Karlsruhe Institute of Technology

Simulating Electric Vehicle Diffusion and Charging Activities in France and Germany

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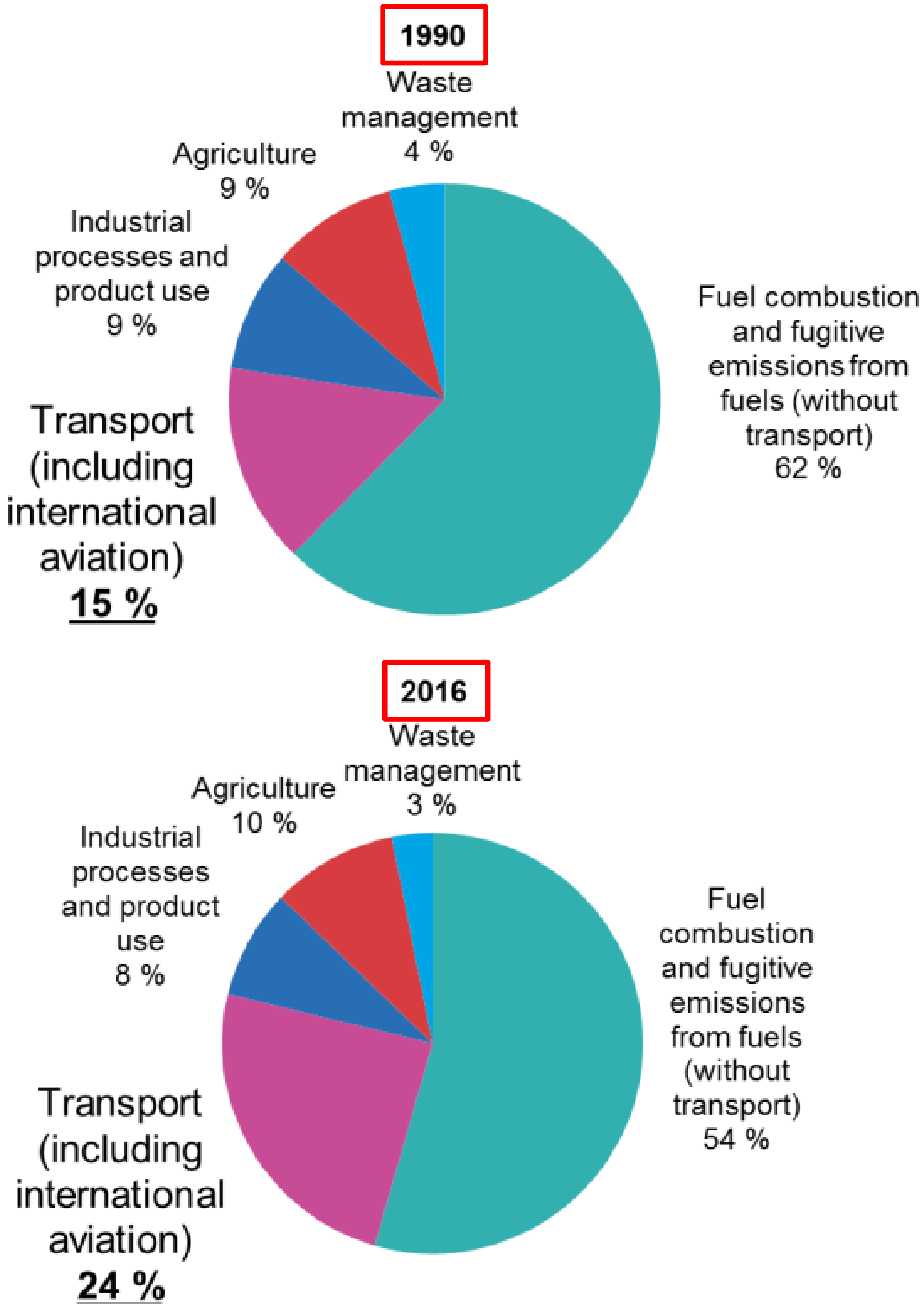
Motivation

- Greenhouse gas (GHG) emissions have an impact on the climate, with associated undesirable side effects (Stern, 2007).
- Consequence in Europe: Agreement on long-term targets to reduce GHG. → Reduction by 80% in 2050 compared to 1990 (European Commission 2019a).
- Growing share of GHG emissions in the transport sector during the last decade. → High need for emission reductions!
- Electrification of cars seems to be a promising strategy.

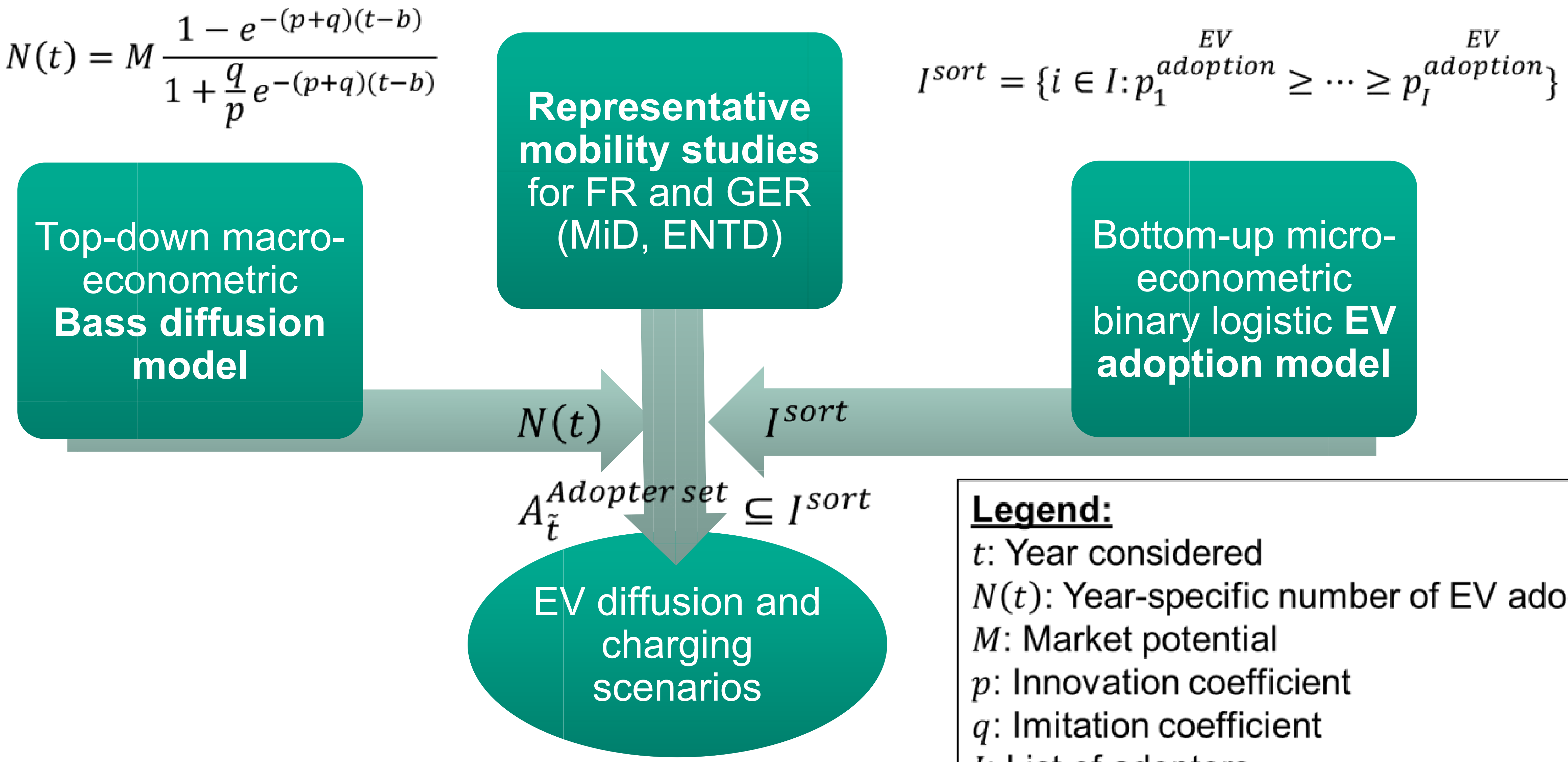


Source: European Commission (2019b)

Research questions

- Knowledge on EV diffusion and user behavior is important in order to analyze **potential future effects on power supply**.
- A large body of literature on electric vehicle (EV) diffusion models is available (e.g. Al-Alawi & Bradley 2013; Gnann & Plötz 2015; Jochem et al. 2018).
- **Hybrid approaches**, considering **micro** and **macro** aspects seem to be promising (Jochem et al. 2018).
- We focus on the following research questions (RQs):
  - RQ1: How could the diffusion and adoption of EV be modelled for France (FR) and Germany (GER)?
  - RQ2: With which EV charging behavior could these diffusion scenarios be associated?
  - RQ3: What are the effects of a re-sampling approach intending to reduce computational effort?

Hybrid EV diffusion modelling approach



How are EV adopters selected?

Method 1: $A_{\tilde{t}}^{Adopter\ set} \subseteq I^{sort}$

Method 2: $\hat{A}_{\tilde{t}}^{Adopter\ set} \subseteq \hat{I}_{\tilde{t}}^{sort}$

Legend:

t: Year considered
$N(t)$: Year-specific number of EV adopters
M: Market potential
p: Innovation coefficient
q: Imitation coefficient
I: List of adopters
I^{sort}: Sorted list of EV adopters (full sample)
$\hat{I}_{\tilde{t}}^{sort}$: Sorted list of EV adopters (reduced sample)
i: Variable of adopters
$p_i^{EV\ adoption}$: EV adoption probability of i
$A_{\tilde{t}}^{Adopter\ set}$: Selection of EV adopters

Pseudocodes of two different sampling methods

Pseudocode of sampling method 1

for all $\tilde{t}$ ***do***
    while $i \in I^{sort} \wedge W \leq N(\tilde{t})$
        Set $W = W + w_i$
        Add i to $A_{\tilde{t}}^{Adopter\ set}$
    end while
end for

- EV adopters with $p_i^{EV\ adoption}$ sufficiently high are considered in $A_{\tilde{t}}^{Adopter\ set}$.

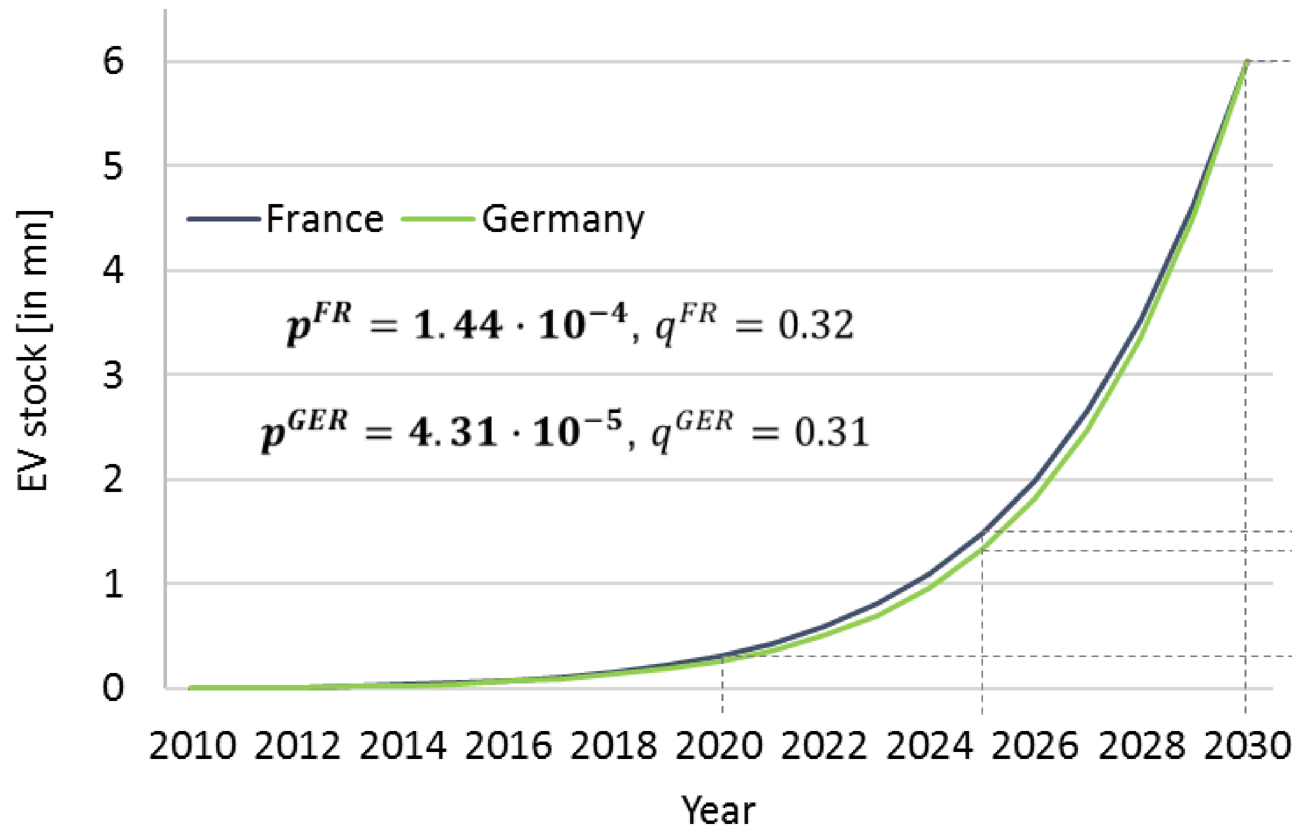
Legend:
$\tilde{t}$: Year considered
$w_i, \hat{w}_{\hat{\imath}}$: Weight of adopter $i, \hat{\imath}$
W: Cumulated weights
$\hat{I}_{\tilde{t}}^{sort}$: Sorted list of adopters (reduced sample)
k^{limit}: Sample size
$\hat{Q}^{\hat{A}_{\tilde{t}}^{Adopter\ set}}$: Cumulated energy consumption (reduced sample before scaling)
$\eta_{\tilde{t}}^{scaling}$: Scaling factor
$\hat{w}_{\hat{\imath}}$: Scaled weight of adopter $\hat{\imath}$

Pseudocode of sampling method 2

for all $\tilde{t}$ ***do***
    Set $\hat{I}_{\tilde{t}}^{sort} = \{I^{sort} \mid i \bmod z_{\tilde{t}} = 0\}$ with $z_{\tilde{t}} = nint\left(\frac{W^{A_{\tilde{t}}^{Adopter\ set}}}{k^{limit}}\right)$
    while $\hat{\imath} \in \hat{I}_{\tilde{t}}^{sort} \wedge \hat{\imath} \leq k^{limit}$
        Set $\hat{Q}^{\hat{A}_{\tilde{t}}^{Adopter\ set}} = \hat{Q}^{\hat{A}_{\tilde{t}}^{Adopter\ set}} + q_{\hat{\imath}}$
        Add $\hat{\imath}$ to $\hat{A}_{\tilde{t}}^{Adopter\ set}$
    end while
    while $\hat{\imath} \in \hat{A}_{\tilde{t}}^{Adopter\ set}$
        Set $\hat{w}_{\hat{\imath}} = w_{\hat{\imath}} \cdot \eta_{\tilde{t}}^{scaling}$ with $\eta_{\tilde{t}}^{scaling} = \frac{Q^{A_{\tilde{t}}^{Adopter\ set}}}{\hat{Q}^{\hat{A}_{\tilde{t}}^{Adopter\ set}}}$
    end while
end for

- k^{limit} is set prior to simulation.
- Selection of EV adopters ($\hat{A}_{\tilde{t}}^{Adopter\ set}$).
- Adopter specific weighting factors $\hat{w}_{\hat{\imath}}$ are scaled with $\eta_{\tilde{t}}^{scaling}$ to adequately

Results (RQ1)



Year 2030:
Original sample: 5115 (FR) , 4864 (GER)
Reduced sample: 1000 (FR & GER)
$\eta^{scaling}_{2030,FR} = 5.0692$, $\eta^{scaling}_{2030,GER} = 4.3177$

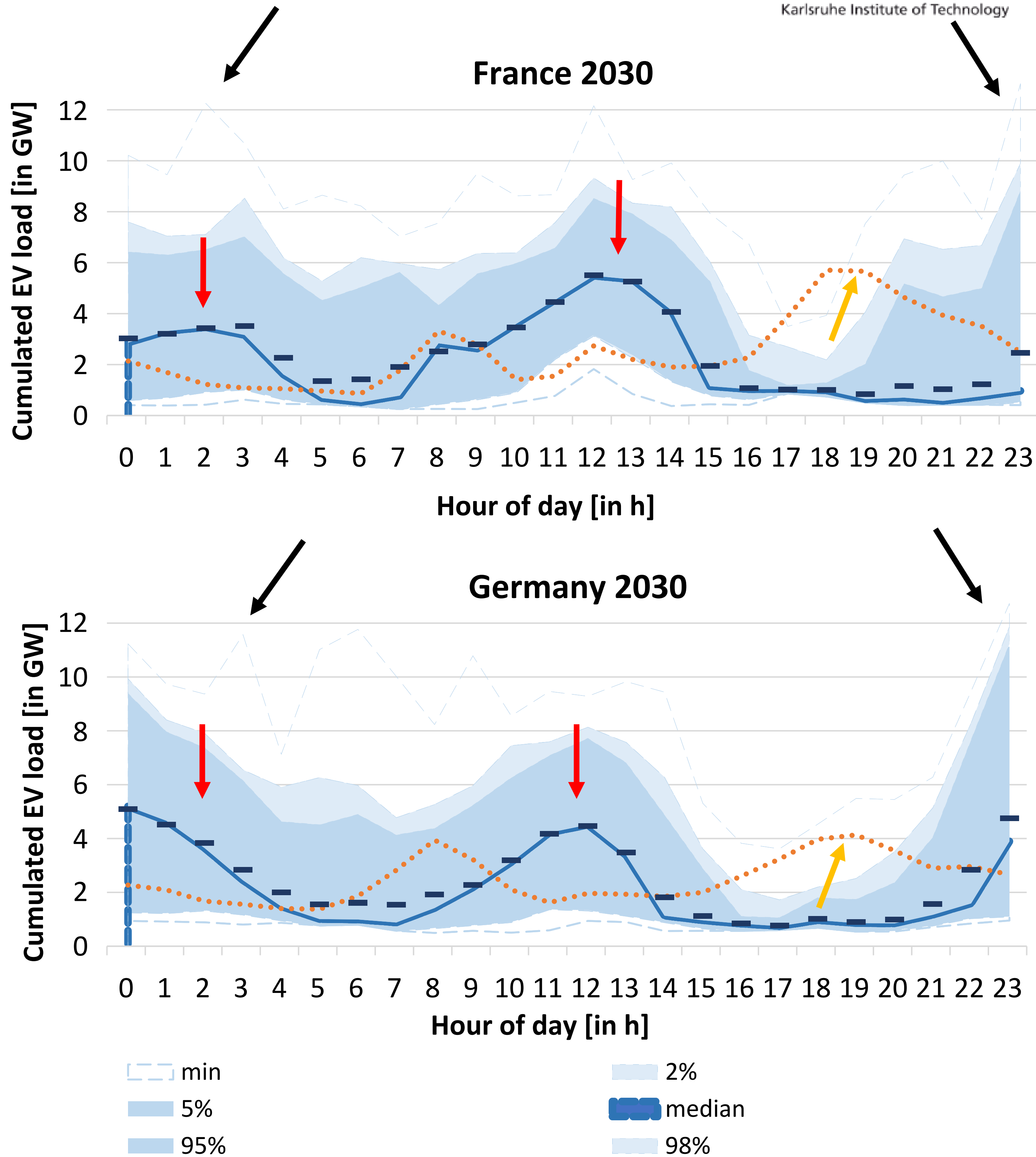
Year 2025:
Original sample: 1396 (FR), 1133 (GER)
Reduced sample: 1000 (FR & GER)
$\eta^{scaling}_{2025,FR} = 1.7431$, $\eta^{scaling}_{2025,GER} = 1.1817$

Year 2020:
Original sample ≙ Reduced sample:
356 (FR), 243 (GER)
$\eta^{scaling}_{2020,FR} = 1$; $\eta^{scaling}_{2020,GER} = 1$

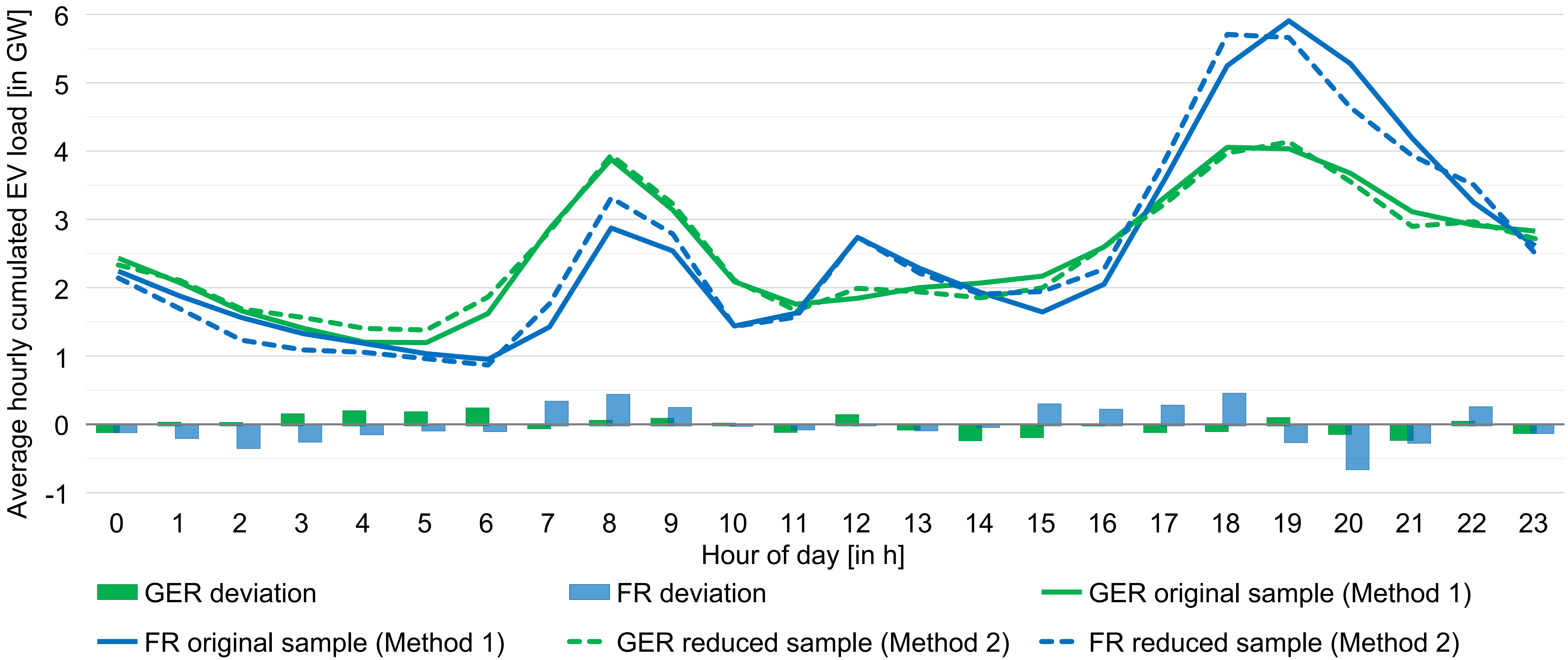
- Assuming 6 million EV in 2030 (Bourbon, 2018; Bundesregierung 2011), diffusion curves look similar.
- However, Bass diffusion model parameters (i.e. innovation coefficients p^{FR} and p^{GER}) indicate higher diffusion dynamics in France than in Germany.
- In early years $\tilde{t}$ all EV adopters in the sample are considered when using method 2 (i.e. $A^{Adopter\ set}_{\tilde{t}} = \hat{A}^{Adopter\ set}_{\tilde{t}}$). Limiting the number of adopters to

Results (RQ2)

- Cumulated specific load curve of direct EV charging and distributions when flexibly charging.
- Distributions of charging profiles in France and German look similar.
  - Load peaks of ~12 GW.
  - EV specific loads are on average shifted into nighttime and noon hours due to lower day-ahead market prices in these hours
- However, evening peaks when directly charging seem to be about 50% higher in France.



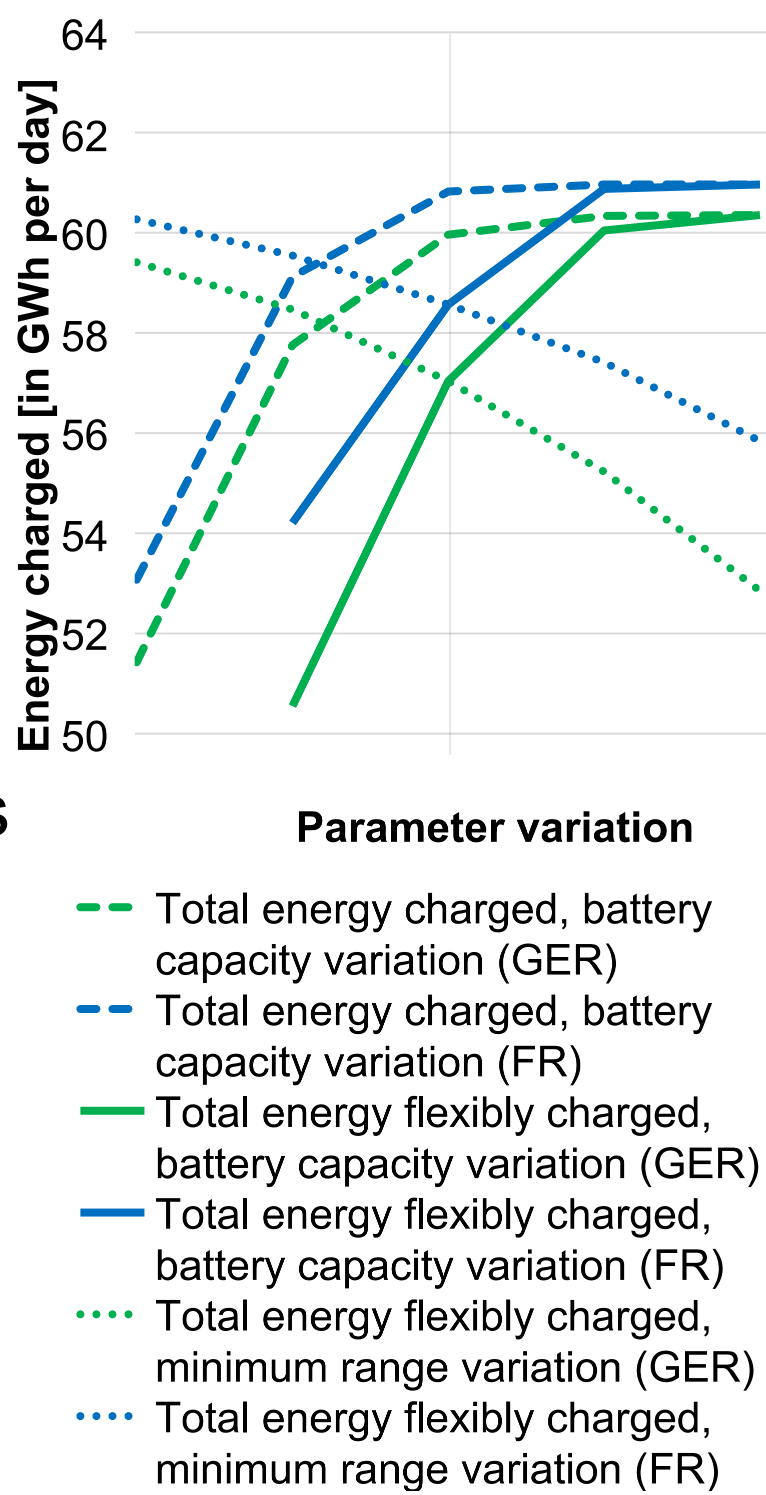
Results (RQ3)

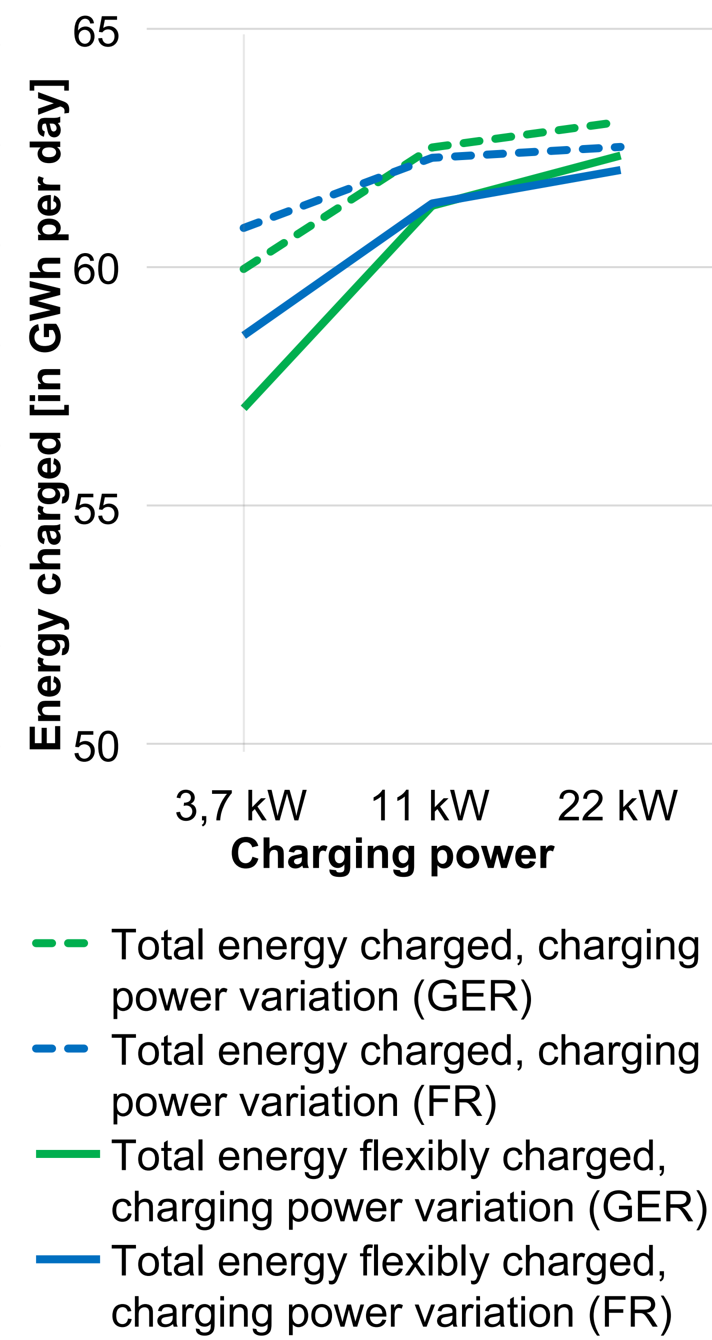


- Slight differences of energy consumption distributions between the two sampling methods are observable.
- Weighting approach assures that total energy needed remains constant.
- Reducing sample sizes (method 2) results in computing time savings of about 85 % in 2030.

Sensitivity analyses

- Similar for FR & GER.
- Full electric mileage increases with increasing battery capacities. A certain level of saturation seems to be reached at 300 km.
- Total energy flexibly charged increases with increasing battery capacities and decreases with increasing minimum range requirements.
- Total energy charged and flexibly charged increase with increasing charging power.





Assumption base case:
300 km range (60 kWh)
3.7 kW maximal charging power
Consumption: 0.2 kWh/km

Conclusion and outlook

- Hybrid EV diffusion modelling approach combines
  - Top-down **Bass diffusion model**
  - Bottom-up **binary logistic EV adoption** model
  - Sampling approach identifies potential EV adopters in representative mobility studies.

- **Flexible charging demand distributions are similar** for FR & GER.
- When direct EV charging is simulated, according to our results …
  - … higher evening peaks can be observed in France.
  - … charging seems to be distributed more evenly over the course of a day in Germany.

- Re-sampling approach results in **significant reductions of computing time**.
- This opens **new possibilities of considering EV on a disaggregated level in energy system modelling**.

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EVS32 INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

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