Integration of electric vehicles into transmission grids: A case study on generation adequacy in Europe in 2040

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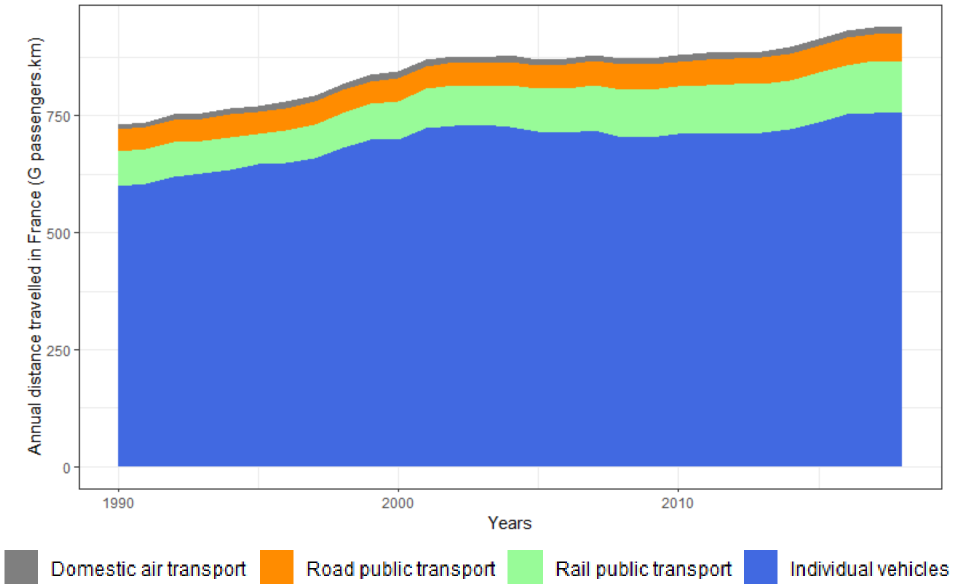
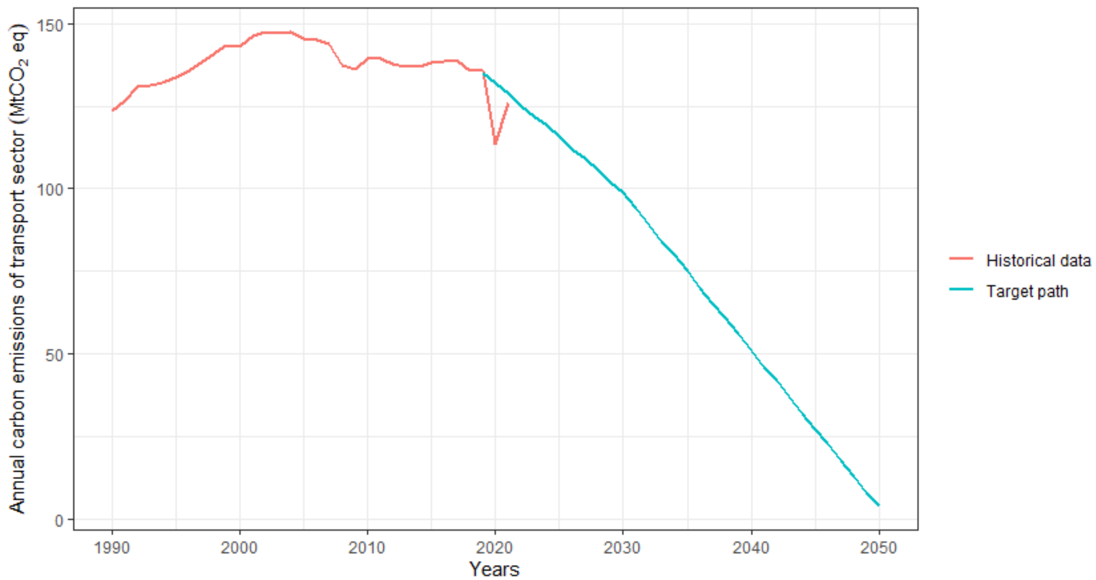
Background: transport sector in France

- **30% of carbon emissions** in France (and at EU level) related to transport sector in 2019
- **80% of distances** are travelled by **individual** road vehicles, especially cars in France
- Transport emissions are to be drastically reduced along decarbonisation pathways towards 2050 (at EU level)
- Governments tend to **promote EVs** as an alternative to thermal powered vehicles



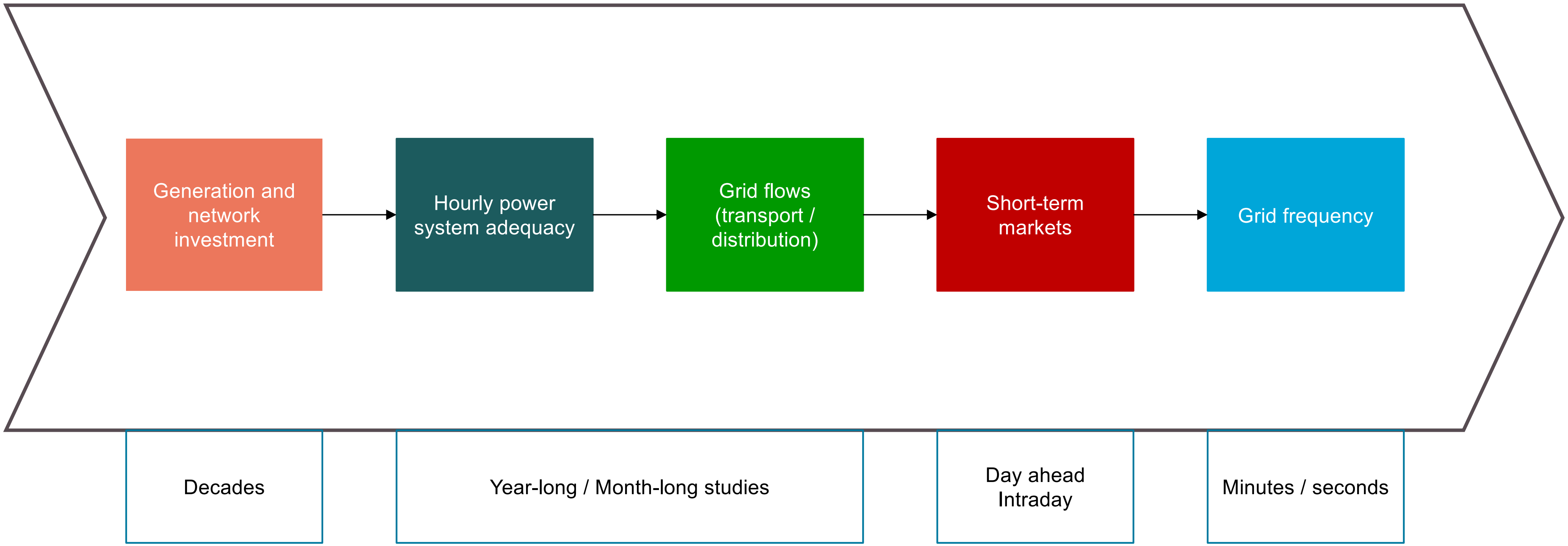
Data from Arafer (2019)



Data from Citepa (2022)

5 main aspects of electric vehicles / power system interaction

- Increasing value of EV demand-side flexibility, along **wind and solar** electricity generation development, on various markets

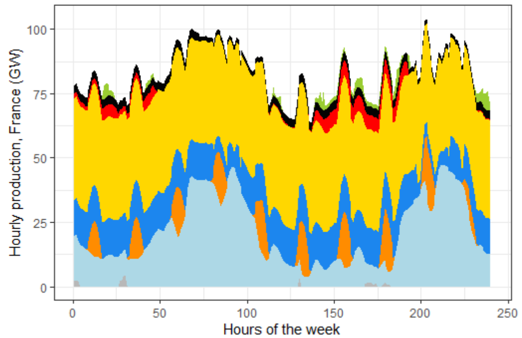


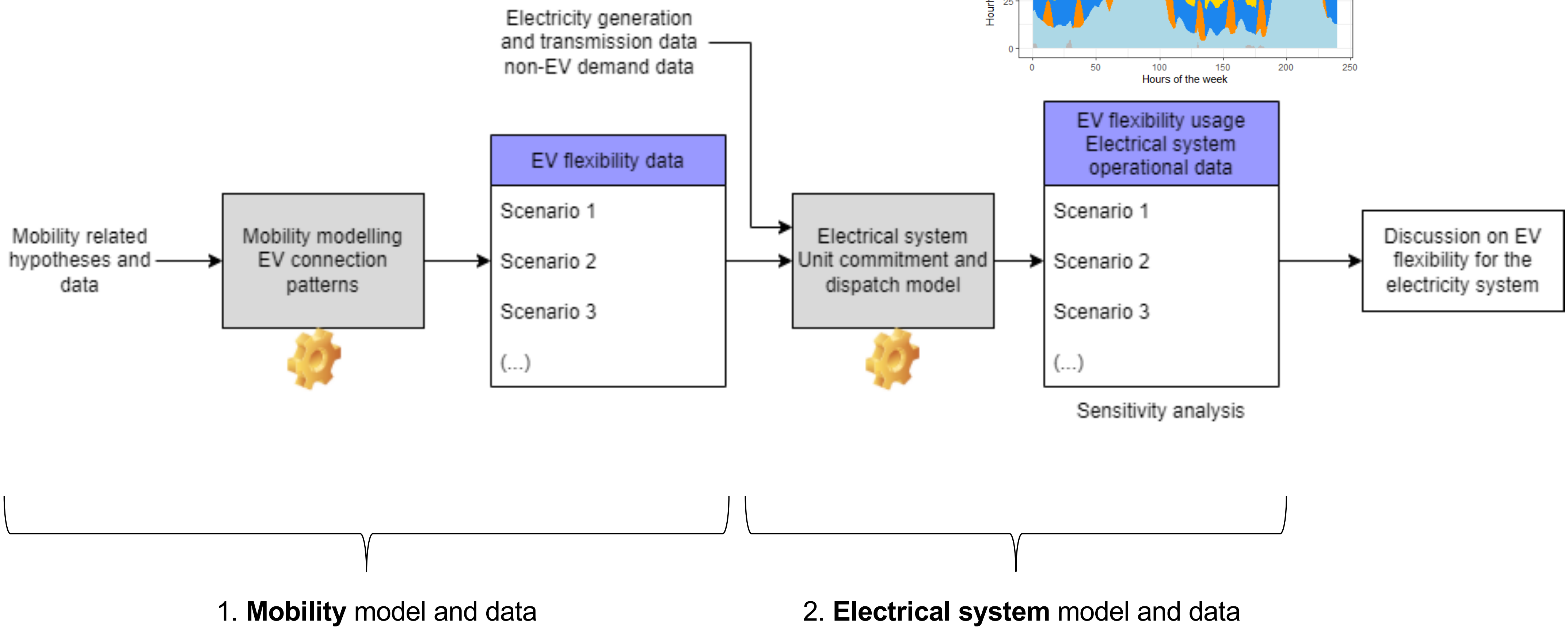
Research questions

- **Focus on hourly power system adequacy**
- Main gaps in the literature to be filled :
  - Study the prospective impacts of a large diffusion of EVs (taking into account the diversity of vehicles and their usage)
  - Study at the national scale, from system operator perspective
  - Impacts of a large share of EVs on prices (sequential modeling from transport sector to electricity generation sector)

- **How to compare the main EV charging modes, and which parameters have the largest impacts on this demand-side flexibility potential?**

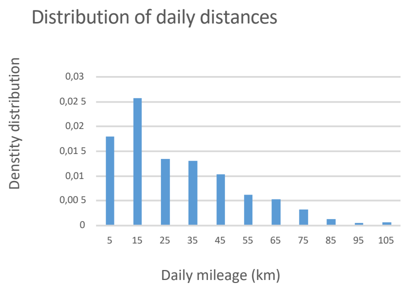
Global framework of this work



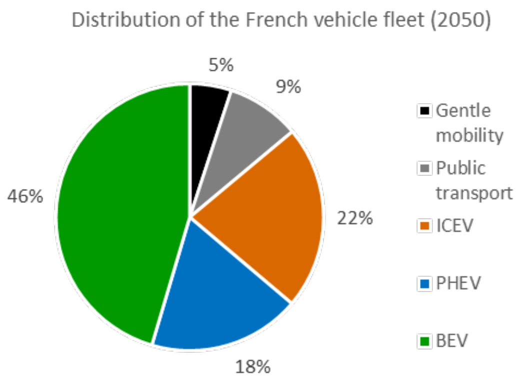


Mobility modeling methodology

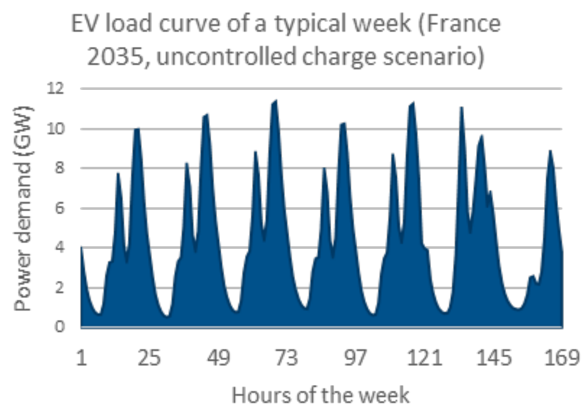
Travel data of electric vehicles



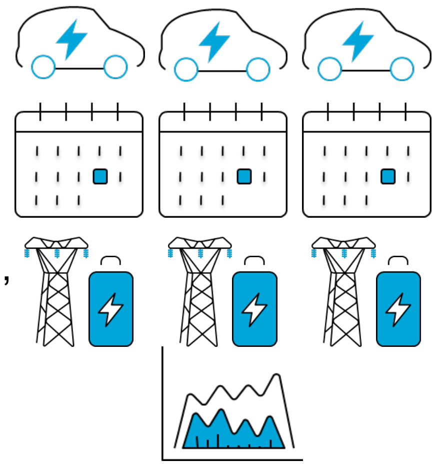
Hypotheses :
Vehicle fleet modelled,
EV owners' behavior …



Vehicle travel and connection algorithm

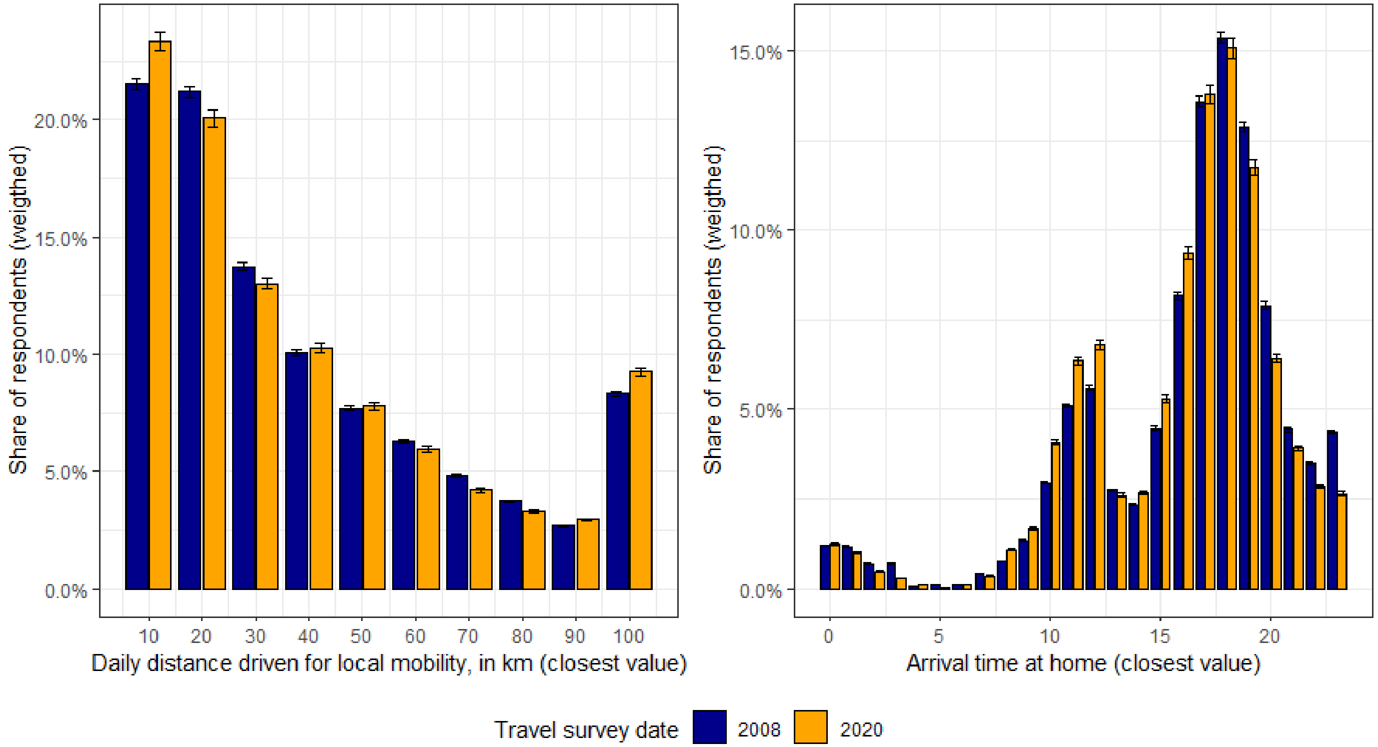


1. Generation of the parameters of each EV (EV type, battery capacity, charging infrastructure …)
2. Generation of the **trip schedule** of each EV (random drawing among travel survey data)
3. Computation of the evolution of each EV consumption, location and then demand from the grid
4. **Summary** of energy demand per category, across multiple MonteCarlo simulations



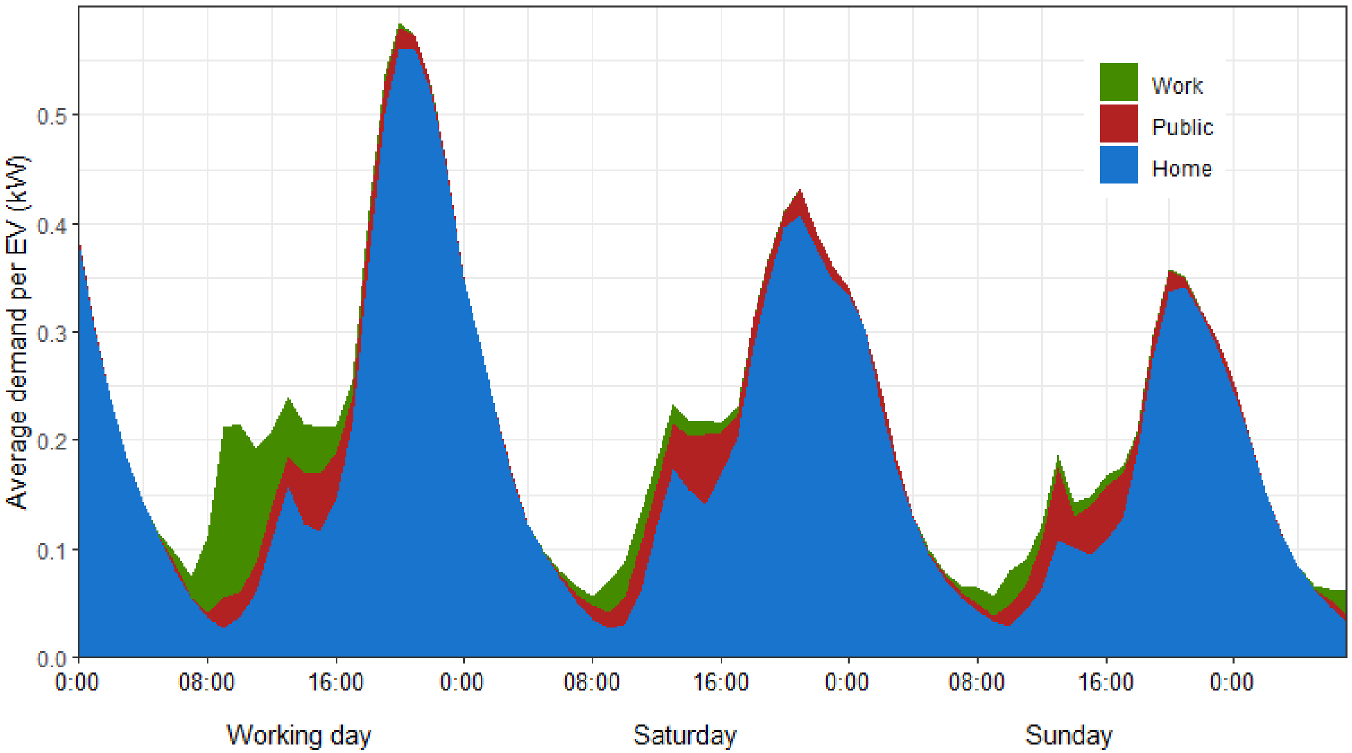
Travel survey data analysis

- **ENTD 2008** : *40 000* respondants, providing their mobility habits
  Good representative dataset, even when divided by day, area and destination type
- **More recent mobility survey** published in 2021: very little evolution of trip distances and departure times between 2008 and 2020



- Travel data differ according to
  - Local mobility and long distance trips
  - The residence area of the EV user
  - The socio-professional type of the EV user
  - The day of travel (working day or week-end)
- Extrapolated to the 2040 horizon along French objectives of travelled distance reduction per vehicle

EV demand data per charging point location

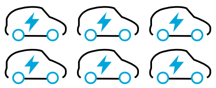


Illustrated with uncontrolled demand

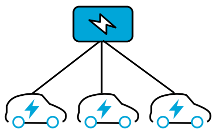
- Significantly more distances travelled on **working days** implies **larger demand** than on weekends
- Most of the charge in our model **at or close to home** (as observed currently)

Literature review of smart charging modeling approaches

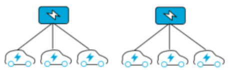
- Many studies, study EV integration to the electricity system as a **price-taker** (use of historical market data)
- Among the studies that integrate EV into more complex methodologies, several approaches can be found :



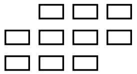
  - **EV per EV optimisation**: suited to simulations at the local scale (smart-grid with limited number of vehicles)



  - Approximation of **an equivalent battery for a large number of EVs** (while adding constraints on maximal connected power, energy to be charged in various time windows …)



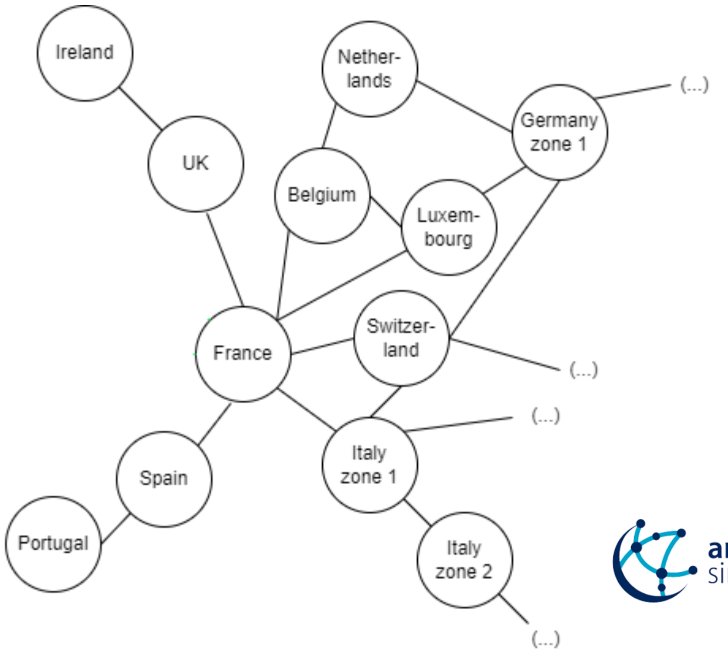
  - **One equivalent battery for EV clusters** that show similar characteristics (e.g. one for company cars, one for personal cars, and one for PHEVs)

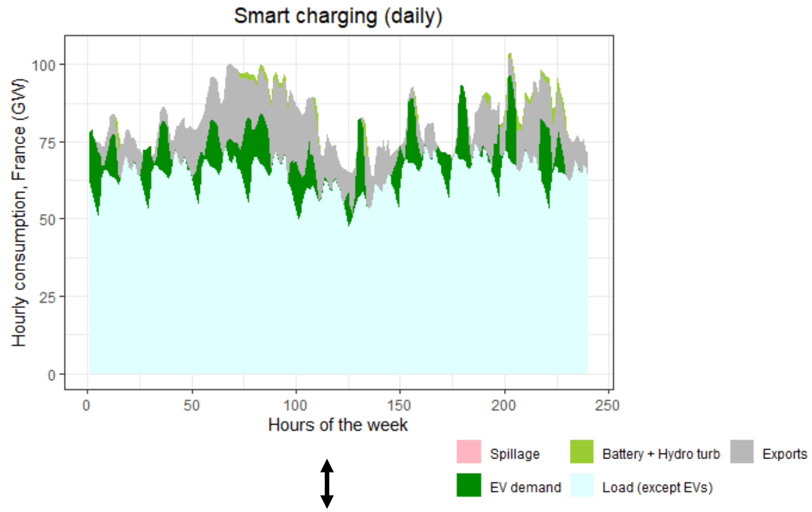


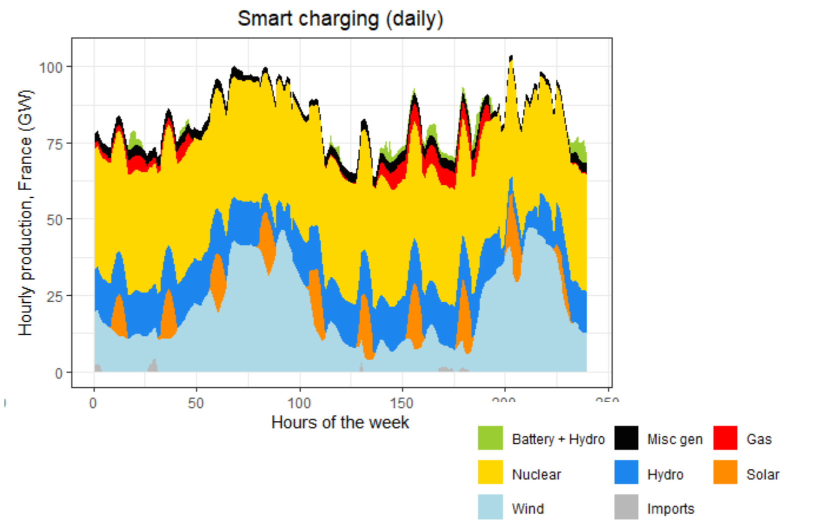
  - **Matrix approach** where all charging windows per vehicles are summarised (not suited for integration into most electricity system models)

EV integration into power system modeling

- One electrical node per price zone
- 1 electrical node for **uncontrolled EVs**
- electrical nodes to model **EV smart charging** (with constraints on connected vehicles)
  Millions of EVs aggregated as 1 flexibility item inside our model







Description of 4 charging modes studied

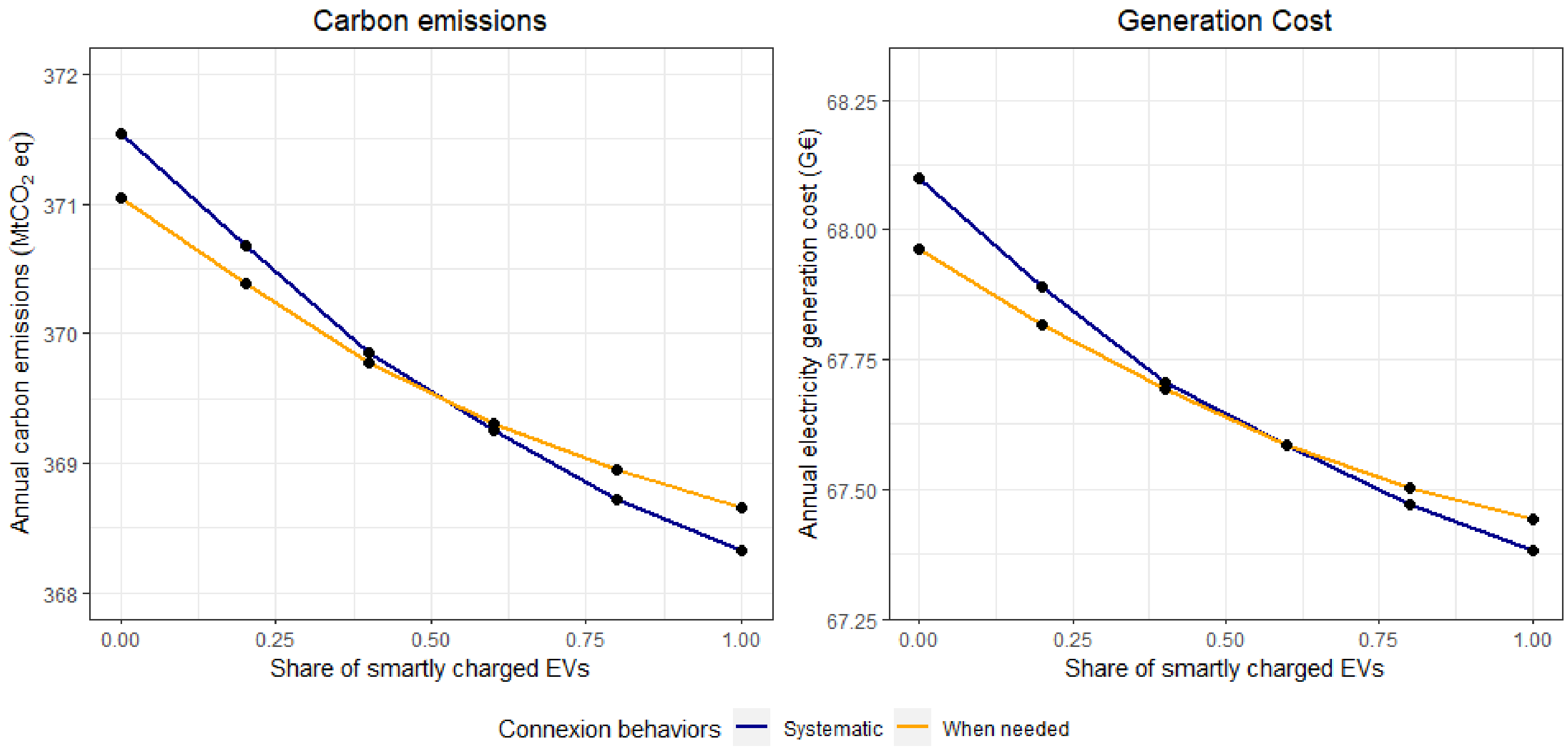
1. **Uncontrolled** charge: adding uncontrolled charge to the EV node

2. **Time-of-use** charge: charging profiles computed prior to the simulation and added as uncontrolled charge. 2 variants:
   1. *Basic* signals, computed by shifting uncontrolled load curve by a few hours
   2. *Improved* signals, generated from averaging smart charging profiles

3. **Unidirectional smart charging**: EVs are free to be charged in their connection time window

4. **Vehicle-to-grid** (V2G) : EVs are free to be charged in their connection time window, and are able to inject energy to the grid (or locally to the home, no difference in our study)

Smart charging diffusion and connection behaviors

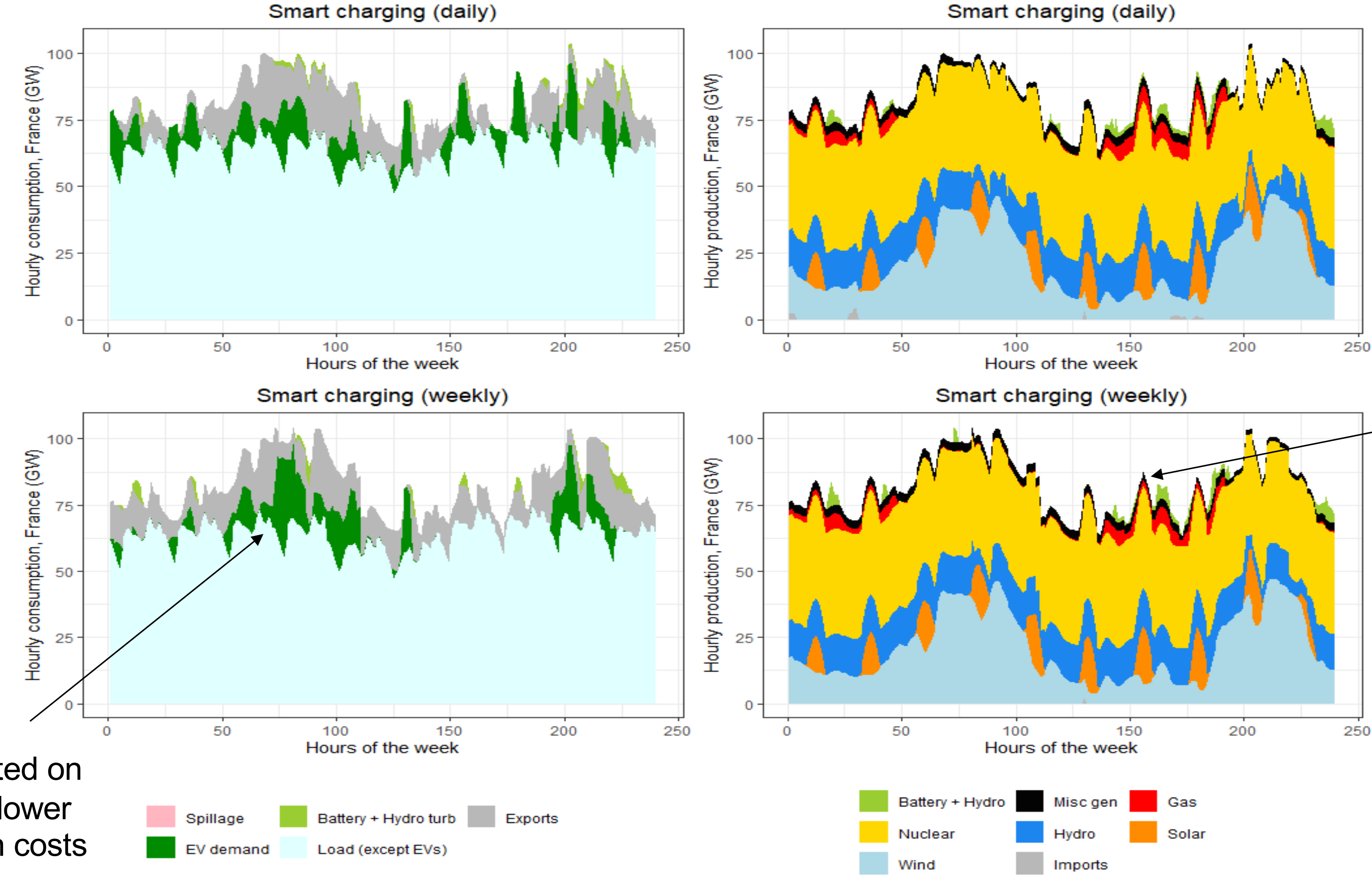


For uncontrolled EV charge, occasional behavior is preferable because recharging is better spread, but **systematic connection is preferable to maximize EV flexibility**.

2 options for EV charge flexibility: daily or weekly

daily

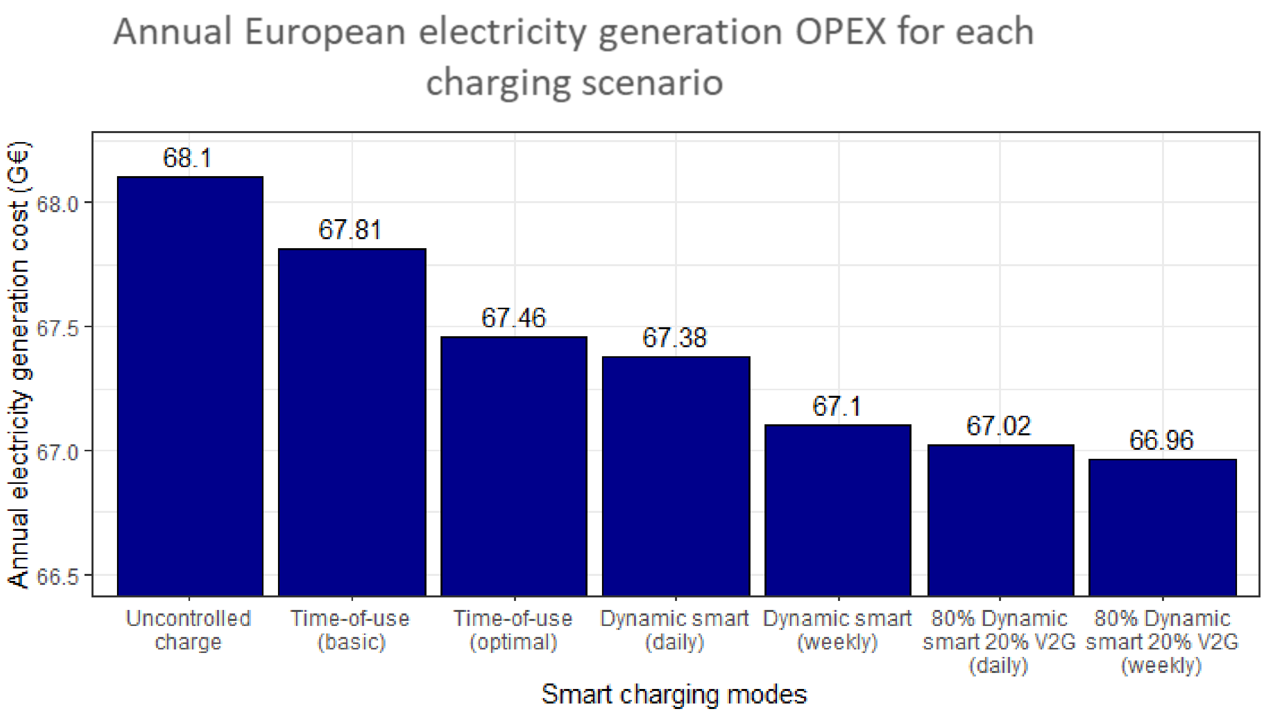
weekly



Lower gas consumption and imports

Demand concentrated on days with lower generation costs

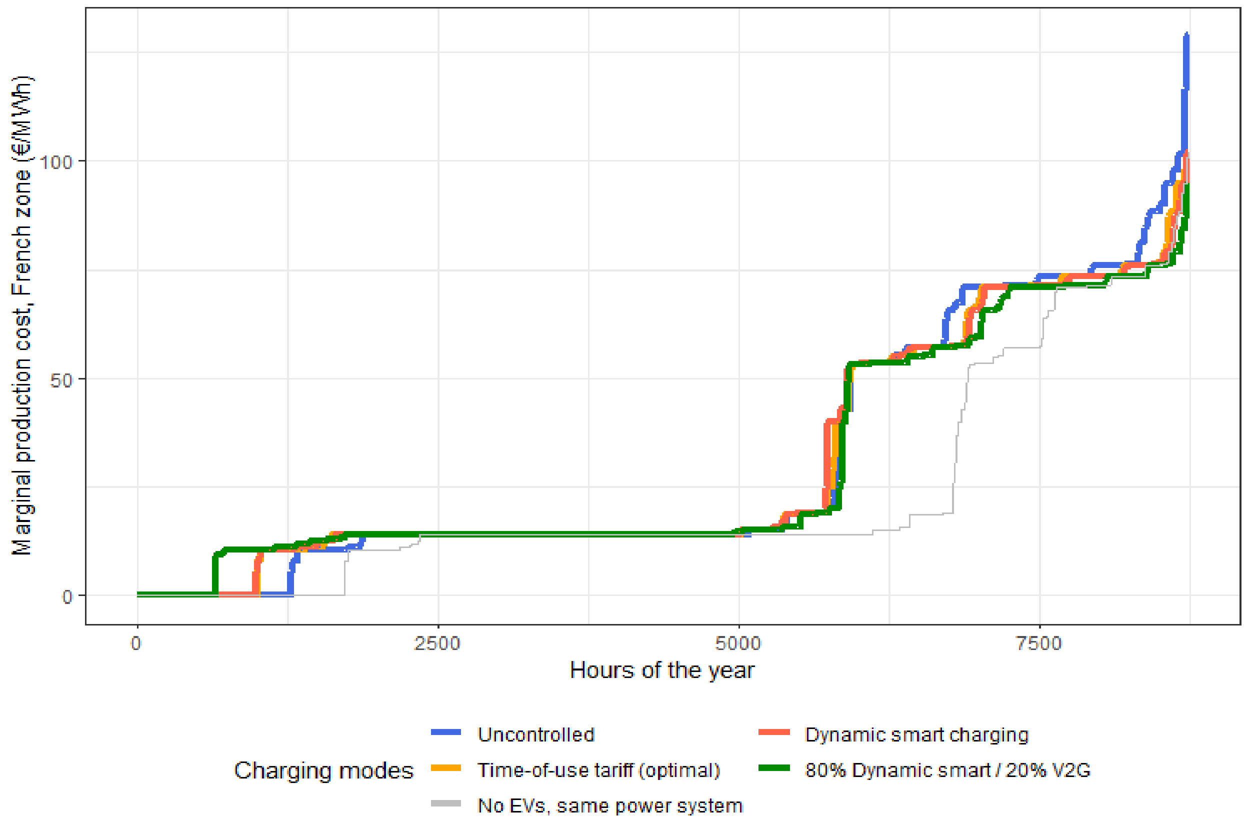
Comparison of charging modes introduced



Comparative flexibility benefits of charging modes studied (from the point of view of the electricity system)

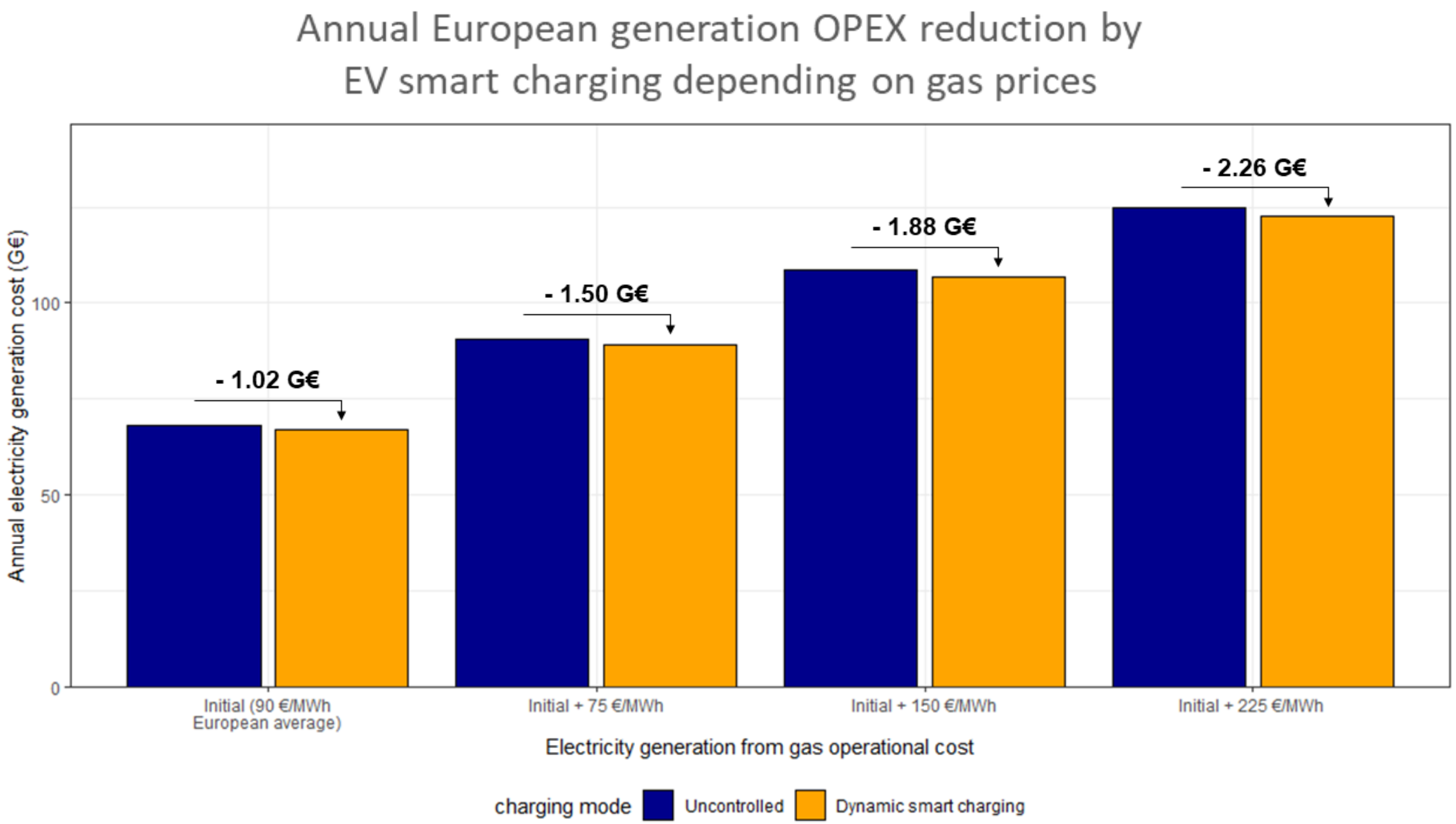
To go further : compare with infrastructure costs (bidirectionnal chargers, communication devices), and simulation where these charging modes coexist.

Marginal production costs depending on charging scenario



Higher EV flexibility reduces the frequency of zero/negative price hours and reduces the marginal cost at peak residual demand

Result sensitivity to higher gas prices



The results are **very sensitive** to the gas price considered in the study, and the higher the gas price, the more beneficial smart charging is for the electrical system

Recap of major parameters that influence EV flexibility

Sensitivity studies	Higher EV flexibility →	Impacts on EV demand flexibility
Gas prices / Electricity generation mix	Low gas prices Low flexibility cost cost … High gas cost High flexibility	**Very high**
Smart charging diffusion	0% … ✖ ~ 37% … 100% EVs	**High**
Smart charging modes	None Time-of-use ~ 75% Smart unidirectionnal ~ 25% V2G < 0,1%	**Incremental** on charging modes

✖

~ 75% BEV ✖ ~ 25% BEV

✖

✖ EV flexibility in France in 2021 (source BVA / Enedis)

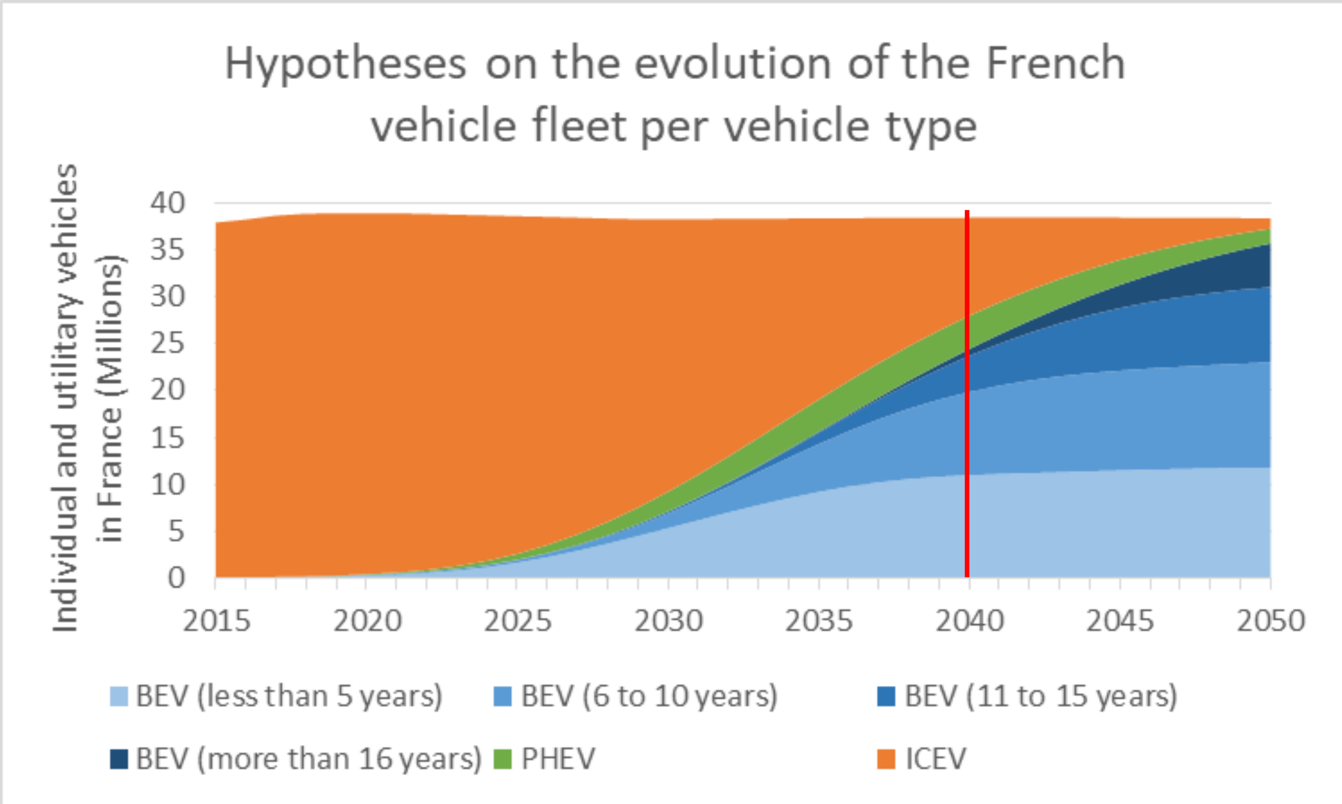
Key take aways on EV demand flexibility in prospective studies

- A methodology that **models sequentially the mobility and power generation** sectors has been introduced to study the interaction between them.
- Our optimization preferentially charges EVs in the **middle of the day** (10:00 - 15:00), which encourages the deployment of charging stations at the workplace and connection of the vehicles in this time window.
- This study is conducted by optimizing EV charge from the point of view of **supply-demand adequacy at the price zone level** with perfect foresight, and whose results are therefore to be supplemented on the local/network aspects.
- EV demand flexibility on a **weekly rather than daily basis** allows a significant gain, but its acceptability needs to be tested (not included in acceptability surveys in the literature), and requires a high battery size, as well as a frequent connection.
- **Several charging modes** show increasing electricity generation cost reduction, that are to be developped according to user acceptance.

Thank you for your attention

Input: prospective EV development in France

- Hypotheses in line with RTE studies (on EV development and 2050 prospective scenarios)

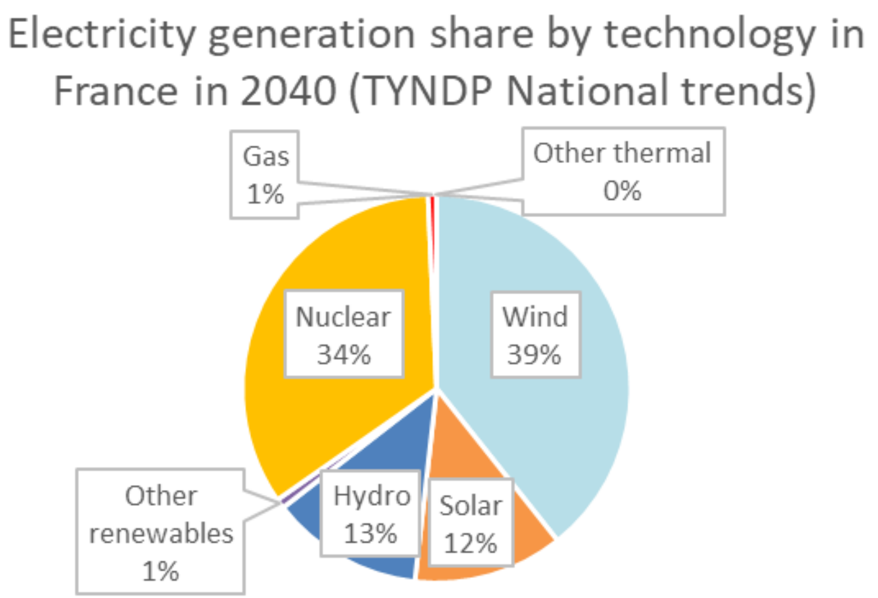


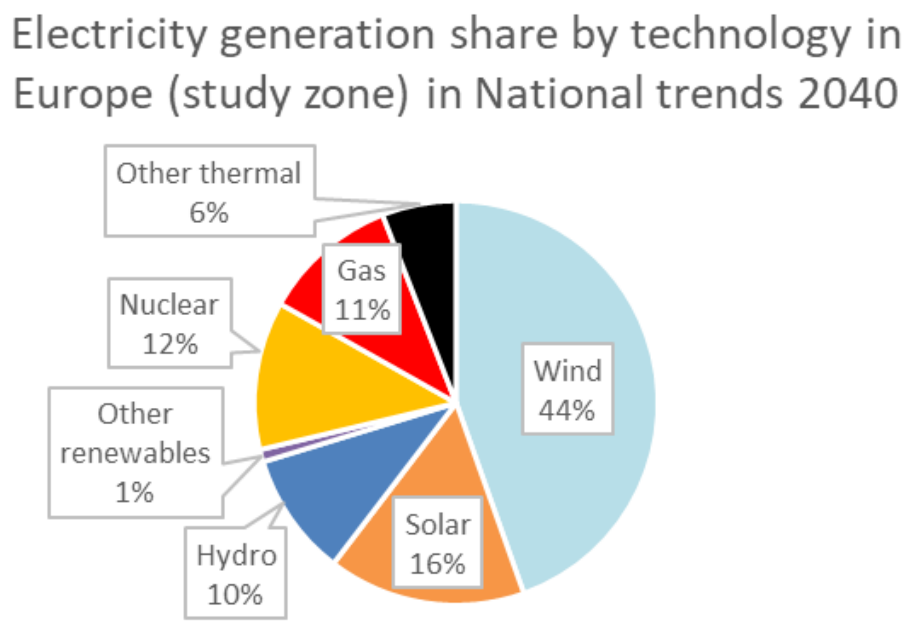
24,4 Million EVs at the 2040 time horizon (most optimistic EV development scenario)

BEV battery capacity	**78 kWh ± 20%**
PHEV battery capacity	15,6 kWh

Hypotheses on prospective electricity generation

- Based on ENTSO-E Ten Year Network Development Plan (2020) for electricity generation capacities and load data for each European country in the zone of study





- Also demand side flexibility in the model: **6 GW / 12 GWh** of stationary batteries (France)