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Integrating Agent-Based Electric Car Simulation in Energy System Optimization – Potential Impact of Controlled Charging and Vehicle-to-Grid on Germany's Future Power System

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Research Gaps and Research Question

Model-based assessment of EV load shifting and V2G within Germany's future power system

Research gaps in existing literature

1. Luca de Tena & Pregger (2018), Hanemann et al. (2017), Loisel et al. (2014) used energy system optimization modeling to analyze full potential of EV charging flexibility in but assumed future power system capacities as given.

2. Sterchele et al. (2020) optimized dispatch and installed capacities in the *REMod* model, but only considered charging at home and up to 40 % flexible charging.

3. Bernath et al. (2021) considered controlled charging as flexibility option within the *Enertile* energy system optimization model, but allowed charging optimization only over time horizon of 24 hours.

Research question

How can load shifting through controlled electric car charging and V2G impact the future expansion and utilization of generation, storage, and transmission capacities in the German power system?

Focus on full flexibility potentials of electric cars

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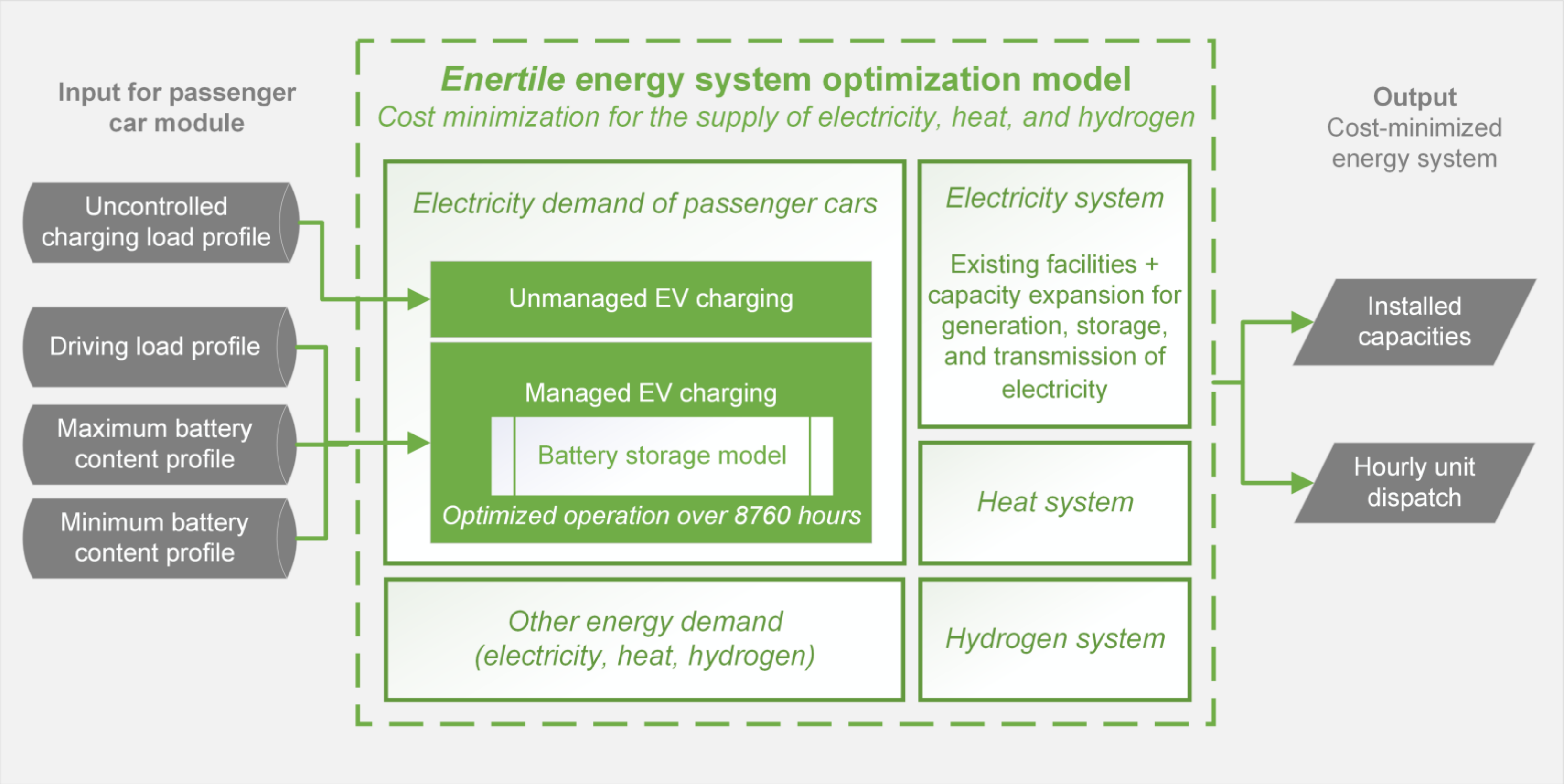
Methodology: Energy system optimization

Enertile minimizes costs of generation, transmission, and storage of energy in Europe

- Based on demand for **electricity, heat, and hydrogen**, *Enertile* optimizes both the **hourly dispatch** of all **system components** and the **investments** in the modeled **infrastructures** in **Europe until 2050**

- Modeling of electric passenger cars:
  - ***Unmanaged EV charging***: fixed load profile is given
  - ***Managed EV charging***: Battery model (representing the entire car stock in a region) optimizes the (dis)charging load acc. to system needs
    - *given*: consumption from driving, storage restrictions
    - *to be optimized*: hourly distributed inflow through EV charging, outflow through V2G



https://enertile.eu/

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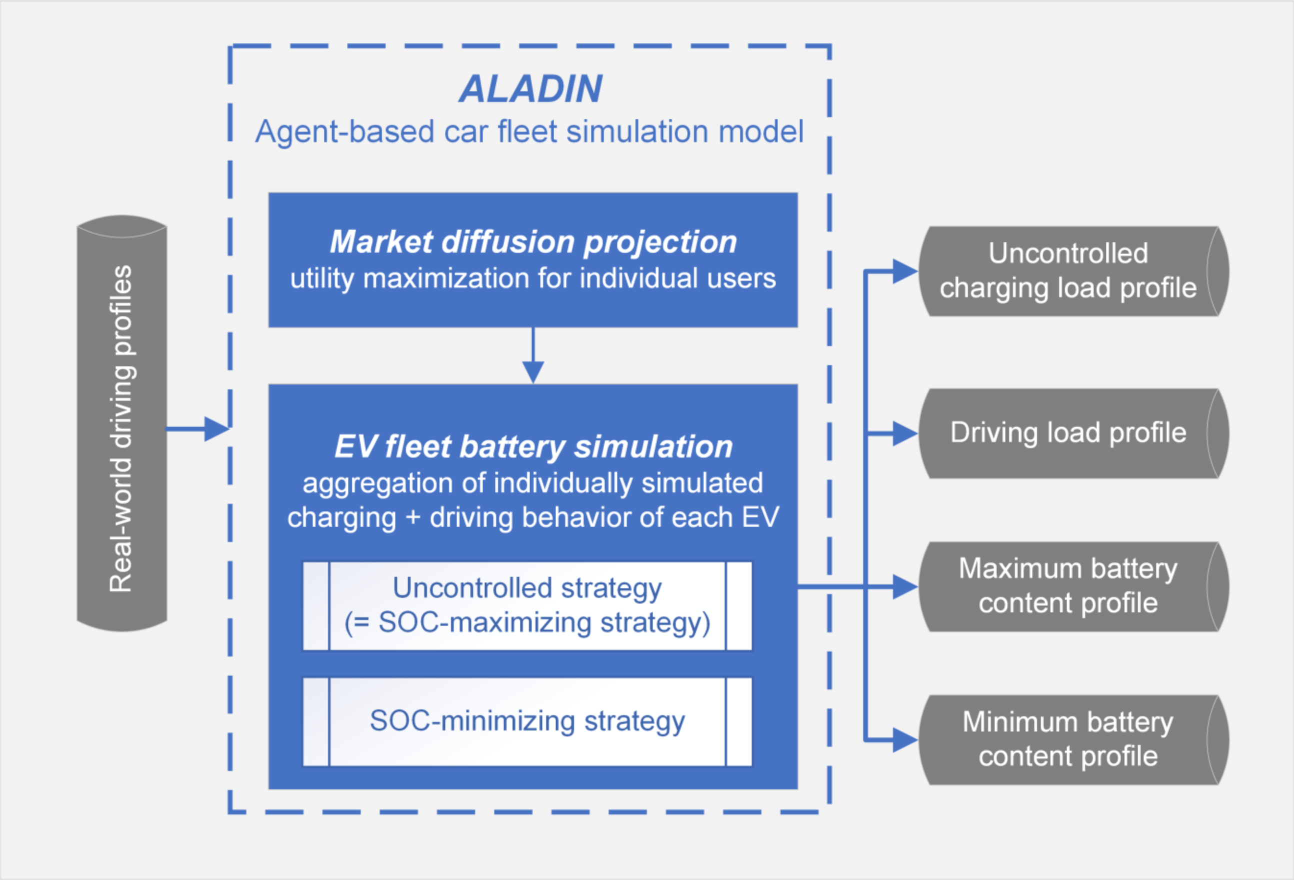
Methodology: Agent-based EV simulation

ALADIN projects future car stock and simulates its charging behavior

- ALADIN projects annual **car registrations** and **stock** in Germany until 2050 based on the **utility-maximizing drive choice** from **6 technology options** (BEV, PHEV, FCEV, Diesel, Gasoline, CNG)
- **Individual car users** are represented by **real-world driving profiles** from traffic surveys
- **Battery simulation** of individual BEVs and PHEVs in the stock
  - Uncontrolled / SOC-maximizing charging strategy
  - SOC-minimizing charging strategy
  - Charging options at home + workplace, depending on year
- **Aggregation** of individual simulations results in 4 time series describing the behavior of the entire German EV stock
  - *Driving profile*
  - *Uncontrolled charging load profile*
  - *Maximum battery content profile*
  - *Minimum battery content profile*



https://aladin-model.eu/

Methodology: Overview of model coupling

Integration of agent-based EV simulation results in energy system optimization

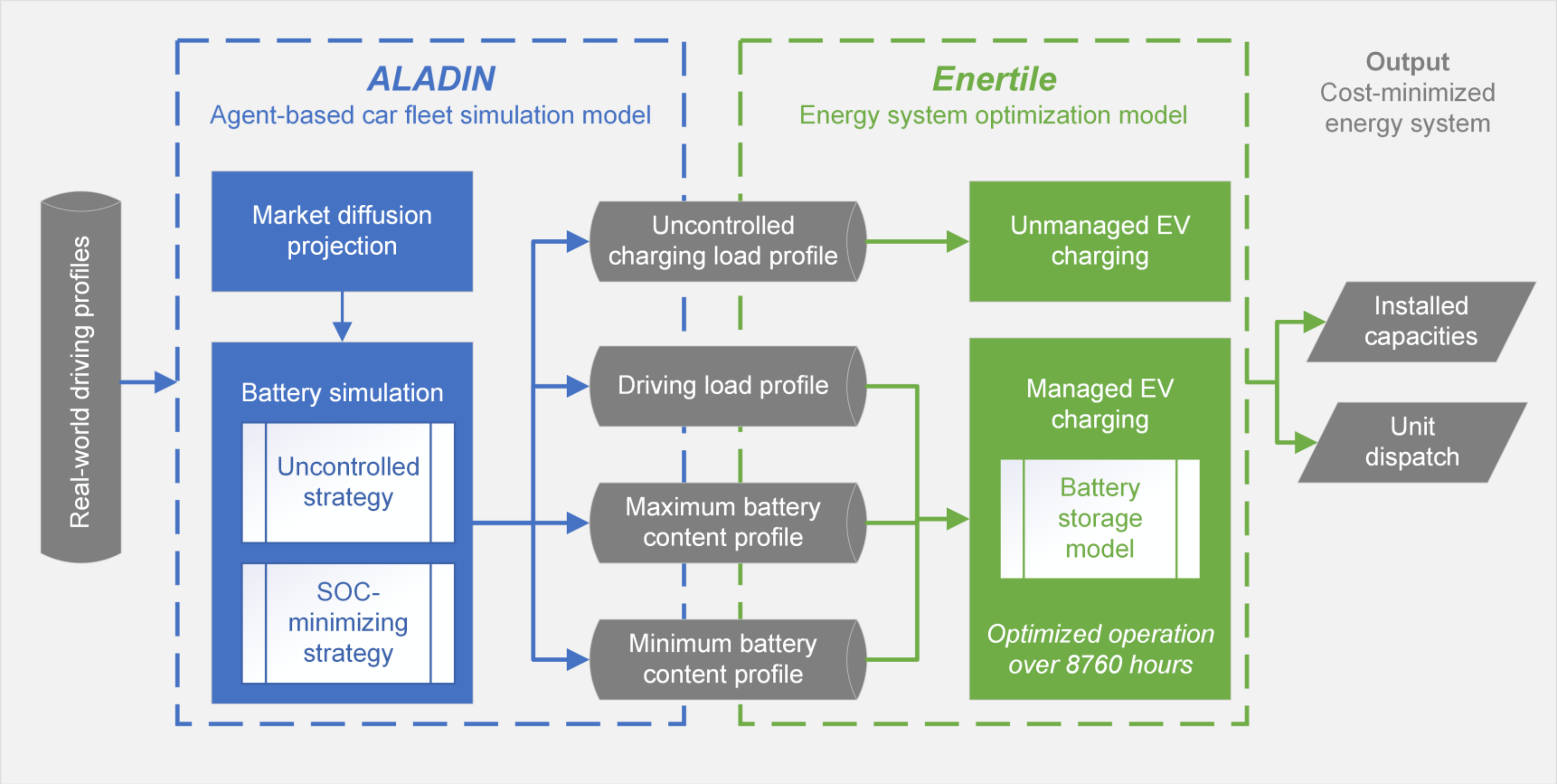
Scenario-based study using the established model coupling

Comparison of 3 scenarios

- ***Uncontrolled***: 100% unmanaged cars
- ***Controlled***: 100% managed cars
  - only DSM, no V2G
  - car batteries are flexible consumers
- ***V2G***: 100% managed cars
  - DSM + V2G
  - car batteries used as storage acc. to system needs

Scope of analysis

- Germany
- 2030, 2045
- Electricity system



https://aladin-model.eu/
https://enertile.eu/

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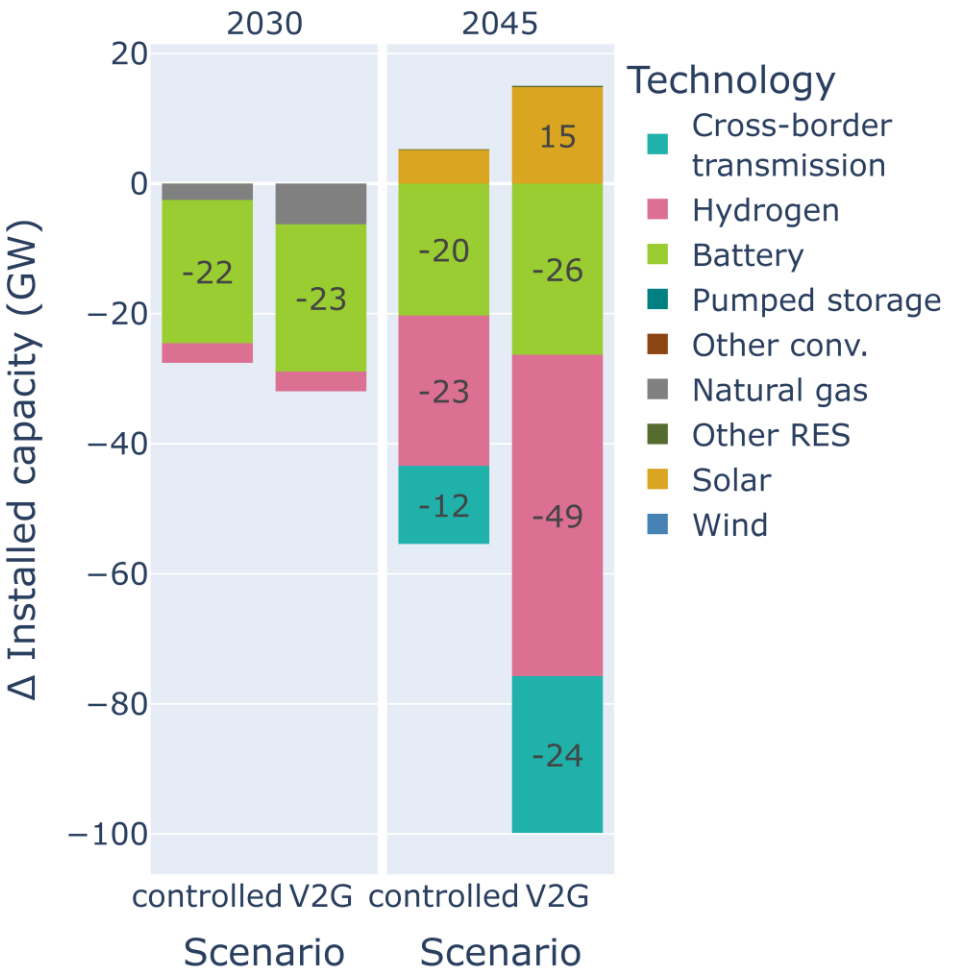
Results: Installed generation, storage, and transmission capacities

If EV flexibility is leveraged, less power system infrastructures needs to be built up in the coming years

Differences in installed power system capacities compared to *uncontrolled* scenario:

- **Reduced** need for **stationary battery storages**
- **Reduction** in **thermal peak power plants**
  - Gas-fired capacity is phased out earlier
  - Less hydrogen-fired generation capacity is built up
- Further **expansion** of **PV systems** after 2030
- **Reduced** cross-border **transmission grid** expansion after 2030

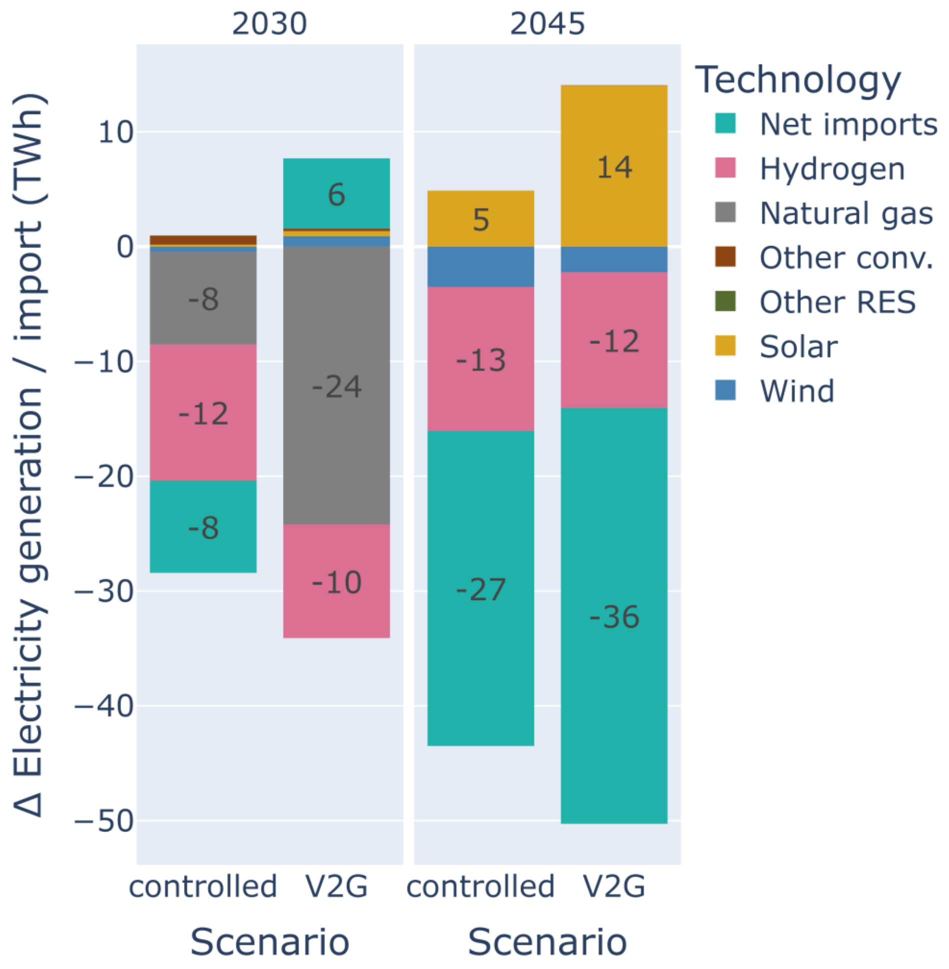


Results: Electricity generation and net imports

Controlled EV charging reduces power generation from gaseous fuels and imports

Differences in annual generation compared to *uncontrolled* scenario

- **Reduction** in generated electricity from **natural gas** and **hydrogen**
- **Reduced net imports** in 2045
- **Increase** in **solar power** generation in 2045
- Slight decrease in wind power generation due to wind turbines located further south

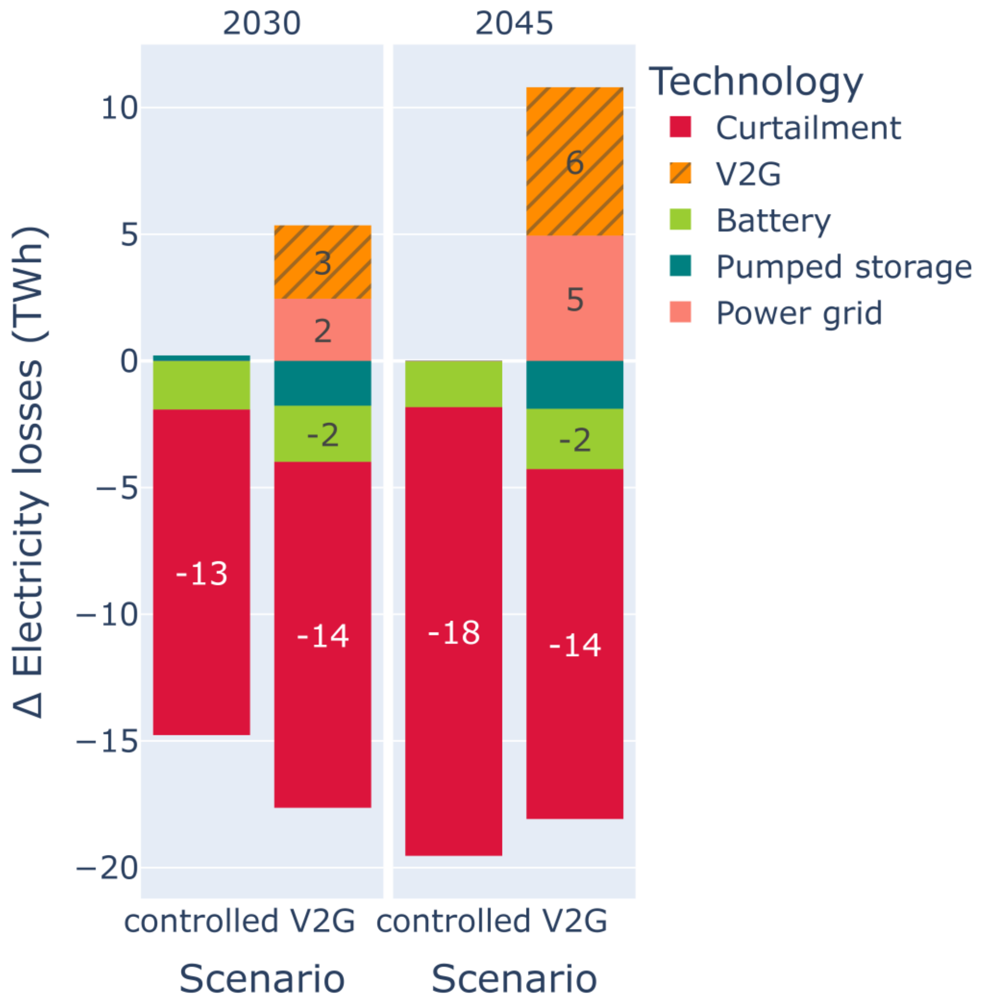


Results: System losses

Load shifting reduces RES curtailment and storage losses

Differences in system losses compared to *uncontrolled* scenario

- Loads are shifted to times of surplus electricity generation – **curtailment** is **reduced** substantially.
- If **charging** is **controlled**, less energy is stored in stationary batteries and hence **storage losses** are **reduced**.
- If **V2G** is enabled, car batteries replace stationary batteries and pumped-storage hydroelectricity but cause its own **storage losses and distribution grid losses.**



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Conclusions

Key findings

With their demand-side flexibility, electric cars can help integrate renewable energy and reduce the need for capacity expansions during the energy transition.

V2G reinforces the positive effects of controlled EV charging on the power system and leads to further system cost savings.

1. Load is shifted in times of surplus generation – RES **curtailment** is **reduced by ~60%.**
2. The expansion of **stationary battery storage** systems can be **halved**.
3. The need for peak power **generation from gaseous fuels** is **reduced** - Natural gas power plants can be phased out earlier and less hydrogen power plants need to be built.
4. <u>In the long term:</u> A slight increase in **PV capacity expansion** (and hence solar power generation) as well as a **decrease in transmission grid expansion** (and hence net imports).

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Thank you for your attention!

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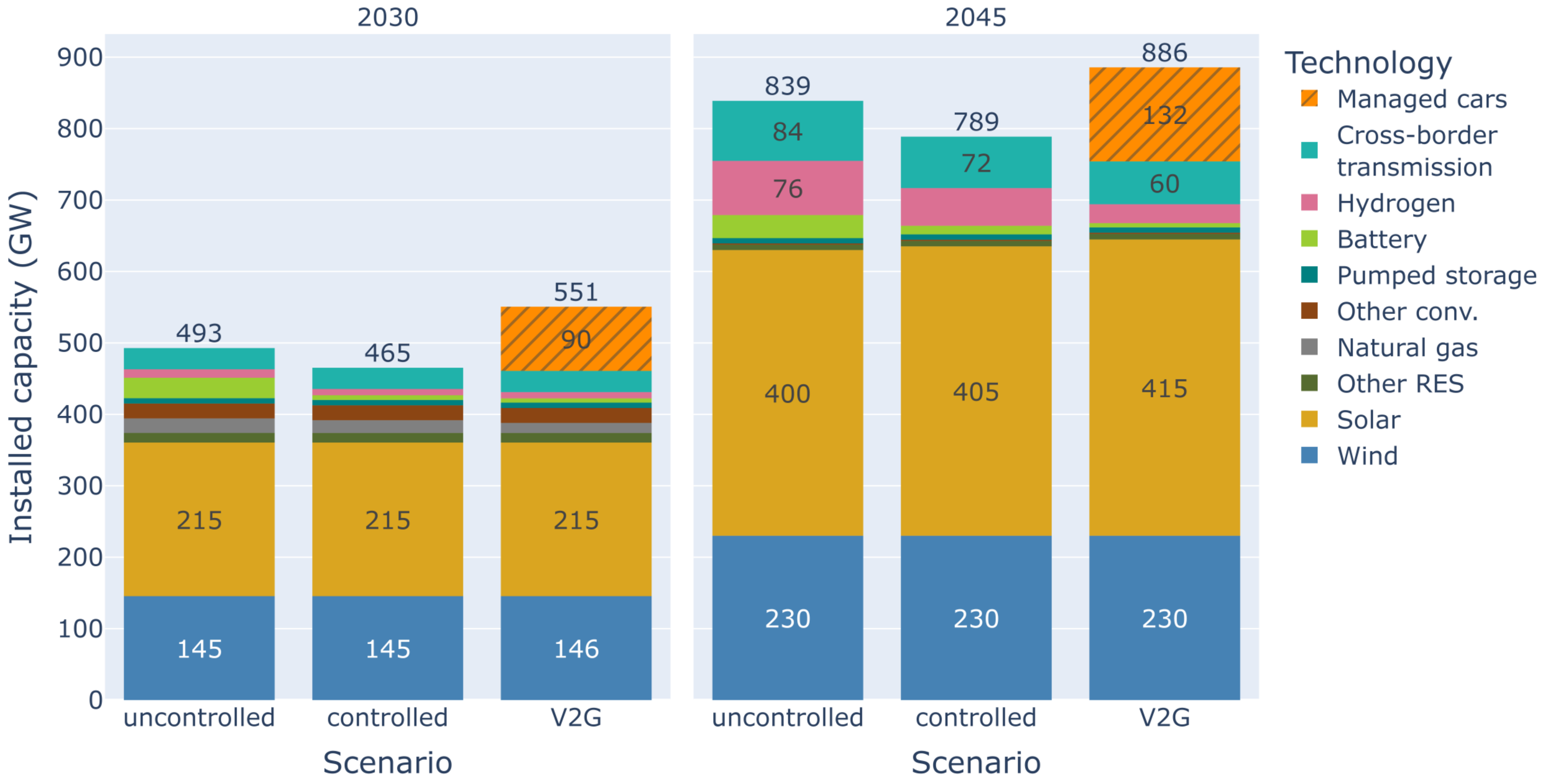
Results: Installed generation, storage, and transmission capacities



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Results: Electricity generation, net imports, and system losses