

#### Future Residential Electricity Consumption (REC) under climate change in France: application of a fine-granularity temperature sensitivity model.

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## Future Residential Electricity Consumption (REC) under climate change in France: application of a fine-granularity temperature sensitivity model.

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+4°C by 2100 if no policy in place  $\Rightarrow$  Policy in which domain and which regions?

Residential sector represents more than 30% of final energy uses and 20% of CO2 emissions.

Renovation slow and ineffective  $\Rightarrow$  Target the places where the renovation will be most effective.

Main research question:

How will climate change geographically influence future residential electricity consumption?



Projection of future electricity consumption

 $\Rightarrow$  Need to know the relationship between temperature and electricity consumption.

⇒ Temperature sensitivity model + Heating degree days
(HDD) + Cooling degree days (CDD)

$$HDD_{i}(y) := \sum_{d=1}^{N_{y}} \max(0; T_{i}^{H} - T_{i}(y, d))$$
$$CDD_{i}(y) := \sum_{d=1}^{N_{y}} \max(0; T_{i}(y, d) - T_{i}^{C})$$



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 $\Rightarrow$  Limitations of previous studies:

National scale
Non-climatic factors for cooling not considered



*Fig. 2*: Representation of part of the IRIS grids of the Hauts-de-France Region in France.

IRIS is the french smallest geographical scale with **2000** inhabitants per cell.

But at small geographical scale, only **annual data** are available. With the notions of DD, the annual electricity consumption can be modeled as:

$$E_i(y) = \beta_i^{\mathrm{H}}(y) \ \mathrm{HDD}_i(y) + B_i \ N_y + \beta_i^{\mathrm{C}}(y) \ \mathrm{CDD}_i(y)$$
  
=  $\alpha_i^{\mathrm{H}} \eta_i^{\mathrm{El}}(y) \ \mathrm{HDD}_i(y)$   
+  $B_i \ N_y$   
+  $\alpha_i^{\mathrm{C}} \eta_i^{\mathrm{AC}}(y) \ \mathrm{CDD}_i(y).$ 

$$\begin{split} E_i(y) &= \beta_i^{\mathrm{H}}(y) \; \mathrm{HDD}_i(y) + B_i \; N_y + \beta_i^{\mathrm{C}}(y) \; \mathrm{CDD}_i(y) \\ &= \alpha_i^{\mathrm{H}} \; \eta_i^{\mathrm{El}}(y) \; \mathrm{HDD}_i(y) \\ &+ B_i \; N_y \\ &+ \alpha_i^{\mathrm{C}} \; \eta_i^{\mathrm{AC}}(y) \; \mathrm{CDD}_i(y). \end{split}$$

Main hypothesis:

The cooling-sensitivity  $\beta^{c}$  is only related to consumption of air conditioners (AC), so that only residences equipped with AC systems will contribute to the temperature sensitive REC during summer. ( $\beta^{c} = \alpha^{c} \eta^{Ac}$ )

The first equation relates to REC a heating, a base and a cooling REC (from left to right). The base REC per day  $B_i$  is the part of the REC that does not depend on temperature. The coefficients of proportionality  $\beta_i^H(y)$  and  $\beta_i^C(y)$  measure the increase in yearly REC per degree-day and per unit of area in cell *i*. The **advantage** of the parametric DD approach is its **easy application and understanding** of the relationship between input and output variables. This advantage can also **facilitate the application of the model with climate change scenarios**.

- E<sub>i</sub>(y) : Total annual electricity consumption for IRIS i and year y (already normalized by the living surface).
- IRIS : The smallest geographical census unit in France (~2000 inhabitants per cell), France has 41000 IRIS.
- β<sub>i</sub><sup>H</sup>(y) and β<sub>i</sub><sup>C</sup>(y): The electricity heating- and cooling-sensitivity, measure the increase in yearly REC per degree-day and per unit of area in cell i.
- HDD and CDD : The annual heating and cooling degree-days.
- η<sup>AC</sup>: The rate of households within the area equipped with air-conditioning systems.
- $\eta^{EI}$ : The rate of households within the area equipped with electric heating systems.
- B<sub>i</sub> : The basic daily electricity consumption which is not temperature-dependent.
- N<sub>v</sub>: Total number of days per year.

#### Preliminary results - Temperature sensitivity

$$\begin{split} E_i(y) &= \beta_i^{\mathrm{H}}(y) \; \mathrm{HDD}_i(y) + B_i \; N_y + \beta_i^{\mathrm{C}}(y) \; \mathrm{CDD}_i(y) \\ &= \alpha_i^{\mathrm{H}} \eta_i^{\mathrm{El}}(y) \; \mathrm{HDD}_i(y) \\ &+ B_i \; N_y \\ &+ \alpha_i^{\mathrm{C}} \eta_i^{\mathrm{AC}}(y) \; \mathrm{CDD}_i(y). \end{split}$$

Observational daily temperature data from **E-OBS** and annual electricity consumption data from **ENEDIS** for calibration from 2011 until 2019.

R<sup>2</sup>>0 &  $\beta^{H}$ >0 & Test of significance

Here we can already see that there is a big variability between the IRIS.



*Fig. 3*: Temperature sensitivity coefficients at IRIS level calibrated with observational data with (left) For the heating uses (right) For the cooling uses.

#### Future temperature projection

Climate change scenario  $\Rightarrow$  RCP8.5 EURO-CORDEX (5 bias-adjusted simulations)

The uncertainty between simulations is considered in future projections.

No.	Institute	Driving GCM model	RCM model
1	CNRM	CERFACS-CM5	ARPEGE51
2	CNRM	CERFACS-CM5	RCA4
3	IPSL	CM5A-MR	RCA4
4	IPSL	CM5A-MR	WRF331F
5	ICHEC	EC-EARTH	RACM022E



*Fig. 4:* Average values of 5 CORDEX simulations of evolution compared to 1975-2005 in (a) HDD for 2025-2055 (b) HDD for 2070-2100 (c) CDD for 2025-2055 (d) CDD for 2070-2100 9

## Future Air-conditioning (AC) scenarios



Number of considered neighbors for average J

5: (left) Electricity heat-sensitivity α<sup>C</sup> calibrated with observational data (right) Possible future electricity heat-sensitivity α<sup>C</sup> with gradual spreading.

#### Future Air-conditioning (AC) scenarios

Air-conditioning scenario on  $\eta^{AC}$ ( $\beta^{C}=\alpha^{C} \eta^{AC}$ )

Air conditioning scenario  $\Rightarrow$  AC rate  $\eta^{Ac} \Rightarrow$  **Same of today** or **100%** 

### Future Air-conditioning (AC) scenarios

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Air conditioning scenario  $\Rightarrow$  AC rate  $\eta^{AC} \Rightarrow$  **Same of today** or **100%** 

Climate change scenario  $\Rightarrow$  RCP8.5 **EURO-CORDEX** (5 simulations) & Hypothesis with imitation (Gradual spreading)

4 different scenarios in total:

- 1. Only temperature changes
- 2. Temperature + AC rate
- 3. Temperature + Gradual spreading
- 4. All extreme values

## Results (without AC scenarios)



Fig.6: (left) Evolution of total temperature sensitive REC in percentage for 2070-2100 (right) Evolution in heat-sensitive consumption (cooling needs) for 2070-2100

80

100

An average decline in total temperature sensitive REC between 20% and 42% per town. With 7% of IRIS experiencing a positive elevation by 2100.

The cooling demand will increase more for southern France than for the north.

On a national scale, the result is coherent with previous studies.

## Results (with AC scenarios)

The two factors (AC rate and Gradual spreading) influence differently the demands.

In a scenario combining gradual spreading and 100% AC rate, almost half of the territory, except the North of France, sees the REC increasing in the near-term future, amounting to a global change of **+2%**.

At the end of the 21st century, this fraction of positive trend increases up to 90%, leading to a global change of **+32%**.



Fig. 7: (left) Evolution of total temperature sensitive REC with AC rate 100% (middle) Evolution of total temperature sensitive REC with Gradual spreading (right) Evolution of total temperature sensitive REC with AC rate 100% + Gradual spreading

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- In our scenario, AC gradual spreading mimics a "do like my neighbor" behavior. Our results show that such behavior has a major and detrimental impact on REC (more than 100% AC rate scenario). Such results call for targeted and local information actions where the risk of spreading is high (i.e. in areas where households are already equipped with AC systems) to limit the spreading or mitigate its effect with at least the most energy-efficient AC systems.

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- The South of France is where the REC trend is expected to occur first with possible impacts on the energy system. Therefore there is a need to target actions to prevent any further deployment of AC systems.
- Our worst-case results clearly show the detrimental impact of the increase in AC rate and spreading. Increasing the cooling setpoint or maintaining an optimal difference with outdoor air temperature to about 7-8°C to maximize the energy efficiency of the AC equipment, could lower the cooling REC. Based on our model, shifting the cooling setpoint from 21°C at present to 23-24°C by 2040 and 26-27°C by 2085 would prevent any cooling REC increase in our worst-case scenarios. These values are consistent with existing recommendations.



# Thank you for your attention! Any suggestions or questions are welcome!

Qiqi TAO, qiqi.tao@polytechnique.edu