

Project for the CEMRACS summer school of 2026

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Abstract

This project aims at evaluating the challenges posed by high, and rare and extreme (high) electricity demand events associated to winter cold spells in France in the next two decades. More specifically, the modelling chain that encompasses the evaluation of dimensioning or high-risk weather events (winter cold spells in a warming climate) and the translation into its associated (extreme) peak electricity demand (data informed modelling of the demand) will be explored, with the following questions in mind:

- when estimating the probability of (extreme) peak demand in the coming two decades, which blocks along the modelling chain are we most sensitive to ?
- which uncertainties and difficulties contribute most to the uncertainty of this estimation: fundamental difficulties in estimating the frequency of dimensioning or high-risk events in a complex physical system (the climate), or uncertainties in the modelling of the demand (involving socio-economic factors that induce essentially different uncertainties) ?
- how much do these uncertainties matter depending on the purpose of the modelling exercise: power/energy system stress-test, public policy or stakeholder informing, projections and scenarization, etc.

Motivation and Research questions

Nuclear energy represents a major part of the French energy mix, between 60 and 65% of the electricity production in recent years. The reactors have been built between 1970 and 2005, with the majority completed in a short interval, between 1980 and 1990. The initial hypothesis for the lifetime of these plants was 40 years. Even with extensions of their lifetime by one or two decades, this implies that crucial choices and decisions need to be made now, for the evolution and transformation of the electricity generation mix over the next two decades: extending nuclear reactors lifetimes following current practices guarantees only 15 GW of nuclear power at the 2050 horizon, whereas an ambitious industrial program could ensure 51 GW of generation capacity by this time, against more than 60 GW today (RTE2022).

When dimensioning the future of the energy mix, characterizing the distribution of likely demand is crucial. Many aspects come into consideration for decision-makers when planning the evolution of the electricity mix and of the grid (the share of renewables, the grid, options for demand flexibility...). Here, we choose to focus on demand (and not residual demand, in order to leave aside the issues and choices regarding the share of renewables), in order to investigate finely the sensitivity and uncertainties in modeling demand, and in particular the peaks of demand. Peak demand results from meteorological conditions such as winter cold spells (enhancing strongly the demand for heating) and summer heat waves (enhancing the demand for cooling). Characterizing finely the tail of the distribution for demand matters crucially to dimension the energy system, and

to distinguish extreme events that may occur, say, every other winter, and exceptional events that may happen once in two decades.

Characterizing peak demand in the future implies several different steps, each with their methodologies, associated assumptions and uncertainties. We group these different steps in two main categories :

- estimates of the meteorological conditions driving the demand. More specifically, for extreme events, one aims at estimating the probability of rare events (extreme cold spells or heat waves with long durations for instance). Difficulties arise from the facts that **1)** observations of the current climate provide only a limited sampling, insufficient to evaluate extreme events ; **2)** climate models and/or Numerical Weather Prediction models allow to explore physically plausible atmospheric states, with the limitations in terms of realism inherent to modeling a physical system with limited resolution. Different methodologies exist to explore rare events, drawing information from both of these sources of information.
- estimates of the demand corresponding to the meteorological conditions. This corresponds to a socio-economic system, involving human beings, for which no laws or firmly established equations are known. Modeling is based on observations, and can involve statistical or Machine-Learning approaches to capture a relationship between inputs (meteorological conditions) and the resulting demand. The approaches and the nature of the problem differ fundamentally from the previous one.

On timescales of several decades, sources of uncertainty associated to scenarios increase for both climate change (emissions) and for the demand, particularly in response to heat waves (evolution of equipment for cooling, as well as behavioral changes). In the current project, we propose to focus on **timescales of one to two decades** : this is extremely meaningful for decision-making and for stakeholders, and the sensitivity to the underlying scenario remains limited. We propose to focus on **winter cold spells** : they will ultimately decrease, but remain present and likely. Interestingly for us, both their occurrences in the current climate and the resulting demand are much better observed than extreme heat waves that are yet to come and remain, consequently, unsampled.

The aim of the project is to explore uncertainties in the modelling chain outlined above. Several different directions could be chosen :

- uncertainty in estimating the **distribution of meteorological variables**, in the next two decades, with a possible focus on the extremes,
- sensitivity of the estimate of the demand to methodological choices in modelling the **relationship between meteorology and demand**.

A discussion of these different directions, based on bibliography and the candidate's interest, will constitute a first part of the project.

References

(RTE2022) Futurs énergétiques 2050, chapter 4, <https://rte-futursenergetiques2050.com/>