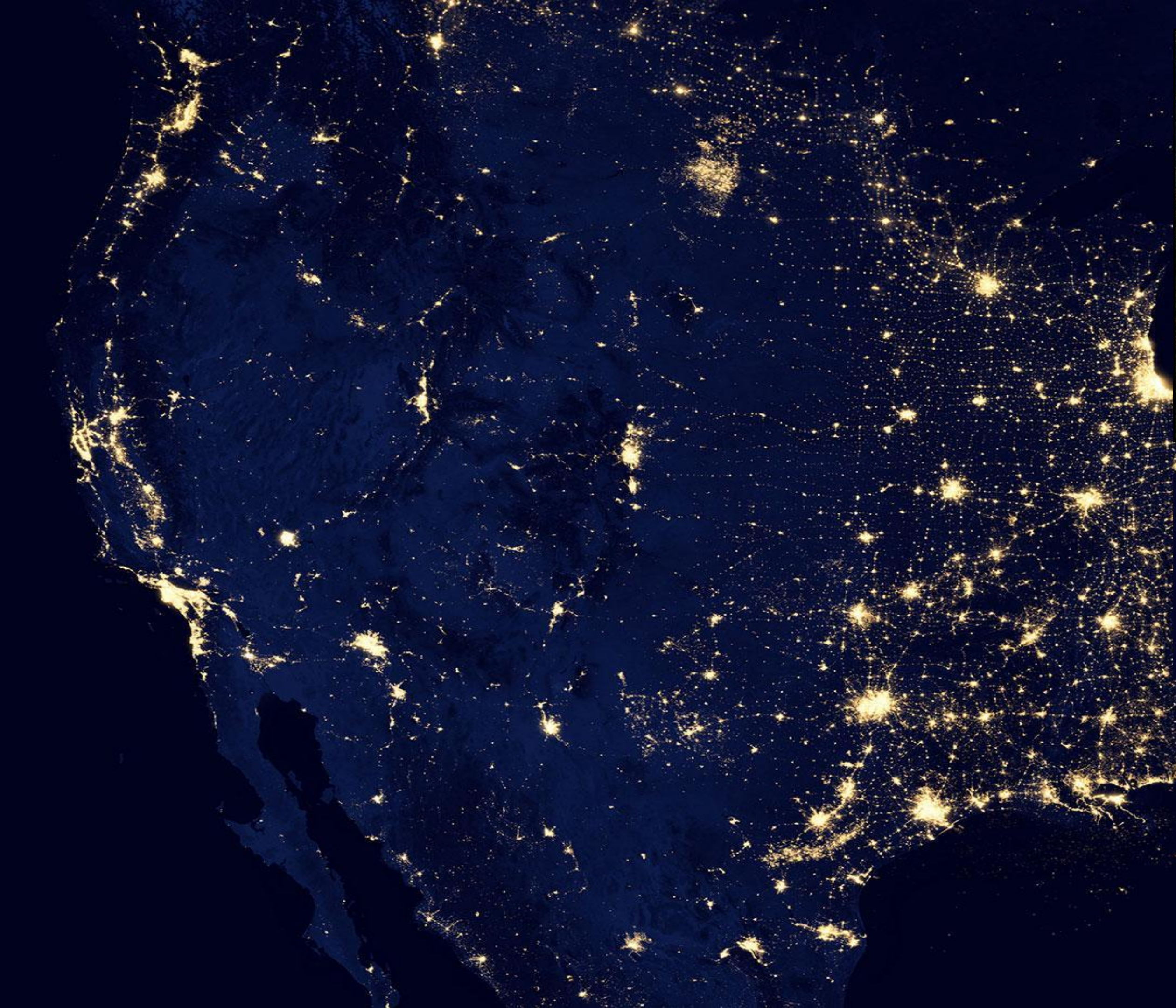
Controlling stationary and mobile batteries

Omid Ardakanian
Assistant Professor

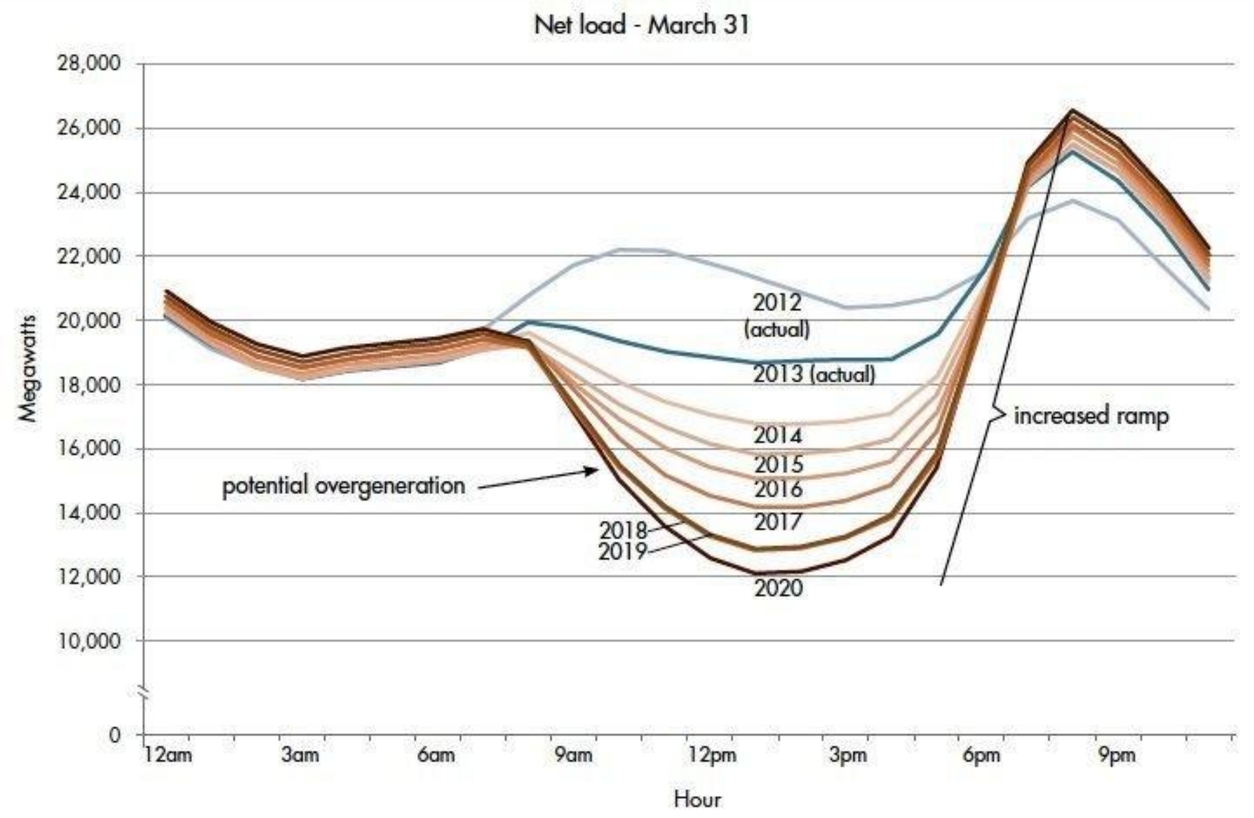
Department of Computing Science
University of Alberta



95% of utility-scale energy storage capacity in the US

550 GWh in total

MORE STORAGE CAPACITY IS NEEDED
Renewable integration is a mixed blessing!



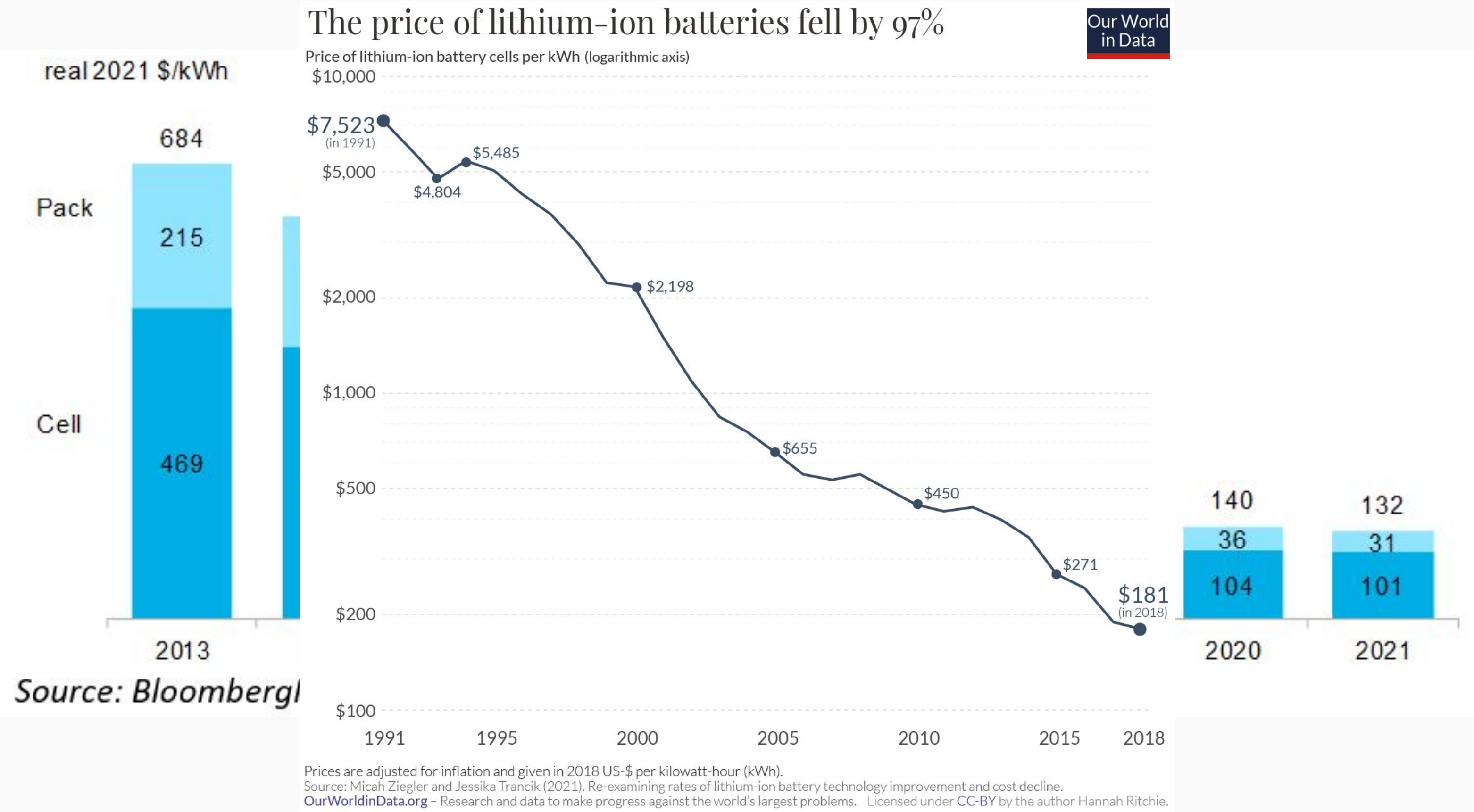
EVEN MORE STORAGE CAPACITY WILL BE NEED IN FUTURE

Extreme weather events are becoming more frequent

The years 2013–2021 all rank among the ten warmest years on record!

Photo by Hans Gutknecht/MediaNews Group/Los Angeles Daily News via Getty Images

Price of lithium-ion battery pack has dropped by 97% since it was first commercially introduced in 1991



DISTRIBUTED ENERGY STORAGE

Stationary and mobile batteries

Image: Tesla Gigafactory in Shanghai

14 kWh

40 - 100 kWh

Can we aggregate and coordinate a large number of “small batteries” to help the grid when it needs emergency support?

electrek

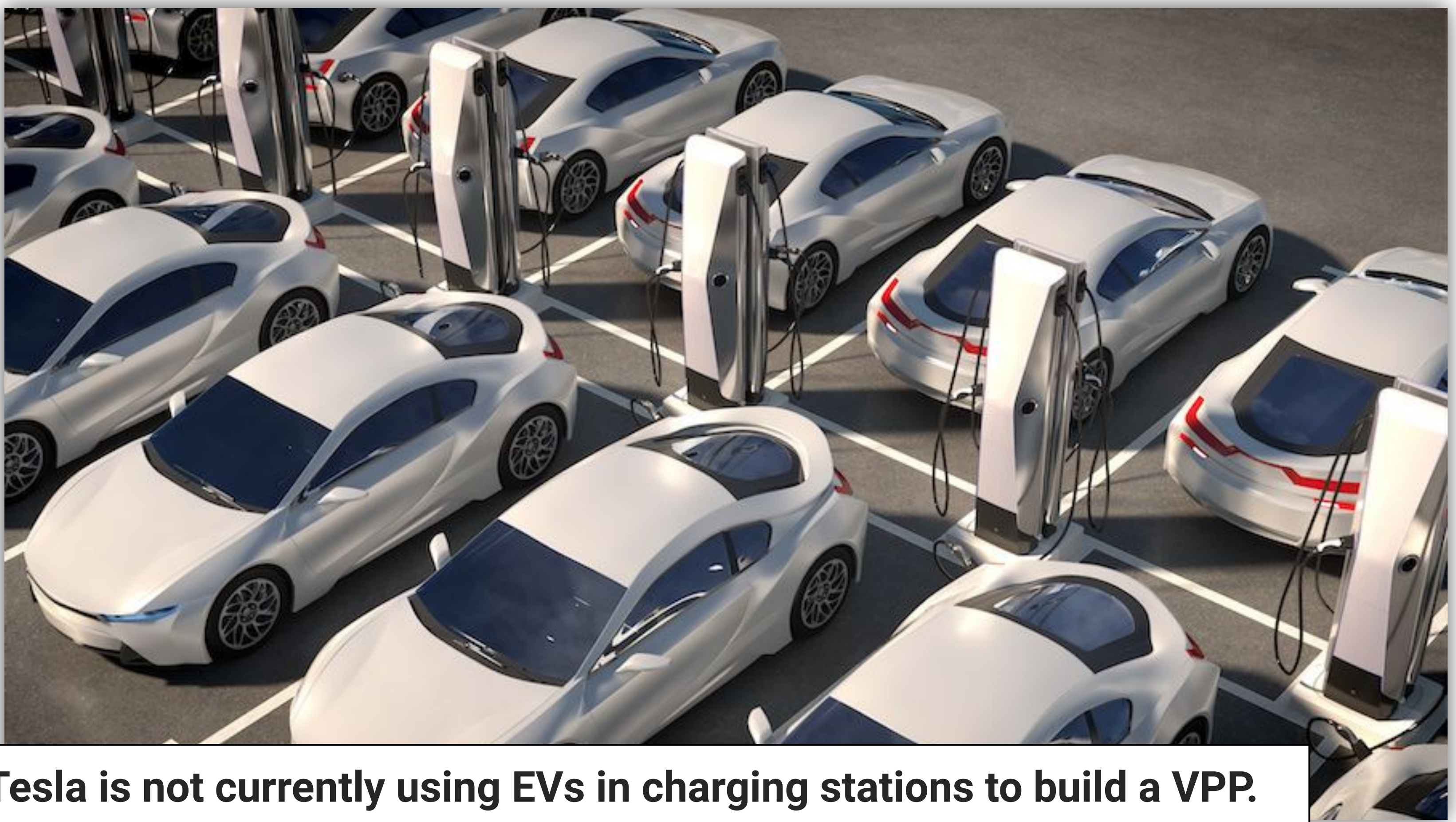
Tesla’s virtual power plant had its first event helping the grid – looks like the future

Fred Lambert | Aug 18 2022 — 2:58 am PT

Tesla Powerwall

vs.

How about a parking lot full of electric cars with bidirectional chargers?

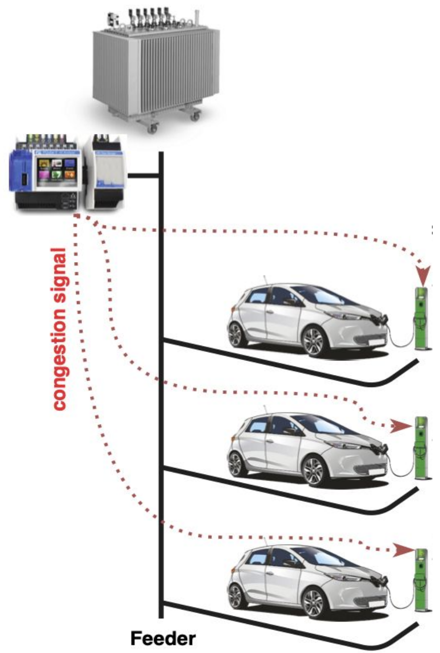


Tesla is not currently using EVs in charging stations to build a VPP.

CHALLENGES IN DESIGNING A VPP USING EV BATTERIES

Congestion control

- (Dis)charging a large number of EVs simultaneously in the same neighbourhood could cause transformer overloading and voltage limit violation problems



We designed a decentralized control algorithm to allocate the available capacity of the network (measured in real-time) to active EV chargers in a **fair** manner

CHALLENGES IN DESIGNING A VPP USING EV BATTERIES

Assuming EVs are owned by different individuals

They must be incentivized to participate in the VPP

- EV owners decide on how much energy can be withdrawn from their battery based on the perceived battery degradation cost (defining their type) and the payoff they receive in return

We designed a set of incentive-compatible contracts between VPP operator and EV owners, denoted $\{(e^1, p^1; \tau), \ldots, (e^M, p^M; \tau)\}$

CHALLENGES IN DESIGNING A VPP USING EV BATTERIES

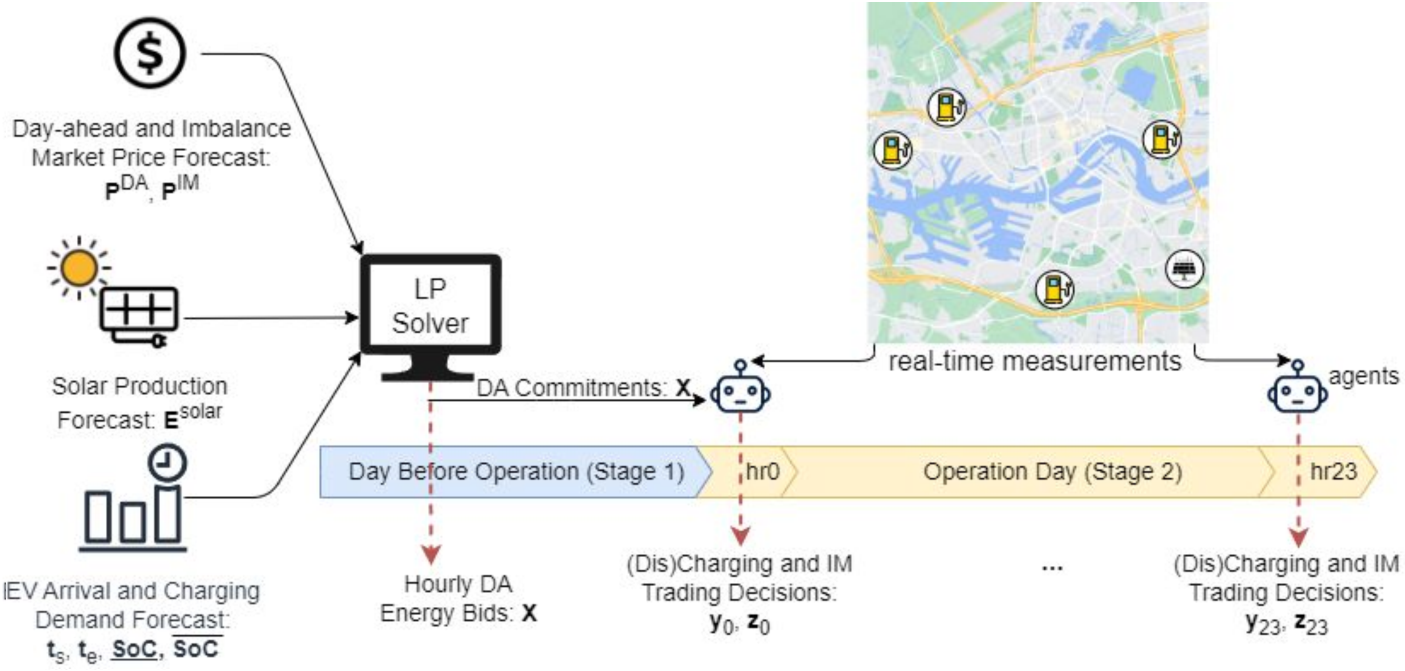
Assuming EV fleet is owned and operated by the VPP

- EV charging demand must be fulfilled before departure
- stochastic EV mobility, price volatility, and intermittency of renewable power make it difficult to accurately estimate the amount of flexibility that can be offered to the grid
- VPP may not be profitable

We designed profit-maximizing strategies for a VPP that
(a) aggregates a fleet of electric cars, bidirectional charging stations, and solar systems;
(b) operates in a two-stage electricity market;
(c) ensures charging demands are satisfied by user-specified deadlines.

PROFIT-MAXIMIZING VPP OPERATION

The 2-stage optimization for decision making under uncertainty and risk



PLACING ENERGY BIDS IN THE DAY-AHEAD MARKET

Wait-and-See method

- Create (more) sample paths by adding noise to expected values of
  - hourly solar generation
  - EV mobility traces
  - hourly price in day-ahead and imbalance electricity markets

- Solve for each forecast scenario

$$\underset{\mathbf{X},\,\mathbf{Y},\,\mathbf{Z},AC,AD}{\text{maximize}} \quad \mathbf{X}^\top \mathbf{P}^{DA} + \mathbf{Z}^\top \mathbf{P}^{IM}$$

subject to:

(1) Energy balance equation
(2) Constraint to separate EV charging and discharging
(3) EV charger-related constraints
(4) EV battery-related constraints

- Average of all forecast scenarios yields a bound on the optimal DA bids

HOW TO ENSURE FEASIBILITY OF THE EV CHARGING PROBLEM

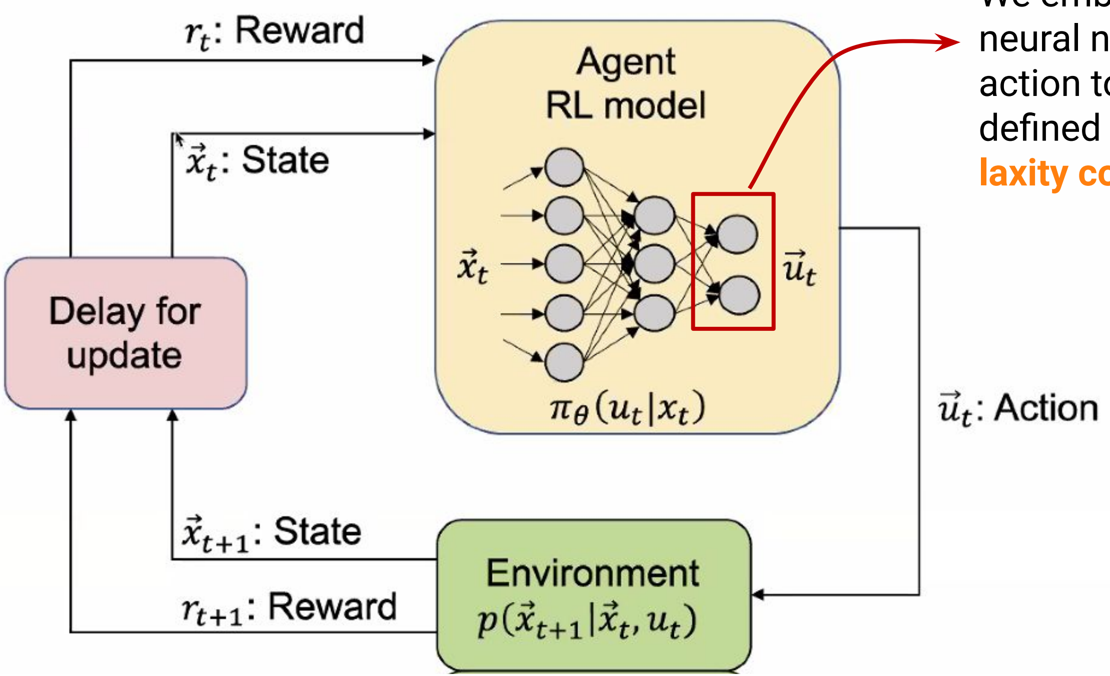
Laxity Lookahead Algorithm

- We use the notion of laxity
  - how long EV charging can be delayed while still being able to fulfill the charging demand if we charge at the maximum power
  - there exists *a* feasible charging schedule if laxity is non-negative

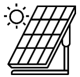
- Laxity Lookahead Algorithm (LLA): ensure feasibility under a certain action, calculate laxity in the next hour for this action
  - EV (dis)charged by some amount
  - carry out laxity lookahead; feasible if laxity will not be negative in the next hour

HOW TO ENSURE FEASIBILITY OF THE EV CHARGING PROBLEM

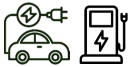
LA-SAC: Differentiable Projection Layer in the Policy Network



We embed a layer in the neural network to project the action to the feasible set defined by **non-negative laxity constraints**



Available solar power



Real-time EV charging info

Electricity market prices

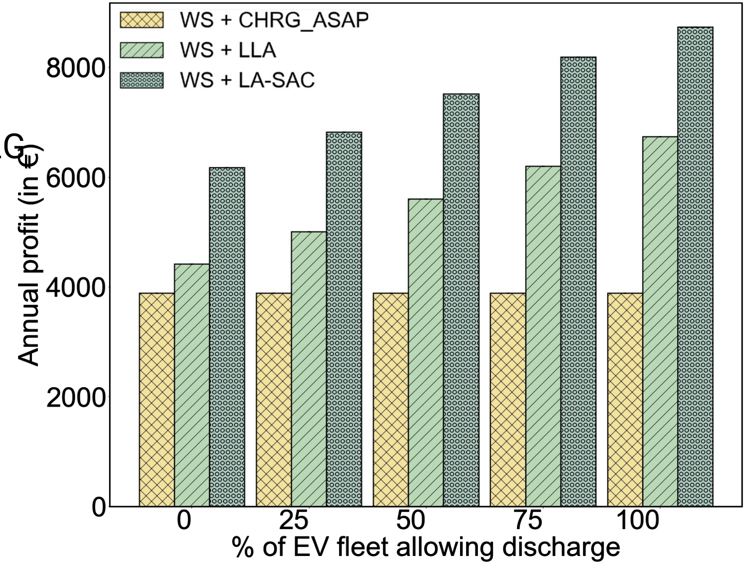
EVALUATION USING REAL DATA

- Datasets
  - Solcast API for solar data
  - ElaadNL for EV data
    (190 municipalities, >900 charging stations in the public domain)
  - TENNET for electricity market prices

RESULTS

How much profit can be made using different VPP operating strategies?

- €2,000-€4,500 increase in annual profit
- LA-SAC achieves
  - 59.6% of the OPTIMAL profit (no uncertainty) for 0% V2G
  - 51.4% of the OPTIMAL profit (no uncertainty) for 100% V2G
- V2G can increase the profit by up to 41.5%



TAKEAWAYS

- Battery-enabled virtual power plants could enhance power grid reliability
- People can offset the cost of charging their car battery by offering flexibility to the grid
- The proposed operating strategies show financial feasibility of this VPP
  - significant profit can be made even in the face of uncertainty!
  - EV charging demands are guaranteed to be satisfied

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