain the world region with the lowest AC prevalence irrespective of a large and quickly growing heat-exposed population.

Moreover, within each region, AC prevalence is and will persistently be highly unequal in different income quintile groups, as seen from Figure 4A. This stratified assessment reveals large inequalities within all regions. Overall, in the world the lowest quintile of income AC penetration is expected to grow from about 13% to 17-35%, whilst in the highest our projections suggest a growth from 33% to about 36-51%.

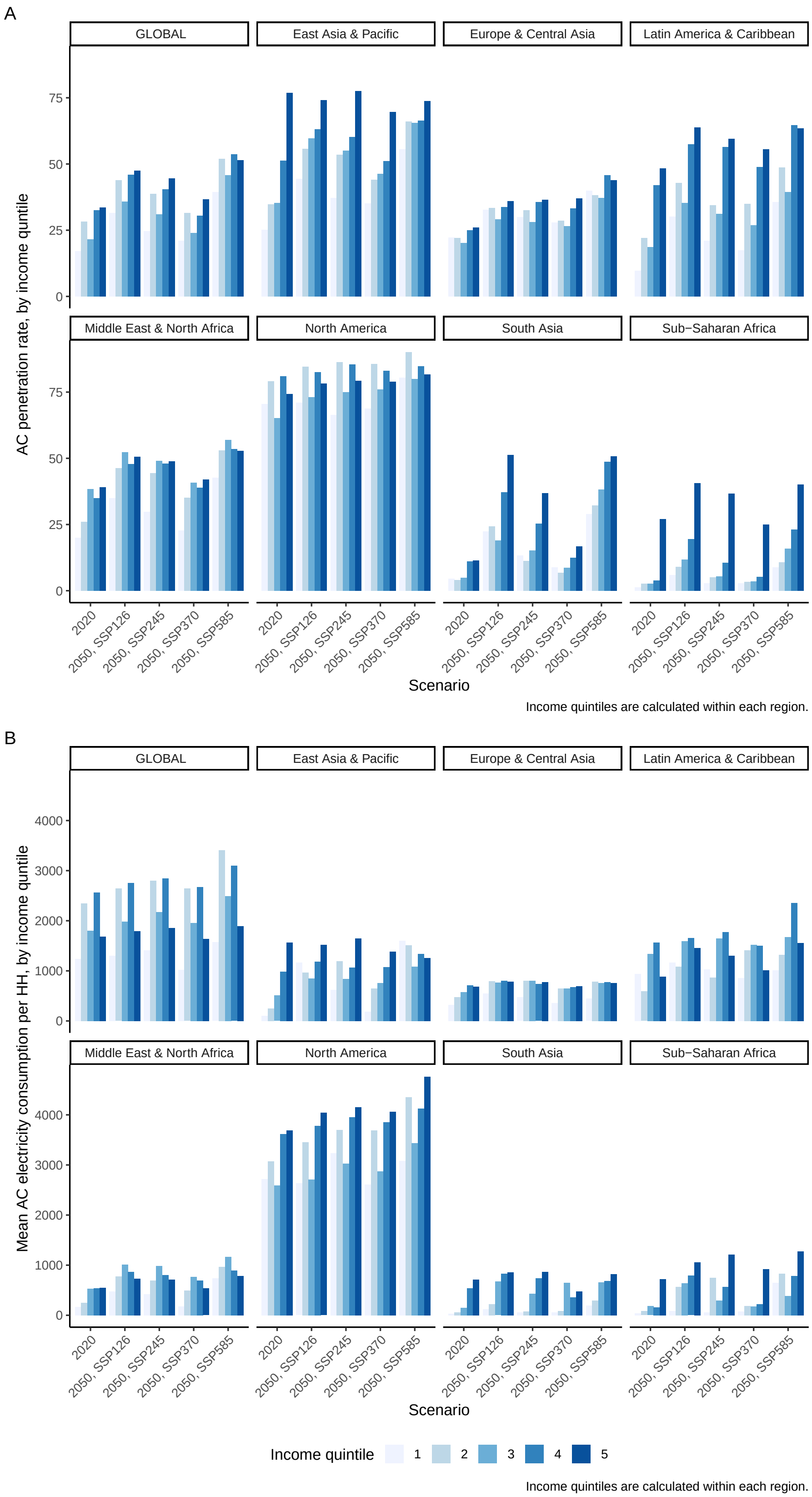

Figure 4. **(A) Household AC penetration (%) and (B) residential sector average AC electricity consumption per HH, by income quintile, region, and scenario.** Note that income quintiles are defined based on each specific region's income distribution in year 2020, and therefore the global pool panel pools together households belonging to each quintile of different regions. The numbers refer to projections calculated with the CMIP6 GCMs enemble median (exluding 'hot models'[26]).

In addition, Figure 4B reveals that household AC electricity consumption is also unequally distributed across income quintiles both globally and within most regions. Crucially, we find consumption (and therefore electricity expenditure) to have a largely regressive distribution. Families in low income quintiles - largely because of their geographical distribution with respect to heat exposure - are consuming similar or higher quantities of electricity to families in higher quintiles in several world regions. Due to lower incomes, this has a significant regressive effect on household energy expenditure. Future evolutions and growing heat exposure as a result of climate change is found to worsen this energy poverty pattern: for instance, in SSP5(85) families in the second income quintile are projected to consume more than families in any other quintile globally. This regressive impact is particularly strong in East Asia & Pacific, Middle East & North Africa, North America, and sub-Saharan Africa.

Figure 5 illustrates another key finding relative to the distribution of future growth in residential AC electricity consumption, showing the cumulative count of individuals in year 2050 as a function the absolute projected change (in kWh/yr.) in AC electricity consumption. The figures show that the AC intensive margin response of people owning an AC unit will vary greatly across scenarios. For example, in the SSP5(85) scenario we observe that about 500 million people will increase their electricity consumption for AC by at least 1,000 kWh per year, with likely important repercussion for their budget allocation.

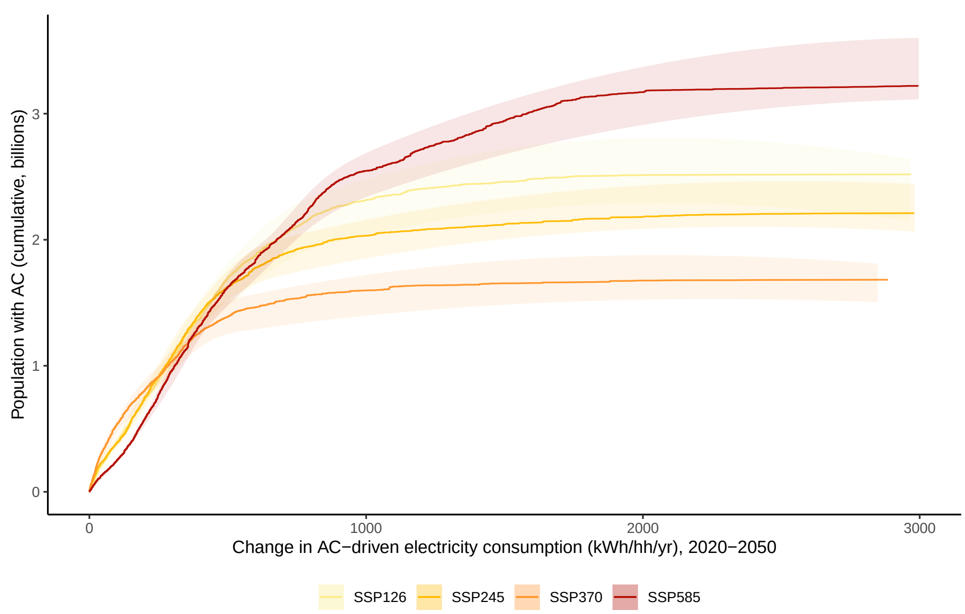

Figure 5. Distribution of future growth in residential AC electricity. Cumulative fraction of the global population with AC by absolute growth (in kWh/household) in residential AC electricity consumption in 2050 (with respect to 2020), in SSP scenarios 1(26), 2(45), 3(70), and 5(85). The ribbon represents the CMIP6 GCMs IQR whilst the solid line depicts the model ensemble median (excluding 'hot models'[26]).

The global adaptation cooling deficit: quantifying current and future deprivation

To conclude the analysis, it is also important to evaluate where - according to our gridded projections - the largest adaptation deficit in terms of AC would be observed. That is, to quantify and locate hotspots of people who are projected to remain without AC by year 2050 (mainly due to income constraints) but live in climates with considerable heat exposure where AC would be a highly effective adaptation strategy. This analysis goes in the same direction of previous studies, e.g. refs.[13,14]. Figure 6, panel A, visualises - globally and for each major world region - the cumulative fraction of people exposed to a certain cumulative heat exposure (quantified in CDDs/yr.) who are estimated not to have AC by year 2050 in the four scenarios considered. Vertical dashed lines highlight the population-weighted average CDDs/yr. in each region under historical climate (1995-2014). In parallel, Figure 6, panel B, quantifies the absolute deficit in terms of billion people without AC exposed to more CDDs/yr. than the regional historical average value (described by a purple dot), and its expected evolution in 2050, driven by both the local demographic growth and the future AC ownership rates from our gridded projections.

The results reveal that globally the number of heat-exposed people without AC will change from around 2.7 billion today to 3.5 billion by 2050 in SSP2(45). Significantly higher exposure will be observed in the low AC and high warming future of SSP3(70), with 4.7 billion exposed people. Interestingly, SSP5(85), the strongest warming future, is projected to be the future with the smallest global adaptation cooling deficit, at 2.5 billion. While this is the result of high economic growth, it also implied the starkest heat exposure for those not gaining access to AC, as seen from panel A. In addition, the increases or only moderate decreases in the gap figure is explained by the expected global demographic growth in highly exposed but adaptation capacity-constrained areas, which may partially or more than counterbalance the projected growth in the global AC penetration rates. As a consequence, the deprivation is and will increasingly be concentrated in Africa and in South Asia.

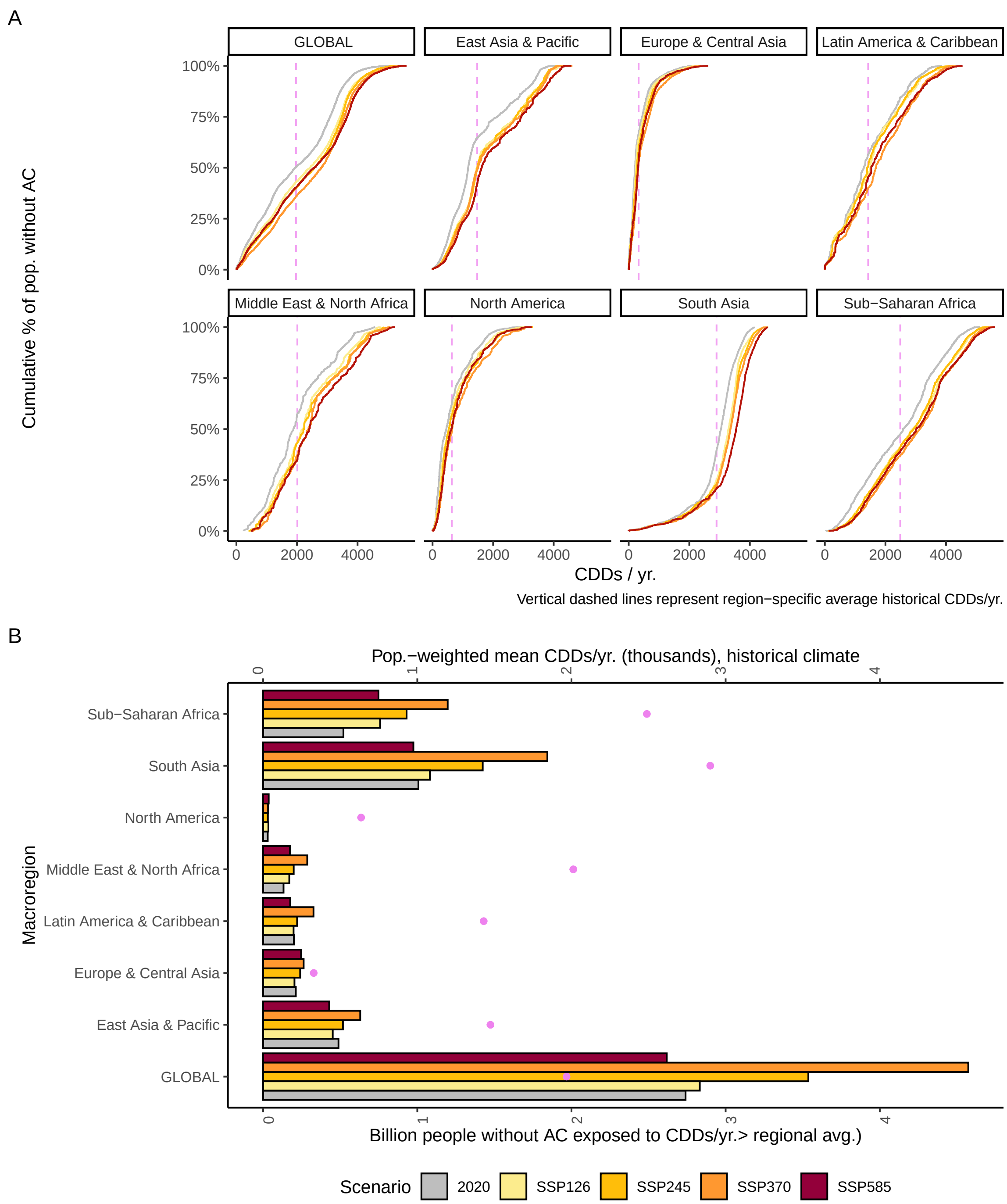

Figure 6. The global adaptation cooling deficit. (A) Cumulative fraction of people living without AC in 2050 as a function of CDDs exposure, by global region and scenario. (B) Count of people exposed to more CDDs/yr. than the regional historical average value and living without AC, by global region and scenario. Purple dots identify the the regional historical average CDDs/yr. The numbers refer to projections calculated with the CMIP6 GCMs enemble median (exluding 'hot models'[26]).

Discussion

Our analysis indicates that the interaction of anthropogenic climate change and changing socio-economic factors will determine a steep growth in the global uptake and utilisation of air conditioning to cope with heat. We estimate that the share of households owning air conditioning could grow from 26% to 38% (28-47%) by 2050, implying a surge in global residential AC electricity consumption from 500 TWh/yr. to about 925 TWh/yr. in SSP2(45) in 2050. We show that such growth will be highly unequally distributed across regions and income groups. The additional household's cooling energy could increase CO_2 emissions up to 781 Mt CO_2 by 2050, unless the electricity sector undergo a deep decarbonisation as descriped in SSP1(2.6).

Our projections are in general agreement with the IEA's *The Future of Cooling* report[11], though slightly more conservative. IEA estimates that globally, the share of households with at least one AC will be of about 65% in 2050, while our projections reach a maximum of almost 50% of households in SSP5(85), i.e. from the current 1.8 billion individuals to about 3.8 billion. Yet, other scenarios modeled in our study, like the SSP3(70), which is characterised by low economic growth and convergence and high population growth in developing countries, lead to a significantly slower pace in the global uptake of AC. In addition, in its baseline scenario, IEA estimates a more than three-fold increase in residential energy use for cooling in by 2050, reaching nearly 4,000 TWh/yr. However, in the IEA's efficient cooling scenario, this growth is reduced by about 45%, bringing IEA's numbers closer to our residential AC electricity consumption projections, which reach up to about 1,500 TWh/yr. Emission projections are also comparable. IEA's estimate of current CO_2 emissions associated with the global cooling sector stand at 1,130 Mt CO_2/yr.. This estimate also considers cooling in the commercial and services sectors, which account for about half of the global cooling capacity. Our estimates for 2020 residential AC use CO_2 emissions are lower, but of comparable magnitude (at most 363 Mt/yr.)

Our results have important policy implications. The sub-national granularity of our projections is an important contributions that yield new evidence at the scale that matters for policy implementation. For instance, we show that in highly exposed regions such as South Asia and sub-Saharan Africa, by 2050 AC will only be extensively available (AC availability >50%) to people belonging to the highest income groups, while the vast majority of poorer households will be remaining without access.

The high spatial resolution and the global coverage of our projections is of crucial importance to reveal future geographical hotspots of climate adaptation inequalities in different world regions and population sub-groups. This new evidence can enable the promotion of more equitable planning of cooling solutions to cope with heat through public subsidies, international donors, building and city planning, and passive cooling solutions.

The output gridded data and the underlying ML model trained on household survey data are made publicly available for future use. In particular, we release global netCDF files with a 0.5 arc-degree spatial resolution (about 55km at the equator) and 10-year time resolution for the period 2010-2050 for the SSP scenarios 1(26), 2(45), 3(70), and 5(85). Dataset for three variables is made available: (i) the AC penetration rate, defined as the fraction of households living at grid cell i in year t owning at least one AC unit; (ii) the population of reference, derived from Gao et al.[29], which can be used as a weight to aggregate AC penetration rates at different spatial scales; (iii) the total AC electricity consumption (in GWh/yr.), defined as the electricity consumed for AC utilisation by households at each grid cell i in year t.

This dataset can contribute to provide the missing input to the modelling community to better assess the impact of air-conditioning on residential electricity demand and investment and planning-related implications, also in relation to climate mitigation and development policy. In addition, it can support vulnerability and adaptation assessments when combined with information on the spatial distribution of vulnerable individuals (e.g. the elderly, see[30]) and it may be fed into global climate-mortality assessment to account for the role of adaptation options in mitigating health risks[31,32].

The study is not without caveats. First, the projected electricity demand and ownership rates only refer to residential cooling demand, and therefore they can be considered as lower-bound estimates, not including cooling energy from commercial, industry, and transport. Second, the empirical approach adopted in this paper is not able to explicitly characterise technological change such as future improvements in the efficiency of appliances, building insulation, or other low-energy cooling solutions. These transformations are partially accounted for by the model non-linearities, which determine highly heterogeneous responses of electricity consumption to AC ownership and utilisation, with such responses being mediated by factors such as income, education and geography. These variables and their projected transformations in different areas of the world implicitly encapsulate these technological and efficiency transformations. Nonetheless, due to lack of information in the survey data, these factors cannot be explicitly included in the models specifications. Third, our projections do not take into account future expansion of electricity access, which in sub-Saharan Africa still stands at less than 50% (more than half a billion people), with important repercussions connecting cooling demand and energy use[33]. Future research could explicitly look at these transformations to assess their potential for reducing future cooling energy demand at a local and global level.

Methods

Multi-country household survey data

We assemble a globally-relevant household micro data database covering a large number of sub-national administrative units from 25 countries. Together, these countries represent 62 percent of the world's population and account for 73% of the global electricity consumption. Table SI-1 lists the countries included in the database, the macro-region of belonging, the year(s) when the interviews were carried out, and the number of households included in the final pooled database for each country.

For each survey we gather information on annual electricity expenditure (also on quantity when available), air-conditioning ownership, total household expenditure and several socio-economic and demographic variables. We limit our sample to nonmissing air conditioning and nonmissing electricity data. This means that our data set excludes households that did not have access to electricity at the survey year. As for not all the surveys electricity quantity is available, we enrich our data set with information on average electricity prices. Electricity prices are either directly obtained dividing electricity consumption by quantity or collected at country or sub-national level from external sources. Similarly, the variable indicating whether a household lives in urban or in a rural area is not reported for all countries. For this reason, we also collect gridded data on urbanisation from Gao et al.[29] to construct sub-national shares.

Climate and socio-economic data

Historical climate data is drawn from the ECMWF's ERA-5 historical climate reanalysis data product[34], covering the period 1970-2019, and having a spatial resolution of 0.25 arc-degrees. We obtain daily average temperature to calculate Cooling and Heating Degree Days (CDDs and HDDs) at each year and pixel, adopting the temperature threshold of 18 C. Both CDDs and HDDs are constructed at the annual level, and they are defined as the cumulative sum of days with daily average temperature above (CDDs) or below (HDDs) the temperature threshold, T^*:

$$CDD = \sum_{d=1}^{365} (\gamma_d)(T - T^*)$$

$$HDD = \sum_{d=1}^{365} (1 - \gamma_d)(T^* - T)$$

where γ_d is the binary multiplier.

For all pixels we construct both weather and climate CDDs and HDDs. On the one hand, weather CDDs and HDDs are defined during the survey year. On the other hand, climate CDDs and HDDs are the averages of the annual CDDs and HDDs respectively across the period 1970-survey year.

Household data are then merged with this information using the most disaggregated geographical information available (e.g. provinces or districts) in each survey, and the year in which the survey is conducted. Particularly, we collapse across grid cells within each administrative unit using population weights in order to represent temperature exposure for the average person within a unit.

To project future AC adoption and electricity consumption, we consider CMIP6 climate change projections coming from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset[35] based on from ScenarioMIP bias-corrected model runs, having a native time resolution of one day and a spatial resolution of 0.25 arc-degrees.

We process both historical and future periods GCM output data from each CMIP6 GCMs model (exluding 'hot models'[26]) as well as for the GCMs enemble median to calculate pixel-wise median values for the 1995-2014 historical and 2041-2060 future periods, respectively, along two scenarios. These, consistently with the CMIP6 logics, are based on SSP-RCP combinations[36]. In particular, we consider the scenarios SSP126, a combination of SSP1 and RCP 2.6, a scenario of strong reduction of greenhouse gases concentration implying a radiative forcing of 2.6 $\frac{W}{m^2}$; SSP245, a combination of SSP2[37] and RCP 4.5, an intermediate greenhouse gases concentration scenario implying a radiative forcing of 4.5 $\frac{W}{m^2}$; SSP370, a combination of SSP3 and RCP 7.0, an high greenhouse gases concentration scenario implying a radiative forcing of 4.5 $\frac{W}{m^2}$; and SSP 585, a combination of SSP5[38] and RCP 8.5, a very high greenhouse gases concentration scenario implying a radiative forcing of 8.5 $\frac{W}{m^2}$.

In addition, to estimate future growth in household expenditure we use yearly per-capita GDP growth rates based on gridded GDP projections compatible with the SSPs[39]. We extract growth rates at the finest level of geographical disaggregation at which survey data are available for each country (e.g., districts or provinces), and we parse each growth rate to household located in the corresponding area. Similarly, SSPs-consistent gridded population growth rates[40] are used to project the growth in the number of households for each geographical disaggregation unit in each country. In addition we exploit SSP-consistent gridded urbanisation projections[29] to assess future change in urban/rural household status. When it comes to country-wide projections data, we draw information on future distribution of households among age, education and gender groups based on the SSP scenarios[41]. To project future household characteristics and exposure we use both gridded, thus subnationally variable data, and national-scale projections. In addition, we adopt the GADM database[42] as the standard administrative boundaries for each country.

Model training and validation

We train two random forest models on the pooled household sample. The first model is a classification probability model to assess whether a household owns at least an AC unit. The second model is a regression model to predict houehold yearly electricity consumption as reported from the survey data. We test a range of modelling techniques and a broad array of hyperparameters to identify the best performing models. In particular, we train:

- (Generalised) Linear Models [(G)LM] (parametric, linear modelling)
- Generalised Additive Models [GAM] (semi-parametric, non-linear modelling)
- Random Forsts [RF] (tree-based, non-parametric, non-linear modelling)

We use 10-fold cross validation to optimise the model hyperparameters selection (Figures SI-3-SI-4). Among the models tested, the the RF models reveal to be the most effective (see Tables SI-4-SI-5 and Figure SI-1)), as they achieve maximum training set *Accuracy* and R^2 values of 93% and 85% for AC ownership and electricity consumption, respectively (Figure SI-1). We also calculate metrics of *Cohen's Kappa* and *AUC* for the AC ownership classification model. The *Kappa*[43] metric is preferred as it is more suitable for evaluating binary classification predictions when the two classes are unbalanced, such as for the case of global AC ownership, where the global pool dataset mean stands at about 0.25. The two metrics yield 79% and 88%, respectively, indicating very good agreement[44]), while the *MSE* (mean squared error) for the electricity consumption regression model yields 0.2. The two trained RF models are then tested on the complementary stratified random sample which was excluded from the training set. Predictions on the test set yield *Accuracy* and R^2 values of 90% and 75% for AC ownership and electricity consumption, respectively. *Cohen's kappa* and *AUC* metrics for the test set yield 73% and 86%, respectively (substantial agreement[44]). The *MSE* metric yields 0.22 and 0.35 for the training and testing sets, respectively.

Altogether these numbers point at a relatively high accuracy of the models in predicting unseen AC ownership and electricity consumption data, and are thus deemed suitable for producing globally-relevant estimates.

Unpacking the models 'black box': Shapely values and partial dependence plots

To provide a set of interpretable metrics to assess the contribution of the predictor variables to the two-stage RF models (otherwise challenging to interpret given their non-parametric, 'black-box' nature), we generate a number of additional metrics and plots:

- We calculate Shapely (SHapley Additive exPlanations)[45,46] values, i.e. a method to attribute the contribution of each variable to the final prediction or outcome. SHAP values consider all possible combinations of features and measure their impact on predictions.
- We also produce partial dependence plots (PDP), a quasi-equivalent of marginal effects plots in non-parametric modelling.

The results are summarised in the SI Appendix. Figures SI-7-SI-8 report a graphical representation of the non-linear responses of AC ownership and electricity consumption on economic and climate drivers; Figure SI-9 illustrates a graphical representation of a single decision tree (CART) benchmark model; and Figures SI-5-SI-6 present Shapely values plots, shedding light on the magnitude and direction of features within the RF model and for each specific macro-region considered.

Gridded projections

To parse the household surveys to the spatially-explicit datasets described above used to make projections, we refer to the most disaggregated spatial unit available to which each household is assigned in the survey data. This varies by country, but spans from the first level of administrative units (the regions of a country) down to the third level of administrative units (districts). Using these geographical boundaries, we extract raster data and join vector data to calculate the relevant statistics.

Whilst in some instances it is possible to directly parse historical data from the survey variables as their definition and units are consistent (e.g. age, gender), in other instances certain processing steps are required to ensure consistency of the historical data upon which the empirical models are estimated, and the future data used for projections. For instance, as income/expenditure is heterogeneously defined across countries, we first convert it into 2011 PPP USD, and then project the baseline value using the local per-capita GDP growth rates from the downscaled GDP projections[39] divided by the dowscaled population projections[40].

An additional challenge in making bottom-up model-based projections from disaggregated survey data relates to binary and factor variables, where a set of assumptions need to be made. Finally, for a set of variables (age, gender, education), SSP-consistent projections are only available at a country-level, and thus we assume socio-demographic transformations to be homogeneous within each country.

External validity and gridded predictions validation

Besides cross-validation at the household level for model training, hyperparameters tuning, and testing, the models output data are also benchmarked against both national AC rates derived from both the household survey training data, and on recent AC ownership statistics from alternative sources[11,24]. Note that grid-cell level model outputs for the base year 2010 are compared with survey data and statistics which span between 2011-2019 (depending on the country; see Table SI-1 for reference). Thus, part of the observed bias might be owing do different year of reference in the survey and modeled data.‘

Figure SI-2 illustrates the results of such comparison. The results (yielding R^2 values of 97% and 92% for aggregated survey data and national statistics, respectively) show that our estimates are broadly consistent with both aggregated training data and national statistics from external sources (including in countries which are not part of our training data pool). This finding provides important evidence for the reliability of our gridded projections, their representativeness at the country-level, and their external validity.

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Author contributions

All authors conceptualised the paper; G.F. designed the methodological framework; G.F. and F.P. assembled the global pool household survey dataset; G.F. performed the statistical analysis and produced the figures and the output data. All contributed to writing and editing the paper.

Competing interests

The authors declare no competing interests.

Data and code availability

The output data can be accessed through the following Zenodo repository: `https://doi.org/10.5281/zenodo.7845126`. The replication code can be accessed through the following Github repository: `https://github.com/giacfalk/ggACene`. **Both repositories will be made publicly available upon acceptance of the manuscript.**

Supplementary Information

Input data and descriptive statistics

Table SI-1. Household survey microdata sources and details

Country	Year of wave analysed	Region	Primary source	$N°$ Households
Canada	2011	North America	EPIC	512
United States of America	2003-2021	North America	AHS	69,144
Mexico	2018	Central America	INEGI	56,474
Brazil	2017 / 2018	Southern America	IBGE	42,393
Argentina	2017 / 2018	Southern America	ENGHO	16,570
Sweden	2011	Europe	EPIC	462
Switzerland	2011	Europe	EPIC	199
Netherlands	2011	Europe	EPIC	453
France	2011	Europe	EPIC	679
Germany	2019	Europe	SOEP	5,316
Spain	2011	Europe	EPIC	528
Italy	2019	Europe	HBS	17,244
Nigeria	2019	Africa	GHS	1,200
Ghana	2017	Africa	GLSS	7,127
Kenya	2015 / 2016	Africa	IHBS	5,512
Burkina Faso	2014	Africa	EMC	1,980
Niger	2014	Africa	ECVMA	830
Malawi	2019 / 2020	Africa	IHS	1,234
Tanzania	2017 / 2018	Africa	HBS	9,123
Pakistan	2018 / 2019	Central Asia	LSM-IHS	19,506
India	2011 / 2012	Central Asia	NSSO	83,352
China	2014	Eastern Asia	CFPS	10,928
Japan	2011	Eastern Asia	EPIC	253
Indonesia	2017	Eastern Asia	SUSENAS	184,950
Australia	2011	Oceania	EPIC	557

Table SI-2. Weighted Descriptive Statistics

	Mean	SD	10th	25th	Median	75th	90th
Dependent							
Electricity Quantity (kWh)	2648.27	37149.98	232.15	600.00	1298.70	2640.00	5721.13
Air-conditioning (Yes = 1)	0.29	0.45	0.00	0.00	0.00	1.00	1.00
Climate and weather							
$\overline{CDD}$ (100s)	16.00	11.63	2.88	5.76	11.35	28.47	32.65
CDD (100s)	16.37	11.73	3.39	6.33	11.57	27.98	32.95
HDD (100s)	12.84	14.78	0.00	0.00	7.39	22.50	33.66
Socio-economic and demographic							
Total Expenditure ($2011 PPP)	17130.57	35768.01	1191.45	3306.90	7148.68	16680.25	41721.43
Electricity Price ($2011 PPP / kWh)	0.19	0.14	0.10	0.12	0.15	0.24	0.33
Urbanisation Share	0.08	0.11	0.00	0.01	0.04	0.10	0.21
Home Ownership (Yes = 1)	0.78	0.42	0.00	1.00	1.00	1.00	1.00
Household Size	3.96	2.41	1.00	2.00	4.00	5.00	7.00
No Education (Yes = 1)	0.23	0.42	0.00	0.00	0.00	0.00	1.00
Primary Education (Yes = 1)	0.27	0.44	0.00	0.00	0.00	1.00	1.00
Secondary Education (Yes = 1)	0.35	0.48	0.00	0.00	0.00	1.00	1.00
Post Education (Yes = 1)	0.16	0.37	0.00	0.00	0.00	0.00	1.00
Age of Household Head	47.75	15.32	28.00	36.00	47.00	59.00	69.00
Female Household Head (Yes = 1)	0.34	0.47	0.00	0.00	0.00	1.00	1.00

Notes: Descriptive statistics are computed survey weights.

Table SI-3. Assumed evolution of drivers in world regions

			Age	CDDs	Education	HDDs	Per-capita GDP	Population
region	year	ssp	Mean	Mean	Mean	Mean	Mean	Mean
East Asia & Pacific	2020	SSP1	37.30	1376.20	1.60	2381.60	19 121.60	2.10
		SSP2	36.90	1323.90	1.50	2412.40	19 108.00	2.10
		SSP3	36.70	1336.70	1.50	2387.80	22 626.80	2.10
		SSP5	37.10	1317.40	1.60	2351.10	23 363.90	2.10
	2050	SSP1	48.10	1490.50	2.00	2294.40	45 943.30	2.00
		SSP2	45.00	1488.80	1.90	2219.80	39 367.10	2.10
		SSP3	43.20	1560.30	1.70	2174.90	36 632.50	2.10
		SSP5	47.10	1606.40	2.00	2094.10	68 905.40	2.00
Europe & Central Asia	2020	SSP1	39.70	165.20	1.80	7487.10	20 327.40	0.80
		SSP2	39.20	164.90	1.80	7457.60	18 667.50	0.80
		SSP3	38.80	164.70	1.70	7449.60	22 423.80	0.80
		SSP5	39.60	168.10	1.80	7409.50	23 015.60	0.90
	2050	SSP1	48.00	205.30	2.10	7175.00	36 637.90	0.90
		SSP2	44.20	227.30	1.90	6950.50	36 942.60	0.90
		SSP3	41.30	214.30	1.80	7057.90	35 132.10	0.80
		SSP5	47.40	249.70	2.10	6792.60	45 346.90	0.90
Latin America & Caribbean	2020	SSP1	33.70	2169.70	1.40	538.50	16 018.20	0.60
		SSP2	33.20	2084.80	1.30	547.90	18 334.30	0.60
		SSP3	32.60	2096.40	1.20	541.30	18 290.20	0.60
		SSP5	33.70	2091.70	1.40	545.10	18 483.10	0.60
	2050	SSP1	45.90	2306.10	1.90	503.30	43 300.80	0.60
		SSP2	41.60	2303.60	1.70	485.80	29 172.70	0.70
		SSP3	37.50	2414.10	1.40	461.60	26 034.00	0.80
		SSP5	46.00	2496.90	1.90	466.10	46 478.80	0.60
Middle East & North Africa	2020	SSP1	30.60	2769.80	1.30	554.20	10 590.20	0.40
		SSP2	30.10	2754.70	1.20	534.60	12 170.30	0.40
		SSP3	29.60	2741.00	1.10	536.40	15 069.00	0.40
		SSP5	30.60	2769.10	1.30	536.40	15 140.00	0.40
	2050	SSP1	43.40	2925.10	1.90	499.20	24 875.90	0.50
		SSP2	39.60	3059.60	1.70	455.20	22 092.80	0.60
		SSP3	35.60	3157.50	1.30	447.10	21 258.40	0.70
		SSP5	43.40	3262.70	1.90	416.80	35 573.50	0.50
North America	2020	SSP1	40.30	255.60	2.00	6242.80	26 593.70	0.30
		SSP2	40.20	263.80	2.00	6277.70	27 060.30	0.30
		SSP3	40.50	262.00	2.00	6199.90	41 973.70	0.30
		SSP5	39.90	267.00	2.00	6271.90	41 347.00	0.30
	2050	SSP1	45.90	297.00	2.20	5922.30	40 141.10	0.40
		SSP2	44.50	331.90	2.20	5771.80	34 870.90	0.40
		SSP3	46.40	327.80	2.10	5728.10	55 634.10	0.30
		SSP5	42.90	353.70	2.10	5529.20	57 877.20	0.50
South Asia	2020	SSP1	28.90	2612.90	0.90	804.60	3391.60	1.80
		SSP2	28.30	2525.30	0.80	783.50	3223.40	1.80
		SSP3	27.80	2536.10	0.70	787.80	3545.70	1.80
		SSP5	28.90	2529.90	0.90	778.40	3743.10	1.70
	2050	SSP1	39.80	2713.30	1.60	740.00	14 572.90	2.00
		SSP2	35.70	2766.00	1.20	687.60	10 162.10	2.30
		SSP3	32.00	2784.20	0.80	696.60	7324.10	2.60
		SSP5	39.80	2935.00	1.60	646.00	24 344.10	2.00
Sub-Saharan Africa	2020	SSP1	24.30	3006.80	0.80	56.40	1796.70	1.00
		SSP2	23.60	2891.30	0.70	64.20	1953.80	1.00
		SSP3	23.00	2934.70	0.60	58.10	2394.10	1.10
		SSP5	24.30	2922.70	0.80	62.40	2496.80	1.00
	2050	SSP1	33.70	3190.00	1.40	48.50	10 253.30	1.50
		SSP2	29.40	3201.40	1.10	43.70	6758.80	1.70
		SSP3	26.40	3339.10	0.70	38.50	4810.40	2.00
		SSP5	33.60	3403.20	1.40	34.60	16 766.40	1.50

Model benchmarking and validation

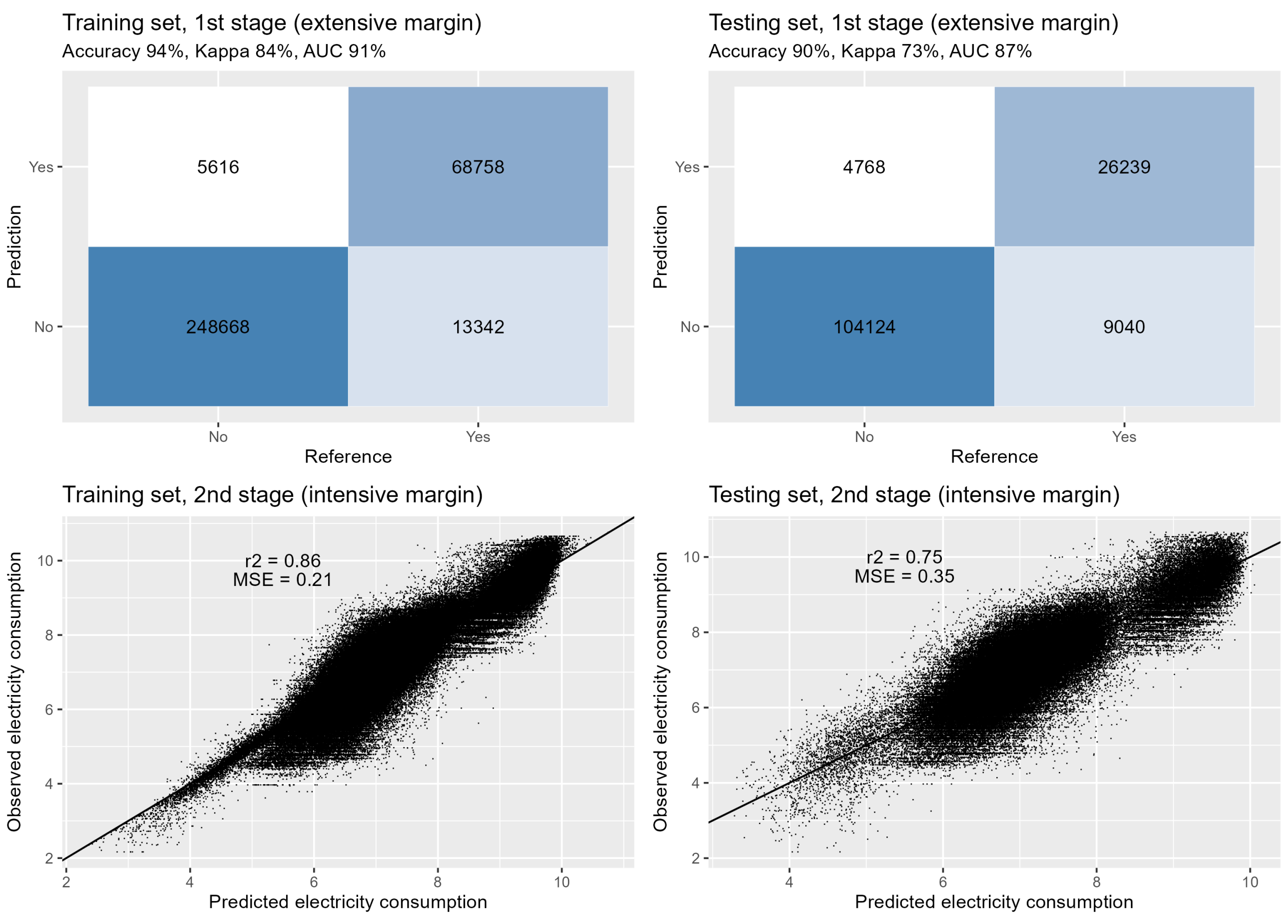

Figure SI-1. Global two-stage RF model of household AC uptake and utilisation. Cross-validation metrics of 1st and 2nd stage models.

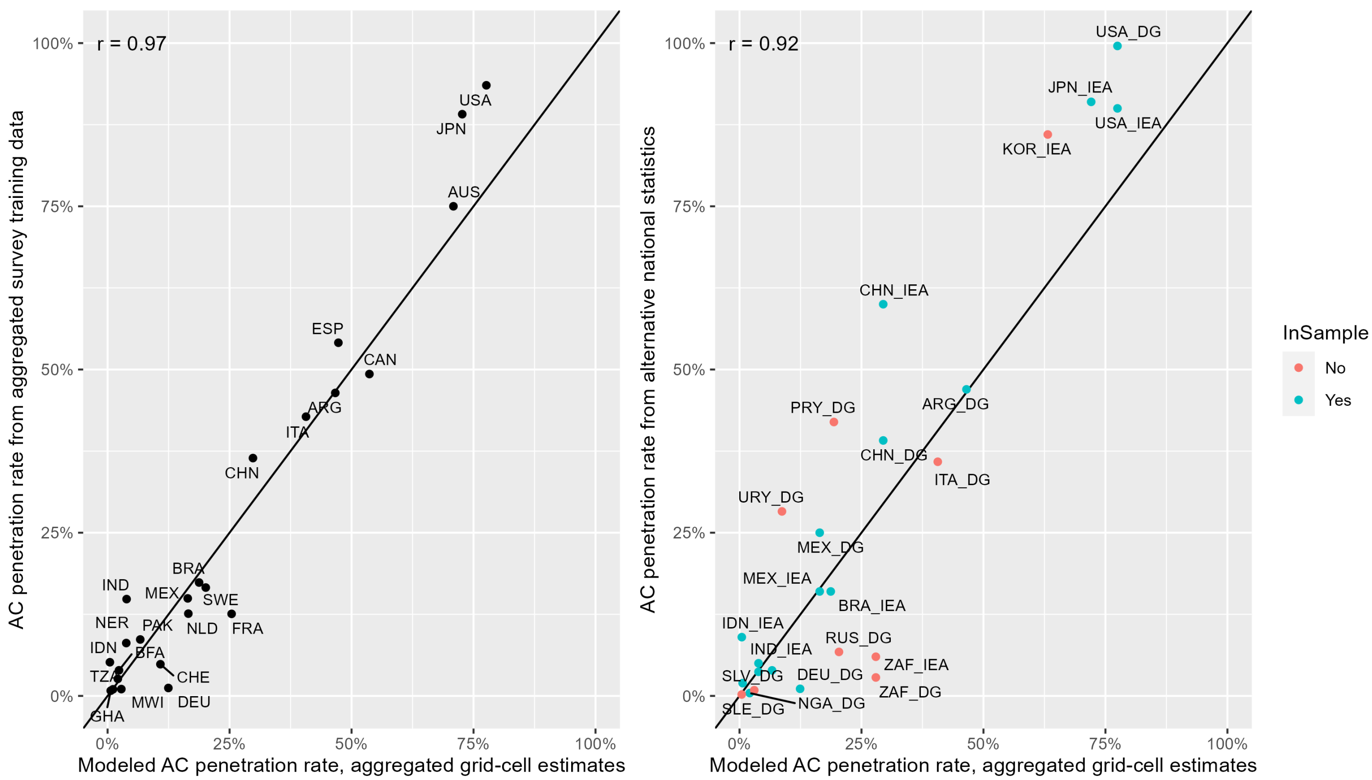

Figure SI-2. Validation of modeled vs. current national AC penetration rates for selected countries and sub-national administrative unites where statistics are available. Symbols describe if the predictions are for country in or out of the global household sample. IEA sufix: statistic from[11]; DG suffix: statistic from[24].

Table SI-4. Model benchmarking results - 1st stage

		Kappa	AUC
Model	Set	mean	mean
GLM	Training	0.64	0.80
	Testing	0.64	0.80
GAM	Training	0.63	0.80
	Testing	0.63	0.79
RF	Training	0.84	0.91
	Testing	0.73	0.87

Table SI-5. Model benchmarking results - 2nd stage

		R-squared	MSE
Model	Set	mean	mean
LM	Training	0.51	0.69
	Testing	0.51	0.69
GAM	Training	0.59	0.58
	Testing	0.59	0.57
RF	Training	0.86	0.21
	Testing	0.75	0.35

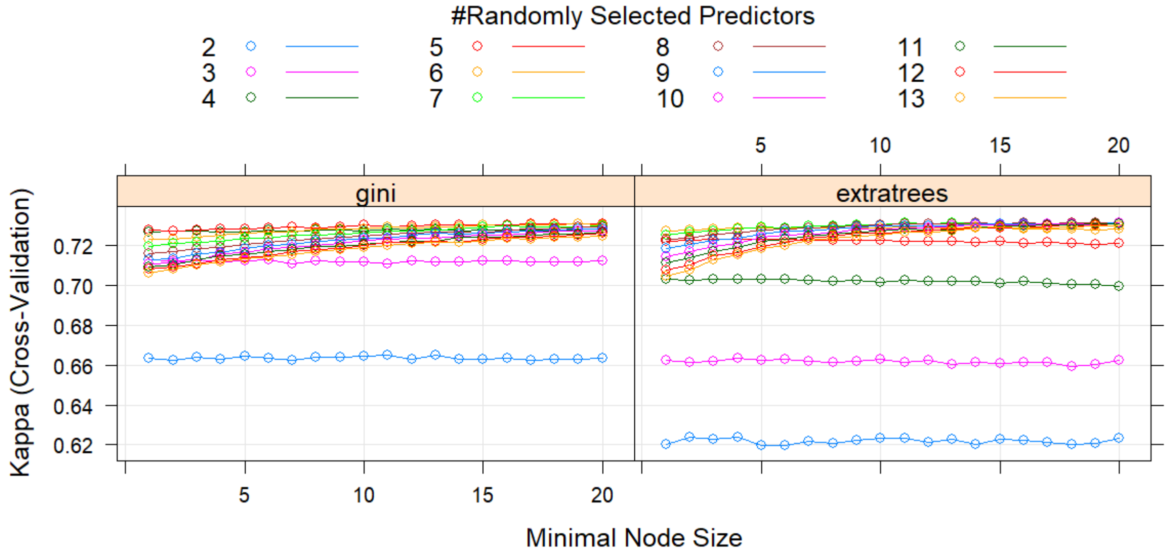

Figure SI-3. Random forests hyperparameters optimisation benchmarks - AC penetration (1st stage) model

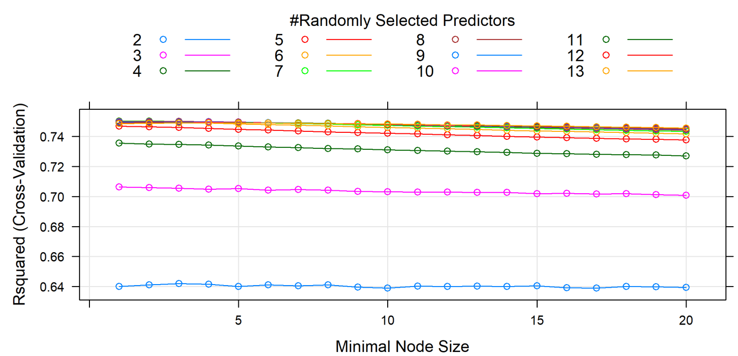

Figure SI-4. Random forests hyperparameters optimisation benchmarks - electricity consumption (2nd stage) model

SHAP (SHapley Additive exPlanations) decompositions

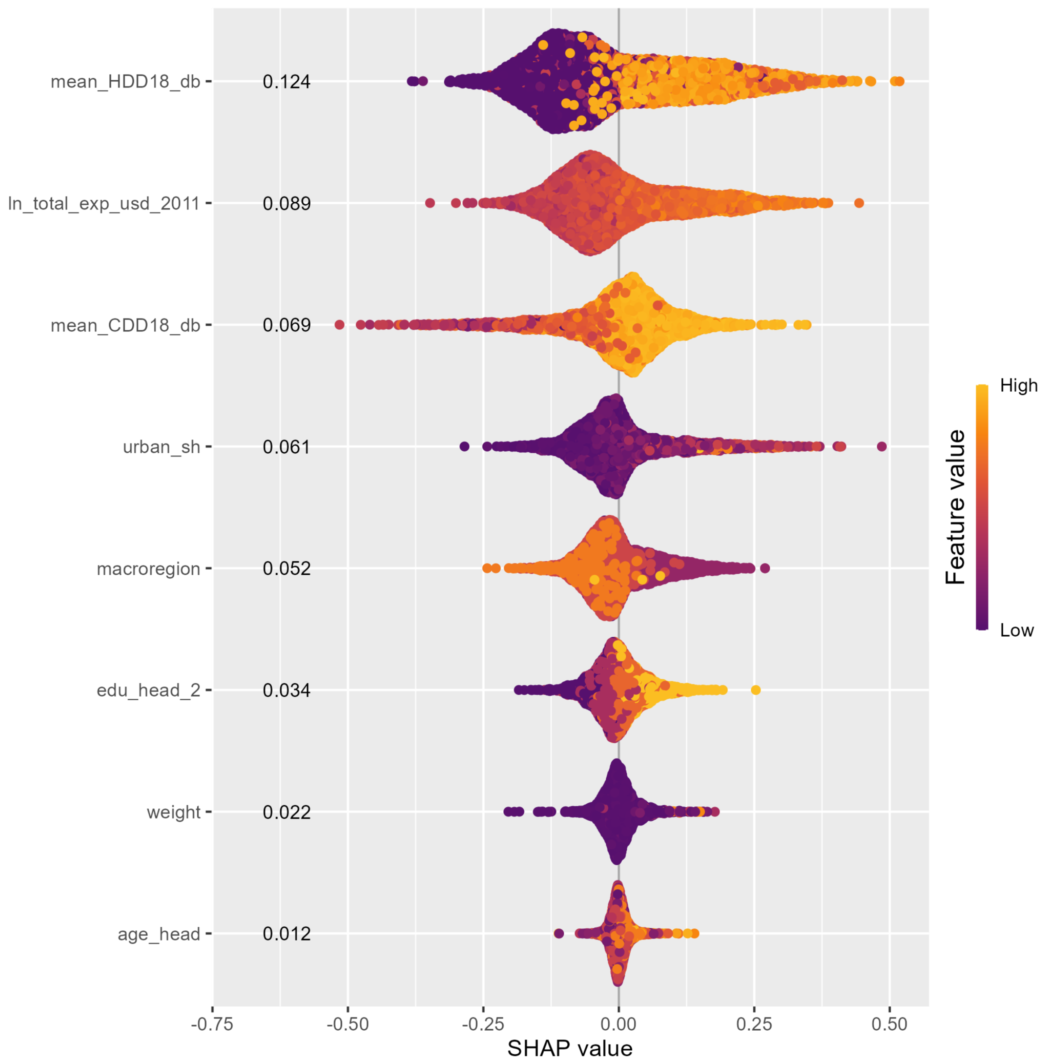

Figure SI-5. Beeswarm importance plot of Shapely values - AC penetration (1st stage) model

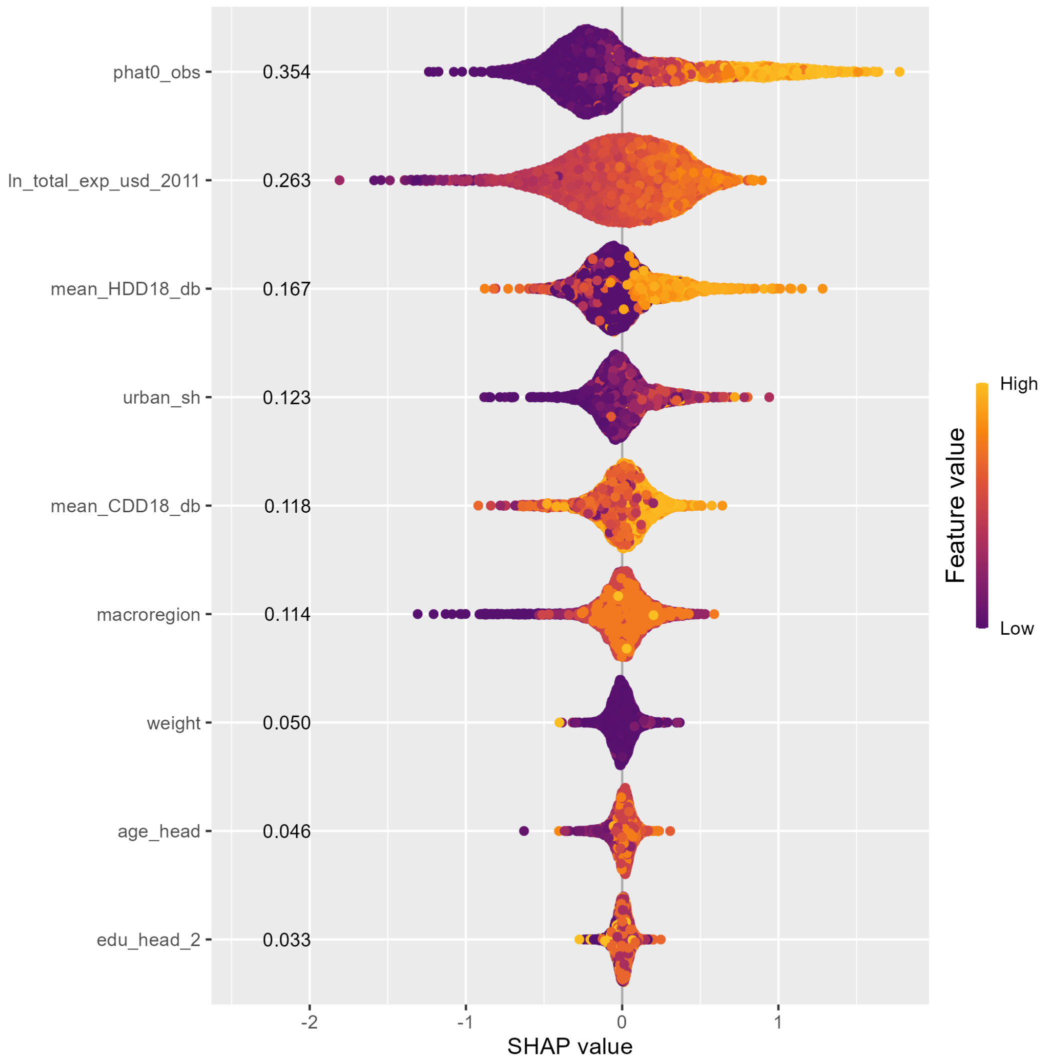

Figure SI-6. Beeswarm importance plot of Shapely values - electricity consumption (2nd stage) model

Partial dependence plots

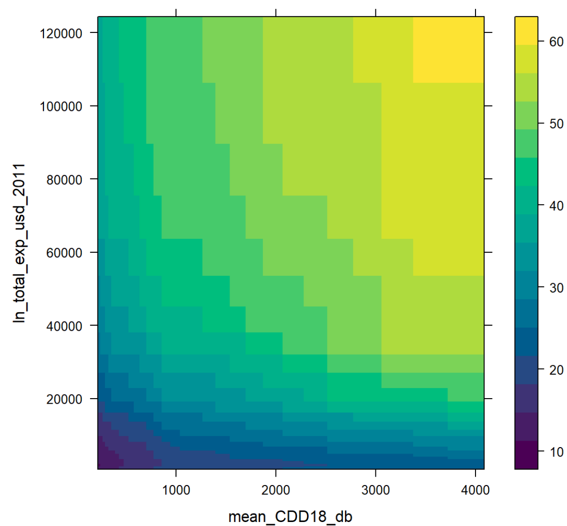

Figure SI-7. Partial dependence plot - AC penetration: conditional probability on expenditure and CDDs levels.

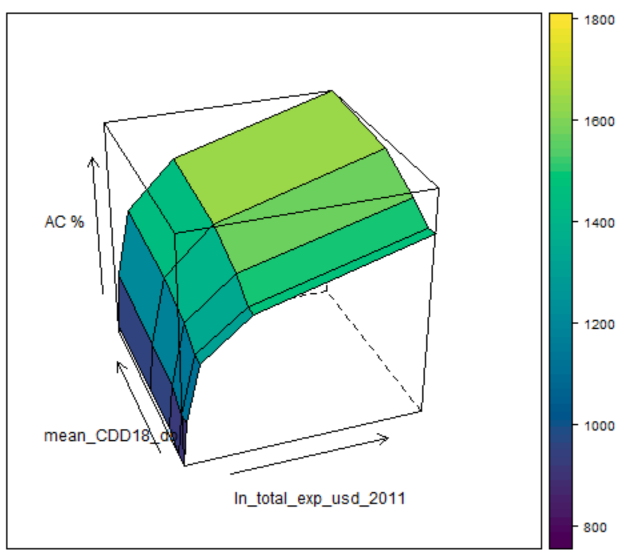

Figure SI-8. Partial dependence plot - electricity consumption, expected value conditional on AC ownership probability, expenditure and CDDs levels.

CART model benchmark: decision tree

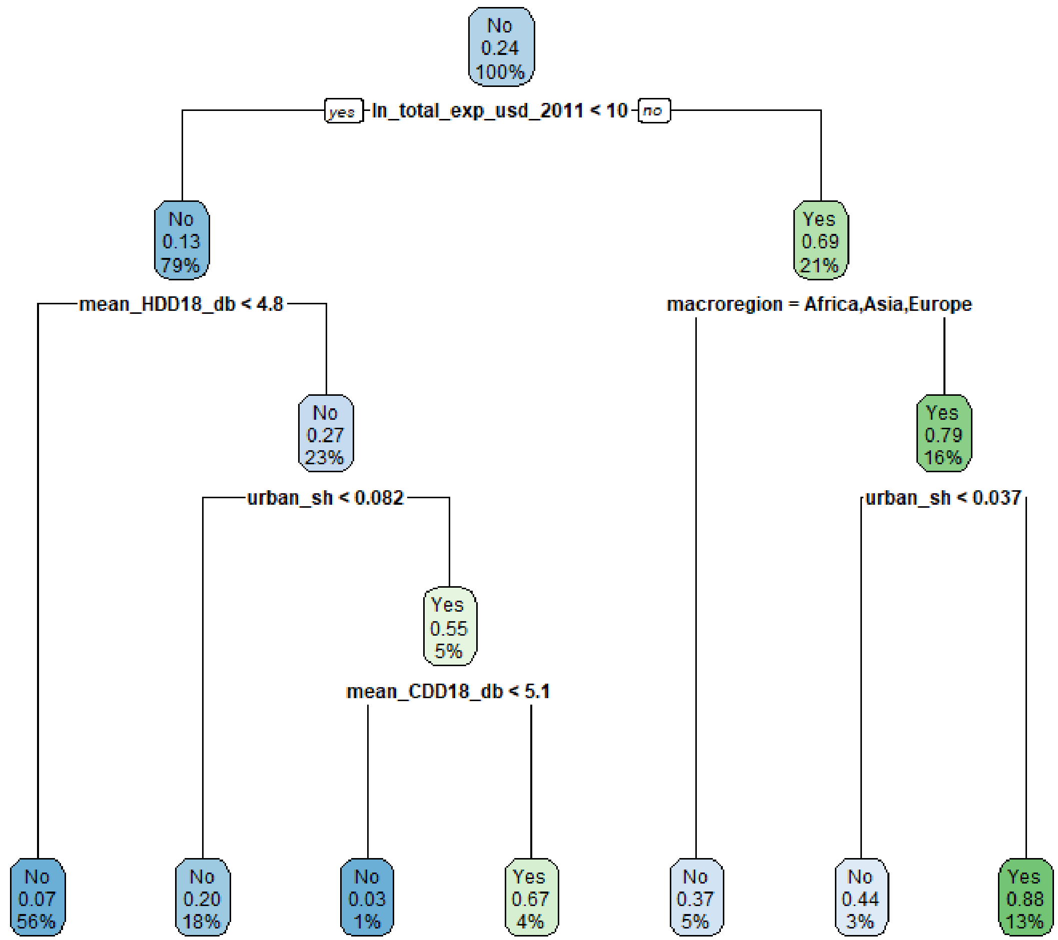

Figure SI-9. Classification tree of AC ownership probability from a single-tree benchmark CART model with complexity parameter set to 0.008.

Country-level projection results

Table SI-6. Projected household AC penetration and residential AC electricity consumption in 2050

	AC penetration (% of HHs)				Electricity consumption for AC (TWh/yr.)			
1	SSP1	SSP2	SSP3	SSP5	SSP1	SSP2	SSP3	SSP5
ISO3	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
AFG	7.90	5.70	4.10	13.40	0.10	0.10	0.10	0.10
AGO	14.70	7.40	5.30	18.50	0.20	0.10	0.00	0.40
ALA	21.40	22.40	21.20	23.40	0.00	0.00	0.00	0.00
ALB	48.80	43.30	46.20	54.40	0.10	0.00	0.10	0.10
ARE	46.40	45.80	41.90	46.70	0.70	0.70	0.50	0.90
ARG	69.60	68.40	61.10	77.20	19.80	23.20	19.80	31.80
ARM	27.90	29.50	24.00	47.30	0.10	0.10	0.10	0.20
AUS	67.40	71.40	65.80	70.70	15.60	16.30	12.50	20.50
AUT	32.90	35.50	34.90	44.30	1.00	0.90	0.70	1.10
AZE	41.10	46.20	37.50	52.60	0.40	0.40	0.30	0.30
BDI	5.00	3.40	2.30	6.80	0.00	0.00	0.00	0.00
BEL	30.80	27.20	42.10	39.50	1.70	1.30	2.10	1.70
BEN	7.30	2.20	1.50	11.70	0.00	0.00	0.00	0.10
BFA	10.00	5.90	3.90	13.00	0.00	0.00	0.00	0.10
BGD	20.60	12.40	2.80	28.50	2.00	0.70	0.00	3.50
BGR	49.80	50.40	48.80	66.10	0.30	0.20	0.20	0.30
BHS	15.80	14.40	14.60	18.40	0.00	0.00	0.00	0.00
BIH	43.80	40.60	35.50	43.20	0.10	0.10	0.10	0.10
BLR	26.10	20.50	18.90	33.20	0.70	0.60	0.60	0.80
BLZ	25.60	17.30	13.60	32.90	0.00	0.00	0.00	0.00
BOL	33.50	29.50	25.20	41.40	1.10	1.00	0.70	1.60
BRA	47.70	38.60	36.40	49.00	25.40	18.90	25.00	30.30
BRN	27.30	17.10	16.60	22.50	0.00	0.00	0.00	0.00
BTN	13.70	23.00	11.40	14.90	0.00	0.00	0.00	0.00
BWA	43.30	39.50	33.40	43.80	0.20	0.10	0.10	0.20
CAF	4.20	2.50	1.90	7.30	0.00	0.00	0.00	0.00
CAN	62.70	66.90	68.00	72.10	27.50	30.00	25.90	46.40
CHE	20.70	26.60	26.50	37.00	0.60	0.70	0.50	1.10
CHL	33.50	38.00	35.30	43.60	3.40	3.80	3.40	4.20
CHN	63.00	61.30	52.80	73.70	147.40	125.10	73.80	271.20
CIV	19.30	10.70	5.40	23.40	0.30	0.10	0.00	0.50
CMR	13.10	6.80	3.20	19.60	0.10	0.00	0.00	0.30
COD	6.70	3.50	2.20	9.80	0.20	0.00	0.00	0.40
COG	29.30	10.20	7.00	21.60	0.50	0.00	0.00	0.30
COL	29.70	23.60	13.50	25.40	3.40	2.70	1.10	2.60
COM	4.30	2.20	4.60	7.30	0.00	0.00	0.00	0.00
CRI	41.90	28.80	25.40	39.60	0.50	0.30	0.30	0.60
CUB	31.80	23.20	19.40	35.90	0.50	0.20	0.20	0.60
CYP	47.00	52.20	34.10	57.10	0.10	0.10	0.00	0.20
CZE	23.40	27.70	27.80	36.80	0.90	0.90	0.70	1.30
DEU	24.20	26.40	29.40	41.20	6.90	6.90	5.80	11.70
DJI	24.30	14.90	8.30	24.00	0.00	0.00	0.00	0.00
DNK	23.40	23.40	22.70	22.80	0.20	0.10	0.10	0.20
DOM	41.10	35.40	21.40	49.40	0.80	0.50	0.20	1.00
DZA	43.20	45.10	34.90	48.50	2.80	3.10	2.20	4.00
ECU	26.90	17.30	14.40	30.30	0.80	0.50	0.30	1.10
EGY	47.90	45.80	38.80	56.10	4.40	4.70	2.20	10.00

ERI	7.20	5.00	2.40	9.20	0.00	0.00	0.00	0.00
ESP	59.50	56.80	54.90	63.10	3.80	2.90	2.70	5.80
EST	21.80	17.30	20.80	16.80	0.10	0.10	0.10	0.10
ETH	7.20	3.90	2.90	10.30	0.30	0.10	0.00	0.40
FIN	22.00	21.70	21.10	22.30	0.70	0.60	0.50	0.80
FJI	41.90	20.80	15.60	32.70	0.00	0.00	0.00	0.00
FLK	19.30	16.10	12.40	28.40	0.00	0.00	0.00	0.00
FRA	38.70	40.80	40.30	50.50	6.30	6.60	4.50	8.50
GAB	32.00	24.00	19.50	33.40	0.00	0.00	0.00	0.00
GBR	20.90	17.80	20.80	22.70	5.40	3.40	3.60	5.80
GEO	59.70	57.10	39.90	53.70	0.40	0.20	0.10	0.40
GHA	14.90	7.00	3.40	20.80	0.30	0.10	0.00	0.60
GIN	22.40	5.20	1.90	24.30	0.10	0.00	0.00	0.10
GLP	13.20	7.80	7.50	19.30	0.00	0.00	0.00	0.00
GMB	16.80	10.30	4.60	18.10	0.00	0.00	0.00	0.00
GNB	11.40	1.60	0.70	15.50	0.00	0.00	0.00	0.00
GNQ	32.00	26.10	22.30	38.80	0.00	0.00	0.00	0.00
GRC	59.80	60.70	59.40	60.80	0.50	0.30	0.20	0.60
GRL	53.20	46.60	42.10	54.50	0.00	0.00	0.00	0.00
GTM	20.10	19.50	8.20	37.50	0.30	0.30	0.10	1.00
GUF	7.70	9.40	11.20	8.10	0.00	0.00	0.00	0.00
GUY	47.50	21.60	24.00	33.00	0.10	0.00	0.00	0.00
HND	16.70	9.70	6.50	19.30	0.10	0.10	0.00	0.20
HRV	50.30	51.00	48.10	59.60	0.10	0.10	0.10	0.20
HTI	15.90	7.20	6.80	15.50	0.10	0.00	0.00	0.00
HUN	42.40	44.60	49.00	57.00	0.60	0.60	0.40	0.70
IDN	33.30	18.70	19.40	38.90	8.90	5.00	4.20	11.90
IND	31.30	21.50	11.60	43.20	44.70	20.50	4.00	78.20
IRL	27.20	27.80	26.30	24.60	0.30	0.20	0.20	0.30
IRN	49.30	43.60	34.80	52.30	5.80	4.70	3.00	11.30
IRQ	36.20	29.60	21.70	47.20	2.70	0.80	0.50	3.00
ISL	24.00	21.00	17.40	22.40	0.00	0.00	0.00	0.00
ISR	50.40	54.40	48.30	62.40	0.50	0.90	0.40	1.70
ITA	55.30	59.20	56.00	61.90	4.00	3.10	2.60	4.50
JAM	17.40	12.60	16.50	18.30	0.00	0.00	0.00	0.10
JOR	54.00	36.70	24.80	60.40	1.20	0.40	0.20	0.90
JPN	80.80	80.80	76.40	80.80	46.30	44.70	31.10	44.20
KAZ	37.20	33.00	26.60	42.80	1.40	1.10	0.70	1.50
KEN	9.80	4.80	2.10	11.80	0.20	0.00	0.00	0.50
KGZ	23.00	20.10	13.00	29.40	0.10	0.10	0.00	0.10
KHM	26.40	10.00	4.70	31.50	0.30	0.00	0.00	0.30
KIR	32.00	29.40	33.70	33.00	0.00	0.00	0.00	0.00
KOR	78.60	82.00	70.20	83.90	14.10	14.40	9.60	15.00
KWT	67.20	63.30	54.20	63.60	0.70	0.60	0.30	0.60
LAO	29.90	19.50	15.00	36.80	0.10	0.00	0.00	0.20
LBN	62.60	59.70	53.70	72.60	0.30	0.30	0.30	1.30
LBR	3.90	3.20	2.80	8.10	0.00	0.00	0.00	0.00
LBY	43.30	48.90	41.10	51.20	1.00	1.20	0.90	1.20
LKA	33.60	15.10	14.80	30.40	0.70	0.20	0.20	0.60
LSO	35.20	27.90	18.60	34.10	0.20	0.10	0.00	0.10
LTU	18.70	13.60	15.50	20.80	0.10	0.10	0.20	0.10
LUX	24.00	25.90	25.60	47.90	0.00	0.00	0.00	0.10
LVA	19.40	15.90	16.60	22.70	0.10	0.10	0.10	0.10
MAR	47.80	44.70	29.50	52.40	2.80	2.50	1.20	3.10
MDA	40.90	43.80	38.60	61.50	0.20	0.10	0.10	0.20
MDG	4.20	2.60	2.80	9.10	0.00	0.00	0.00	0.10

MEX	33.10	29.70	32.60	48.60	12.60	13.20	15.90	21.50
MHL	34.50	32.00	37.60	34.50	0.00	0.00	0.00	0.00
MKD	41.50	41.20	38.40	52.10	0.10	0.00	0.00	0.00
MLI	6.50	6.90	3.50	8.20	0.00	0.00	0.00	0.00
MMR	11.50	5.40	2.80	27.70	0.30	0.00	0.00	0.70
MNE	38.20	34.60	36.60	41.50	0.00	0.00	0.00	0.00
MNG	21.40	19.80	15.50	30.00	0.20	0.20	0.10	0.20
MOZ	9.50	3.40	4.40	11.80	0.10	0.00	0.00	0.10
MRT	18.70	13.30	11.10	19.30	0.00	0.00	0.00	0.00
MWI	11.70	7.30	6.30	14.70	0.10	0.00	0.00	0.20
MYS	43.90	36.70	31.10	45.70	1.90	1.40	1.20	2.20
NAM	36.30	33.00	30.70	40.90	0.10	0.10	0.10	0.10
NCL	40.60	41.60	36.50	41.30	0.00	0.00	0.00	0.00
NER	11.80	6.20	8.30	18.90	0.00	0.00	0.00	0.20
NGA	19.50	9.40	3.70	20.60	2.80	0.80	0.10	3.70
NIC	29.60	14.80	10.30	35.60	0.20	0.10	0.00	0.20
NLD	22.70	21.70	26.50	26.90	1.10	1.00	1.00	1.20
NOR	22.90	25.00	23.50	28.60	0.70	0.80	0.60	1.20
NPL	18.80	12.00	6.80	18.90	0.20	0.20	0.20	0.40
NZL	60.30	61.40	61.00	64.80	1.60	1.50	1.50	2.50
OMN	43.00	37.10	27.60	41.20	0.10	0.10	0.00	0.10
PAK	25.30	13.40	7.60	26.50	1.30	0.50	0.20	1.50
PAN	51.90	38.50	24.10	40.30	0.50	0.30	0.20	0.40
PER	34.90	28.40	23.40	34.60	3.00	2.50	2.00	2.60
PHL	16.30	12.00	3.50	25.20	1.50	0.70	0.10	2.50
PNG	35.90	29.20	21.40	39.60	0.70	0.40	0.20	0.90
POL	22.00	25.60	26.80	37.60	1.70	2.10	1.60	2.50
PRI	40.70	34.70	35.80	64.30	0.30	0.10	0.40	0.60
PRK	17.90	18.10	18.30	29.10	0.30	0.20	0.20	0.40
PRT	54.90	46.00	57.20	56.10	0.40	0.40	0.30	0.50
PRY	51.80	44.10	34.10	56.00	0.60	0.50	0.40	0.90
PSE	63.20	56.00	44.30	79.30	0.20	0.10	0.10	1.10
PYF	31.50	31.30	34.50	32.80	0.00	0.00	0.00	0.00
QAT	57.10	52.30	45.00	55.70	0.20	0.20	0.10	0.30
ROU	40.80	38.40	34.40	50.30	0.70	0.50	0.40	0.90
RUS	28.40	28.00	25.40	34.40	11.00	10.40	7.30	13.20
RWA	6.20	2.90	3.10	8.00	0.00	0.00	0.00	0.00
SAU	43.10	43.50	39.50	49.50	2.40	2.30	1.40	3.60
SDN	28.00	23.40	15.30	31.00	0.70	0.30	0.10	0.90
SEN	19.50	4.10	4.10	12.60	0.10	0.00	0.00	0.10
SLB	34.10	25.10	15.30	30.40	0.00	0.00	0.00	0.00
SLE	7.20	3.10	1.60	12.60	0.00	0.00	0.00	0.00
SLV	47.90	20.40	17.00	47.00	0.30	0.10	0.10	0.30
SOM	1.20	0.90	0.60	1.70	0.00	0.00	0.00	0.00
SRB	37.60	34.50	33.10	46.50	0.20	0.20	0.20	0.30
SUR	49.30	44.80	42.30	72.00	0.10	0.00	0.10	0.20
SVK	28.00	31.50	32.60	43.80	0.40	0.40	0.30	0.50
SVN	42.10	45.10	45.50	54.70	0.30	0.20	0.20	0.30
SWE	21.60	21.20	22.90	24.70	0.60	0.50	0.50	0.80
SWZ	24.80	19.10	9.40	24.80	0.00	0.00	0.00	0.00
SYR	37.60	32.10	22.00	45.40	0.70	0.70	0.20	1.70
TCD	13.20	12.00	5.50	20.20	0.00	0.00	0.00	0.10
TGO	2.90	2.60	4.20	5.90	0.00	0.00	0.00	0.00
THA	42.00	39.50	34.50	42.80	4.40	3.60	2.40	5.10
TJK	37.70	30.50	23.20	45.70	0.20	0.10	0.10	0.20
TKM	34.70	37.40	30.50	42.60	0.20	0.20	0.10	0.30

TLS	11.80	6.00	0.80	17.00	0.00	0.00	0.00	0.00
TTO	33.70	26.70	21.10	47.10	0.10	0.00	0.00	0.10
TUN	42.20	49.30	38.50	54.50	1.30	1.50	1.10	1.70
TUR	45.30	39.00	28.80	52.10	4.60	4.20	2.00	7.30
TWN	30.60	32.00	27.90	33.50	0.50	0.50	0.50	0.70
TZA	6.10	3.20	3.00	13.80	0.10	0.00	0.00	0.40
UGA	5.90	2.40	2.80	8.70	0.10	0.00	0.00	0.20
UKR	31.30	30.70	29.40	43.00	2.10	2.00	1.30	2.90
URY	25.10	30.10	27.80	41.80	0.10	0.20	0.20	0.40
USA	82.60	84.20	83.00	86.40	438.80	465.80	368.50	622.60
UZB	61.90	61.40	49.20	69.20	1.80	2.40	0.90	2.20
VCT	10.90	5.90	7.00	18.20	0.00	0.00	0.00	0.00
VEN	51.60	49.80	46.00	54.50	2.90	2.70	2.90	4.00
VIR	10.10	6.60	6.70	19.90	0.00	0.00	0.00	0.00
VNM	32.90	27.70	24.90	42.20	3.80	1.90	1.50	5.80
VUT	26.60	21.70	15.70	25.70	0.00	0.00	0.00	0.00
WSM	30.90	30.40	29.50	32.00	0.00	0.00	0.00	0.00
YEM	14.00	9.40	4.10	12.80	0.10	0.00	0.00	0.10
ZAF	50.30	53.80	40.30	48.40	8.50	10.30	5.60	10.20
ZMB	17.10	9.60	8.20	25.30	0.20	0.00	0.00	0.40
ZWE	10.90	7.40	5.80	14.50	0.00	0.00	0.00	0.00

Table SI-7. Estimated CO_2 emissions from electricity use for cooling in the residential sector, by country and scenario. Note: the main numbers refer to projections calculated with the CMIP6 GCMs enemble median (exluding 'hot models'[26]), whilst the number in parentheses describe the IQR of CMIP6 GCMs.

	ISO3	2020	SSP126 (2050)	SSP245 (2050)	SSP370 (2050)	SSP585 (2050)
1	AFG	0 (0 - 0)	0 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)
2	AGO	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0 (0 - 0)	0.3 (0.2 - 0.3)
3	ALA	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
4	ALB	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0 - 0.1)
5	ARE	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.3)	0.4 (0.3 - 0.4)	0.3 (0.2 - 0.4)	0.5 (0.4 - 0.6)
6	ARG	6.7 (5.5 - 7.9)	3.8 (3.2 - 4.7)	9.5 (8.3 - 10.8)	7.9 (6.4 - 9.2)	16.4 (12.8 - 19.1)
7	ARM	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)
8	AUS	9.7 (8.2 - 10.8)	6.5 (5.7 - 7.9)	12.1 (9.9 - 14.6)	9.1 (8.3 - 10.1)	12.9 (11 - 15.2)
9	AUT	0.2 (0.1 - 0.4)	0.3 (0.2 - 0.3)	0.5 (0.4 - 0.6)	0.4 (0.3 - 0.5)	0.7 (0.4 - 0.9)
10	AZE	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.2 (0.2 - 0.3)
11	BDI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
12	BEL	0.3 (0.2 - 0.4)	0.4 (0.3 - 0.7)	0.6 (0.5 - 1)	1.2 (0.5 - 1.7)	1 (0.6 - 1.5)
13	BEN	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
14	BFA	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0 - 0.1)
15	BGD	0 (0 - 0)	0.9 (0.6 - 1.2)	0.6 (0.3 - 1)	0 (0 - 0.1)	2.4 (1.7 - 3.4)
16	BGR	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.2)
17	BHS	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
18	BIH	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0.1)	0.1 (0 - 0.1)	0.1 (0 - 0.1)
19	BLR	0.3 (0.2 - 0.3)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.3)	0.3 (0.2 - 0.5)	0.5 (0.3 - 0.6)
20	BLZ	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
21	BOL	0.1 (0.1 - 0.2)	0.2 (0.2 - 0.3)	0.4 (0.3 - 0.5)	0.3 (0.2 - 0.4)	0.8 (0.7 - 0.9)
22	BRA	3.3 (2.4 - 3.8)	4.9 (3.6 - 7.2)	7.7 (6.3 - 10.3)	9.9 (4.8 - 11.6)	15.6 (12.9 - 21.8)
23	BRN	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
24	BTN	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
25	BWA	0 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)
26	CAF	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
27	CAN	11.4 (9.7 - 12.8)	5.3 (4.1 - 6.5)	15.2 (12.3 - 17.7)	15.6 (13.1 - 18.1)	23.2 (18.6 - 28)
28	CHE	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.3)	0.4 (0.3 - 0.5)	0.3 (0.2 - 0.4)	0.7 (0.3 - 0.9)
29	CHL	1.2 (1 - 1.3)	0.7 (0.5 - 0.8)	1.6 (1.4 - 1.8)	1.3 (1.2 - 1.5)	2.2 (1.9 - 2.5)
30	CHN	20.2 (15 - 26.6)	61.1 (48.9 - 73.6)	92.3 (69.9 - 112.1)	53.9 (42 - 66.1)	171.3 (148.5 - 195.3)
31	CIV	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0 (0 - 0)	0.3 (0.3 - 0.3)
32	CMR	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.2 (0.2 - 0.2)
33	COD	0 (0 - 0)	0.1 (0.1 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.3 (0.2 - 0.4)
34	COG	0 (0 - 0)	0.2 (0.1 - 0.2)	0 (0 - 0)	0 (0 - 0)	0.2 (0.2 - 0.3)
35	COL	0.4 (0.3 - 0.5)	0.7 (0.5 - 0.8)	1.1 (1 - 1.3)	0.5 (0.3 - 0.6)	1.3 (1.2 - 1.6)
36	COM	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
37	CRI	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.3 (0.3 - 0.4)
38	CUB	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0 - 0.1)	0.3 (0.3 - 0.3)
39	CYP	0 (0 - 0.1)	0 (0 - 0)	0.1 (0 - 0.1)	0 (0 - 0)	0.1 (0.1 - 0.2)
40	CZE	0.2 (0.1 - 0.4)	0.2 (0.1 - 0.3)	0.4 (0.3 - 0.5)	0.4 (0.2 - 0.5)	0.8 (0.5 - 1)
41	DEU	2.1 (1 - 3.7)	1.8 (0.9 - 2.8)	3.3 (2.1 - 5.2)	3.2 (2 - 4.7)	6.9 (3.6 - 10.1)
42	DJI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
43	DNK	0 (0 - 0.1)	0 (0 - 0.1)	0.1 (0 - 0.1)	0.1 (0 - 0.1)	0.1 (0.1 - 0.2)
44	DOM	0 (0 - 0)	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.1 (0.1 - 0.1)	0.5 (0.4 - 0.6)
45	DZA	0.6 (0.4 - 0.6)	0.9 (0.8 - 1)	1.6 (1.4 - 1.7)	1.4 (1.2 - 1.6)	2.2 (2 - 2.7)
46	ECU	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.2 (0.2 - 0.3)	0.1 (0.1 - 0.2)	0.6 (0.4 - 0.7)
47	EGY	0.5 (0.1 - 1.2)	1.3 (1 - 1.9)	2.4 (1.9 - 3.1)	1.4 (1.1 - 1.8)	5.6 (4.6 - 8)
48	ERI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
49	ESP	0.9 (0.7 - 1.2)	1 (0.7 - 1.2)	1.4 (1.1 - 1.7)	1.5 (1.2 - 1.8)	3.4 (2.8 - 4.1)
50	EST	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0.1)	0 (0 - 0.1)
51	ETH	0 (0 - 0)	0.1 (0.1 - 0.2)	0 (0 - 0.1)	0 (0 - 0)	0.3 (0.2 - 0.4)

52	FIN	0.3 (0.2 - 0.4)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.4)	0.3 (0.2 - 0.4)	0.5 (0.4 - 0.7)
53	FJI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
54	FLK	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
55	FRA	1.8 (1.1 - 2.7)	1.6 (0.9 - 2.7)	3.2 (2.2 - 4.7)	2.4 (1.7 - 3.4)	5 (3.4 - 7)
56	GAB	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
57	GBR	1.3 (0.8 - 1.8)	1.4 (1 - 1.7)	1.6 (1.2 - 2.2)	1.9 (1.4 - 2.6)	3.4 (2.6 - 4.6)
58	GEO	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.3)
59	GHA	0 (0 - 0)	0.1 (0.1 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.4 (0.4 - 0.4)
60	GIN	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
61	GLP	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
62	GMB	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
63	GNB	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
64	GNQ	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
65	GRC	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.1 (0.1 - 0.2)	0.3 (0.3 - 0.4)
66	GRL	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
67	GTM	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0.1 - 0.2)	0 (0 - 0.1)	0.5 (0.4 - 0.7)
68	GUF	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
69	GUY	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
70	HND	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
71	HRV	0 (0 - 0.1)	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)
72	HTI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
73	HUN	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.4)	0.2 (0.1 - 0.3)	0.4 (0.3 - 0.5)
74	IDN	0.2 (0.2 - 0.3)	3.7 (3.2 - 4.3)	3.7 (3.4 - 4)	3 (2.6 - 3.5)	7.5 (6.9 - 8.2)
75	IND	1.1 (0.7 - 1.9)	21.1 (16.7 - 25.3)	15.5 (12.3 - 19.2)	2.9 (2 - 4.7)	54.5 (45.6 - 63.1)
76	IRL	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.1 - 0.2)
77	IRN	0.7 (0.5 - 0.8)	1.8 (1.6 - 2.2)	2.4 (2.1 - 2.9)	1.9 (1.6 - 2.3)	6.3 (5.5 - 7.2)
78	IRQ	0.1 (0.1 - 0.1)	0.8 (0.8 - 0.9)	0.4 (0.3 - 0.5)	0.3 (0.2 - 0.3)	1.7 (1.6 - 1.8)
79	ISL	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
80	ISR	0.3 (0.1 - 0.3)	0.2 (0.1 - 0.4)	0.5 (0.3 - 0.7)	0.2 (0.2 - 0.3)	1 (0.4 - 1.8)
81	ITA	1.2 (0.8 - 1.6)	1 (0.8 - 1.3)	1.5 (1.2 - 1.8)	1.4 (1.2 - 1.7)	2.7 (2.2 - 3.3)
82	JAM	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
83	JOR	0 (0 - 0)	0.4 (0.3 - 0.4)	0.2 (0.2 - 0.3)	0.1 (0.1 - 0.2)	0.5 (0.4 - 0.6)
84	JPN	36 (31.8 - 41.9)	19.2 (16.6 - 21.4)	33 (29.6 - 37.1)	22.7 (19.6 - 25.6)	27.9 (24.6 - 31.6)
85	KAZ	0.1 (0.1 - 0.2)	0.4 (0.3 - 0.4)	0.6 (0.5 - 0.7)	0.4 (0.3 - 0.5)	0.9 (0.7 - 1.1)
86	KEN	0 (0 - 0)	0.1 (0.1 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.3 (0.3 - 0.4)
87	KGZ	0 (0 - 0)	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0)	0.1 (0.1 - 0.1)
88	KHM	0 (0 - 0)	0.1 (0.1 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.2 (0.2 - 0.2)
89	KIR	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
90	KOR	5.6 (4.5 - 6.8)	5.8 (5.1 - 6.7)	10.6 (9.4 - 11.8)	7 (6 - 8.1)	9.5 (8.5 - 11.3)
91	KWT	0.1 (0.1 - 0.1)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.4)	0.2 (0.2 - 0.3)	0.3 (0.3 - 0.7)
92	LAO	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0.1)	0 (0 - 0)	0.1 (0.1 - 0.1)
93	LBN	0.2 (0.2 - 0.3)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.2)	0.2 (0.2 - 0.2)	0.7 (0.6 - 0.8)
94	LBR	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
95	LBY	0.3 (0.2 - 0.3)	0.3 (0.3 - 0.3)	0.6 (0.5 - 0.6)	0.6 (0.5 - 0.7)	0.6 (0.5 - 0.7)
96	LKA	0 (0 - 0)	0.3 (0.3 - 0.4)	0.2 (0.1 - 0.3)	0.2 (0.1 - 0.2)	0.4 (0.4 - 0.5)
97	LSO	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0 (0 - 0)	0.1 (0.1 - 0.1)
98	LTU	0.1 (0 - 0.1)	0 (0 - 0.1)	0 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0 - 0.1)
99	LUX	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0.1)
100	LVA	0.1 (0 - 0.1)	0 (0 - 0)	0 (0 - 0.1)	0.1 (0 - 0.1)	0.1 (0 - 0.1)
101	MAR	0.2 (0.2 - 0.2)	0.9 (0.8 - 1)	1.3 (1.1 - 1.4)	0.8 (0.7 - 0.9)	1.8 (1.4 - 2.1)
102	MDA	0.1 (0 - 0.1)	0 (0 - 0.1)	0.1 (0 - 0.1)	0 (0 - 0.1)	0.1 (0.1 - 0.1)
103	MDG	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0.1)
104	MEX	2.8 (2.3 - 3.5)	2.4 (1.8 - 3.6)	5.4 (3.8 - 6.3)	6.3 (5.2 - 7.5)	11.1 (8.8 - 13.4)
105	MHL	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
106	MKD	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
107	MLI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)

108	MMR	0 (0 - 0)	0.1 (0.1 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.5 (0.3 - 0.6)
109	MNE	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
110	MNG	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.2)
111	MOZ	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
112	MRT	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
113	MWI	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
114	MYS	0.3 (0.3 - 0.4)	0.8 (0.6 - 0.9)	1 (0.9 - 1.2)	0.9 (0.8 - 1)	1.4 (1.3 - 1.5)
115	NAM	0 (0 - 0)	0 (0 - 0.1)	0.1 (0.1 - 0.1)	0 (0 - 0.1)	0.1 (0.1 - 0.1)
116	NCL	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
117	NER	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.2)
118	NGA	0 (0 - 0)	1.1 (0.9 - 1.4)	0.6 (0.6 - 0.9)	0.1 (0 - 0.1)	2.7 (2.4 - 3.2)
119	NIC	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
120	NLD	0.3 (0.2 - 0.4)	0.3 (0.2 - 0.4)	0.5 (0.4 - 0.7)	0.5 (0.3 - 0.8)	0.7 (0.5 - 1.1)
121	NOR	0.2 (0.2 - 0.3)	0.2 (0.1 - 0.2)	0.4 (0.3 - 0.5)	0.3 (0.2 - 0.4)	0.7 (0.6 - 0.9)
122	NPL	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.2)	0.1 (0.1 - 0.2)	0.3 (0.2 - 0.4)
123	NZL	1 (0.9 - 1.1)	0.7 (0.6 - 0.7)	1.1 (1 - 1.4)	1.1 (1 - 1.3)	1.6 (1.4 - 1.8)
124	OMN	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0.1)
125	PAK	0.1 (0 - 0.1)	0.6 (0.4 - 1.1)	0.4 (0.2 - 0.6)	0.1 (0.1 - 0.2)	1.1 (0.8 - 1.4)
126	PAN	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.3)
127	PER	0.5 (0.4 - 0.6)	0.6 (0.5 - 0.7)	1 (0.9 - 1.1)	0.8 (0.7 - 0.9)	1.3 (1.2 - 1.5)
128	PHL	0 (0 - 0)	0.6 (0.4 - 0.8)	0.5 (0.4 - 0.7)	0.1 (0 - 0.1)	1.6 (1.3 - 1.9)
129	PNG	0 (0 - 0)	0.3 (0.3 - 0.3)	0.3 (0.3 - 0.3)	0.1 (0.1 - 0.1)	0.6 (0.6 - 0.6)
130	POL	0.5 (0.3 - 0.9)	0.4 (0.3 - 0.7)	1 (0.7 - 1.4)	0.9 (0.5 - 1.4)	1.5 (0.9 - 2.4)
131	PRI	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0 - 0.1)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.3)
132	PRK	0.1 (0 - 0.1)	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.4)
133	PRT	0.1 (0.1 - 0.2)	0.1 (0.1 - 0.2)	0.2 (0.2 - 0.2)	0.1 (0.1 - 0.2)	0.3 (0.3 - 0.4)
134	PRY	0 (0 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.3)	0.2 (0.1 - 0.2)	0.4 (0.4 - 0.5)
135	PSE	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.6 (0.5 - 0.6)
136	PYF	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
137	QAT	0 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)
138	ROU	0.2 (0.1 - 0.3)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.4)	0.2 (0.2 - 0.3)	0.6 (0.4 - 0.7)
139	RUS	3.1 (2.5 - 4)	2.9 (2.2 - 3.6)	5.1 (4.1 - 6.3)	4 (3 - 5.3)	7.8 (6.3 - 9.2)
140	RWA	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
141	SAU	0.3 (0.2 - 0.4)	0.7 (0.6 - 0.9)	1.2 (1 - 1.4)	0.9 (0.7 - 1.1)	2 (1.7 - 2.3)
142	SDN	0 (0 - 0)	0.2 (0.2 - 0.3)	0.2 (0.2 - 0.2)	0.1 (0.1 - 0.1)	0.6 (0.6 - 0.7)
143	SEN	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
144	SLB	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
145	SLE	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
146	SLV	0 (0 - 0)	0.1 (0 - 0.1)	0 (0 - 0.1)	0 (0 - 0.1)	0.2 (0.1 - 0.2)
147	SOM	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
148	SRB	0.1 (0.1 - 0.2)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.2)	0.2 (0.1 - 0.2)
149	SUR	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
150	SVK	0.1 (0 - 0.2)	0.1 (0.1 - 0.1)	0.2 (0.1 - 0.2)	0.2 (0.1 - 0.2)	0.3 (0.2 - 0.4)
151	SVN	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.1 - 0.2)
152	SWE	0.2 (0.1 - 0.2)	0.1 (0.1 - 0.2)	0.3 (0.2 - 0.3)	0.3 (0.2 - 0.4)	0.5 (0.4 - 0.6)
153	SWZ	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
154	SYR	0 (0 - 0.1)	0.2 (0.2 - 0.3)	0.4 (0.3 - 0.4)	0.1 (0.1 - 0.2)	1 (0.9 - 1.1)
155	TCD	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
156	TGO	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
157	THA	0.8 (0.6 - 1)	1.8 (1.6 - 2.3)	2.7 (2.2 - 3.2)	1.7 (1.3 - 2.1)	3.2 (2.7 - 4.3)
158	TJK	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0.1)	0 (0 - 0.1)	0.1 (0.1 - 0.1)
159	TKM	0 (0 - 0)	0.1 (0 - 0.1)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.2)
160	TLS	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
161	TTO	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
162	TUN	0.2 (0.2 - 0.3)	0.4 (0.4 - 0.4)	0.8 (0.7 - 0.8)	0.7 (0.6 - 0.8)	0.9 (0.8 - 1)
163	TUR	0.4 (0.3 - 0.6)	1.2 (1 - 1.5)	2 (1.7 - 2.4)	1.1 (0.9 - 1.3)	4.3 (3.7 - 5.1)

164	TWN	1.1 (0.8 - 1.4)	0.2 (0.2 - 0.3)	0.4 (0.4 - 0.7)	0.3 (0.3 - 0.4)	0.5 (0.4 - 0.5)
165	TZA	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.3 (0.2 - 0.4)
166	Total	312.7 (268.1 - 362.8)	261.1 (216.9 - 308.7)	507.3 (428.1 - 588.3)	408.4 (344.6 - 470.3)	780.6 (671 - 897.7)
167	UGA	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0.1 (0.1 - 0.1)
168	UKR	0.7 (0.5 - 0.9)	0.6 (0.4 - 0.7)	1 (0.7 - 1.3)	0.7 (0.4 - 1.1)	1.7 (1.3 - 2.3)
169	URY	0.1 (0 - 0.1)	0 (0 - 0)	0.1 (0.1 - 0.1)	0.1 (0.1 - 0.1)	0.2 (0.2 - 0.3)
170	USA	185.3 (165.9 - 205.8)	84.1 (74.7 - 92.7)	236.2 (209.8 - 261.1)	220.9 (196.7 - 242.4)	310.7 (278.3 - 340.1)
171	UZB	0.2 (0.2 - 0.3)	0.5 (0.4 - 0.6)	1.2 (1 - 1.4)	0.5 (0.4 - 0.9)	1.3 (1.1 - 1.5)
172	VCT	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
173	VEN	0.4 (0.3 - 0.4)	0.6 (0.5 - 0.6)	1.1 (1 - 1.4)	1.2 (1 - 1.3)	2.1 (1.9 - 2.2)
174	VIR	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
175	VNM	0.1 (0 - 0.1)	1.6 (1.3 - 1.8)	1.4 (1.2 - 1.6)	1.1 (0.7 - 1.5)	3.6 (3 - 4.5)
176	VUT	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
177	WSM	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
178	YEM	0 (0 - 0)	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.1 (0 - 0.1)
179	ZAF	4 (3.4 - 4.5)	3.2 (2.5 - 3.7)	8.2 (6.8 - 9.2)	4.3 (3.7 - 5.1)	7.5 (5.4 - 8.9)
180	ZMB	0 (0 - 0)	0.1 (0.1 - 0.1)	0 (0 - 0)	0 (0 - 0)	0.3 (0.2 - 0.3)
181	ZWE	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)

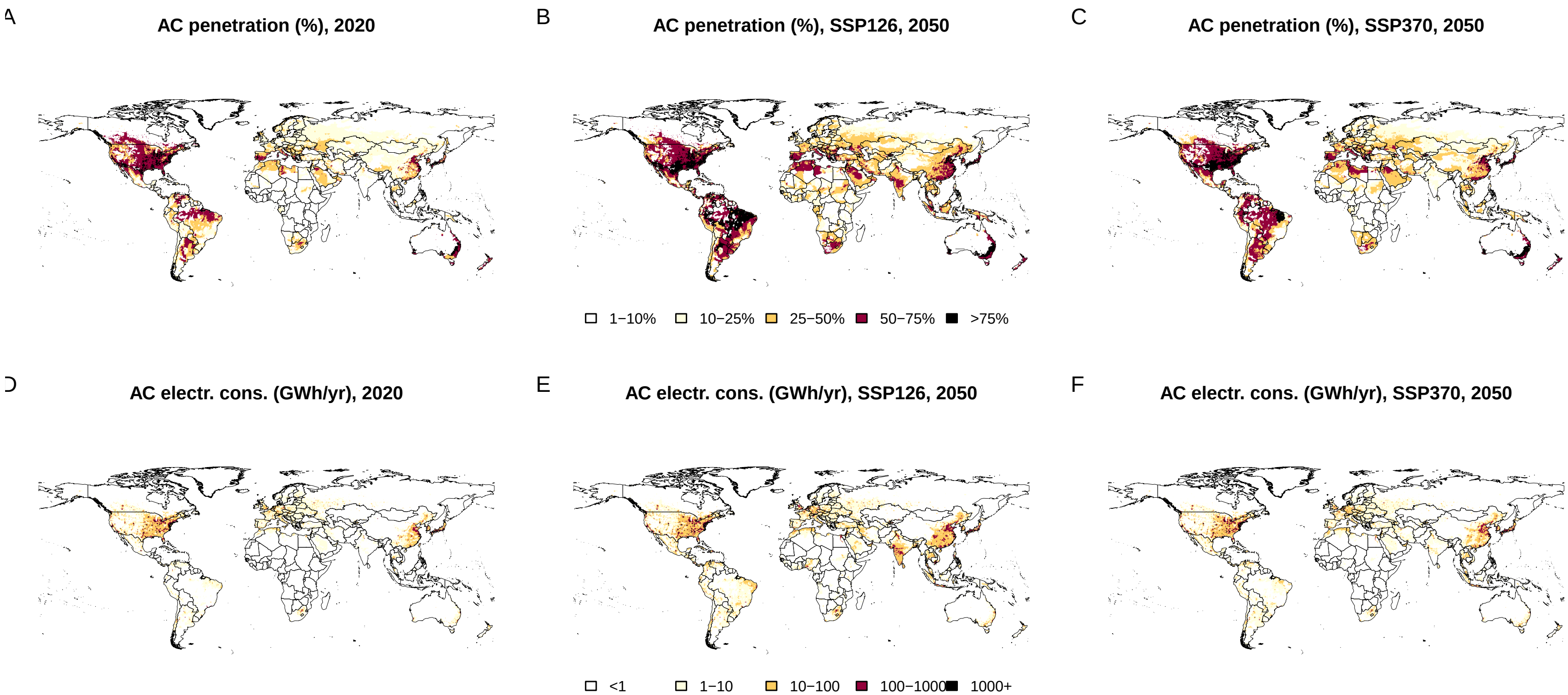

Figure SI-10. Global gridded projections for residential air conditioning. Maps of AC ownership (% of households) (A,B,C) and (D,E,F) residential sector AC electricity consumption, SSP scenarios 1(26) and 3(70) in 2020 and 2050, CMIP6 GCMs enemble median (exluding 'hot models'[26]).