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IMPROVING THE MODELLING OF AIR CONDITIONING ADOPTION

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Overview

Cooling systems, and air conditioning (AC) in particular, are key to reducing the mortality risk associated with higher temperature (Barreca et al. 2016). Against these benefits, AC adoption increases energy use and adds stress on electricity networks (IEA 2022), thus creating a risk of 'maladaptation' (Viguié, Juhel, et al. 2021).

Research into AC adoption has identified two main determinants: outdoor temperature, via cooling degree-days (sometimes factoring in relative humidity (RH)), and income level (Akpinar-Ferrand and Singh 2010; Davis et al. 2021; Mastrucci et al. 2022). While these variables adequately capture aggregate trends at, say, the national level, they are limited in their ability to capture adoption at finer spatial and temporal scales. Other important variables include: socio-economic characteristics, e.g., age, gender (Khosla et al. 2021); the duration and intensity of heat events (Viguié, Lemonsu, et al. 2020); building characteristics, e.g., architectural layout, insulation level (CODA Stratégies and ADEME 2020); and urban forms, in particular the prevalence of urban heat island (UHI) effects (Tremeac et al. 2012).

These less-studied variables are important to take into account to fully assess the risk of "maladaptation" associated with AC adoption. The paper proposes an original way to do so.

Methods

We estimate AC adoption with a non-linear multivariate model resulting from a parametric optimisation with minimisation of an error indicator: the root mean square error (RMSE). The target values are the adoption rates of the different air conditioning systems. The equipment rate is considered to be proportional to the cumulative sales of cooling systems, with some corrections (lifetime, etc.). We specify the model with past data (since 2000) for a set of variables for which good quality projections with quantified uncertainties are available. These include:

- AC sales (by system, for each year or semester) come from the sources used in the report from CODA Stratégies and ADEME (2020): *UNICLIMA* and *PAC & Clim Info*.
- Socio-economic data data are taken from INSEE, the national statistics institute in France, and are complemented by survey data from the report from CODA Stratégies and ADEME (2020). This includes data on gender, age and income of the population, and AC ownership in particular. Based on these data, projections are made using the 6th IPCC publication cycle: the shared socio-economic pathways (SSPs) (Riahi et al. 2017).
- Climate data, both historic and projected, come from the results of the CMIP EURO-CORDEX programme (Jacob et al. 2014). This includes temperature, HR, etc. For the quantification of UHIs, we rely on the national building database, which is managed by the CSTB, the French scientific centre for construction.
- Building characteristics are available through the ADEME energy performance analysis database, and projected data are derived from the Res-IRF model (Giraudet et al. 2012).

Once specified, the model is calibrated so as to be consistent with aggregate data from CEREN, the French centre for the analysis of energy needs.

Results

Applying the model to a range of parameter specifications yields two main results. First, climate variables have the strongest influence on the model outcomes (AC adoption, AC-related energy consumption). Specifically, a steady increase of average temperature has a stronger influence than a steady increase in the frequency of heat waves (up to a certain degree of warming where heat waves grow so frequent that they become the number one driver). Second, an analysis of variance suggests that the influence of the next two sets of determinants, namely income and a bundle of all other socio-economic variables, is similar.

Conclusion

Our analysis shows that ignoring a broad set of socio-economic variables leads projections to significantly under-estimate AC adoption and the associated energy consumption. It is therefore crucial to take them into account in order to better assess the risk of maladaptation. This additionally calls for new building retrofit and urban planning policies precisely addressing these drivers (prevalence of urban heat island effects, etc.).

The methodology used above can be adapted for similar work in different contexts – for instance in Spain or Italy, which are experiencing the climate that France is expected to have in several decades (e.g., Paris having the climate of current Seville in 2050).

References

Akpinar-Ferrand, E. and A. Singh (2010). “Modeling increased demand of energy for air conditioners and consequent CO2 emissions to minimize health risks due to climate change in India”. In: *Environmental Science & Policy* 13.8. Number: 8, pp. 702–712. ISSN: 1462-9011. DOI: 10.1016/j.envsci.2010.09.009.

Barreca, A. et al. (2016). “Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century”. In: *Journal of Political Economy* 124.1. Number: 1 Publisher: The University of Chicago Press, pp. 105–159. ISSN: 0022-3808. DOI: 10.1086/684582.

CODA Stratégies and ADEME (2020). La climatisation de confort dans les bâtiments résidentiels et tertiaires. ADEME, p. 104.

Davis, L. et al. (2021). “Air conditioning and global inequality”. In: *Global Environmental Change* 69, p. 102299. ISSN: 0959-3780. DOI: 10.1016/j.gloenvcha.2021.102299.

Giraudet, L.-G., C. Guivarch, and P. Quirion (2012). “Exploring the potential for energy conservation in French households through hybrid modeling”. In: *Energy Economics* 34.2, pp. 426–445. ISSN: 0140-9883. DOI: 10.1016/j.eneco.2011.07.010.

IEA (2022). Climate Resilience for Energy Security. OECD. ISBN: 978-92-64-53454-4. DOI: 10.1787/2a931f53-en.

Jacob, D. et al. (2014). “EURO-CORDEX: new high-resolution climate change projections for European impact research”. In: *Regional Environmental Change* 14.2, pp. 563–578. ISSN: 1436-378X. DOI: 10.1007/s10113-013-0499-2.

Khosla, R. et al. (2021). “The what, why, and how of changing cooling energy consumption in India’s urban households”. In: *Environmental Research Letters* 16.4. Publisher: IOP Publishing, p. 044035. ISSN: 1748-9326. DOI: 10.1088/1748-9326/abecbc.

Mastrucci, A. et al. (2022). “Cooling access and energy requirements for adaptation to heat stress in megacities”. In: *Mitigation and Adaptation Strategies for Global Change* 27.8, p. 59. ISSN: 1573-1596. DOI: 10.1007/s11027-022-10032-7.

Riahi, K. et al. (2017). “The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview”. In: *Global Environmental Change* 42, pp. 153–168. ISSN: 0959-3780. DOI: 10.1016/j.gloenvcha.2016.05.009.

Tremeac, B. et al. (2012). “Influence of air conditioning management on heat island in Paris air street temperatures”. In: *Applied Energy* 95, pp. 102–110. ISSN: 0306-2619. DOI: 10.1016/j.apenergy.2012.02.015.

Viguié, V., S. Juhel, et al. (2021). “When adaptation increases energy demand: A systematic map of the literature”. In: *Environmental Research Letters* 16.3. Number: 3 Publisher: IOP Publishing, p. 033004. ISSN: 1748-9326. DOI: 10.1088/1748-9326/abc044.

Viguié, V., A. Lemonsu, et al. (2020). “Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris”. In: *Environmental Research Letters* 15.7. Publisher: IOP Publishing, p. 075006. ISSN: 1748-9326. DOI: 10.1088/1748-9326/ab6a24.