

Automating Storage Arbitrage In German Electricity Market

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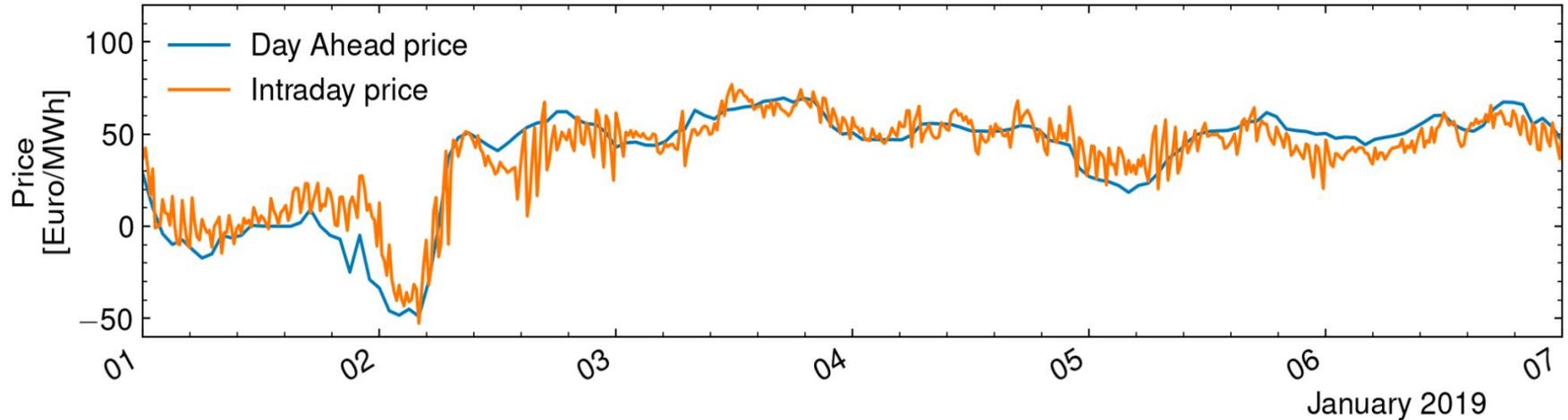


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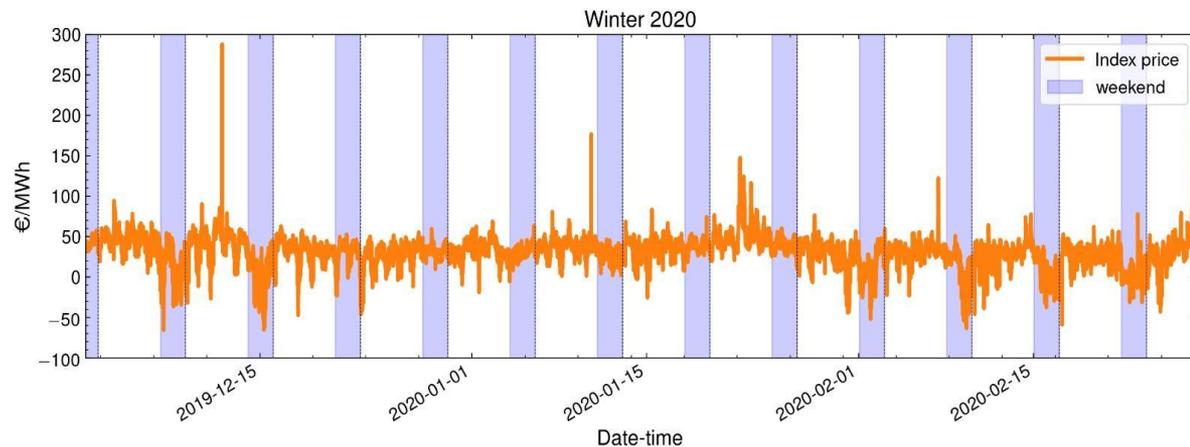
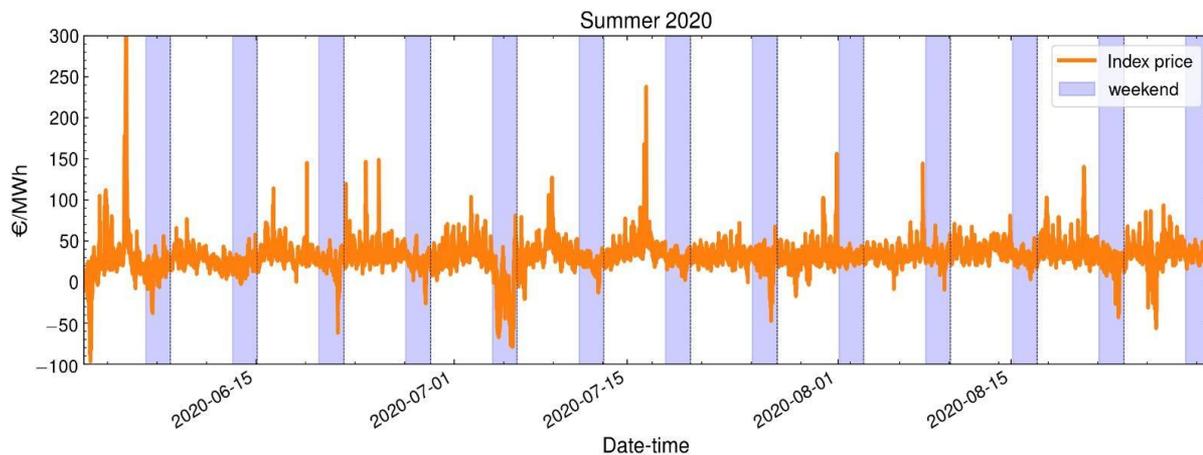
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Opportunities for arbitrage at German electricity market



Intraday electricity market is volatile enough to allow for possible arbitrage.

Price dynamics



price dynamics:
stochastic
+
daily/weekly/monthly
trends

**How to automate
the arbitrage
strategy?**

Storage

Arbitrage — practice of taking advantage of a difference in prices, striking a combination of matching deals to capitalise on the difference.

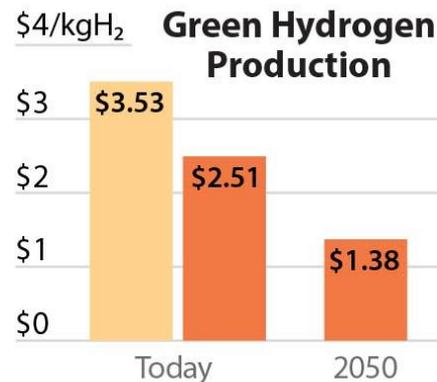
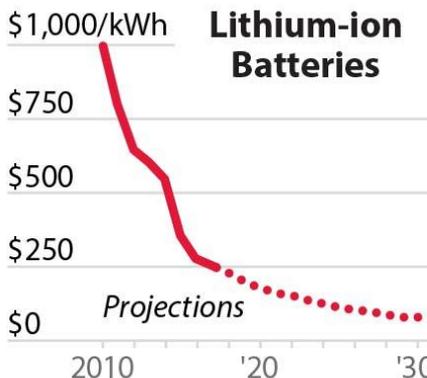
Contrary to stock trading, energy arbitrage **requires storage**.

...which is essential for transitioning to sustainable energy network.



Battery and Green Hydrogen Costs Are Falling

Utility-scale energy storage is about to take off



Sources: Bloomberg NEF, IRENA

IEEFA

Mass market storage



In the following we use
Tesla Powerwall 2

Price : 9600 EUR (+installation)

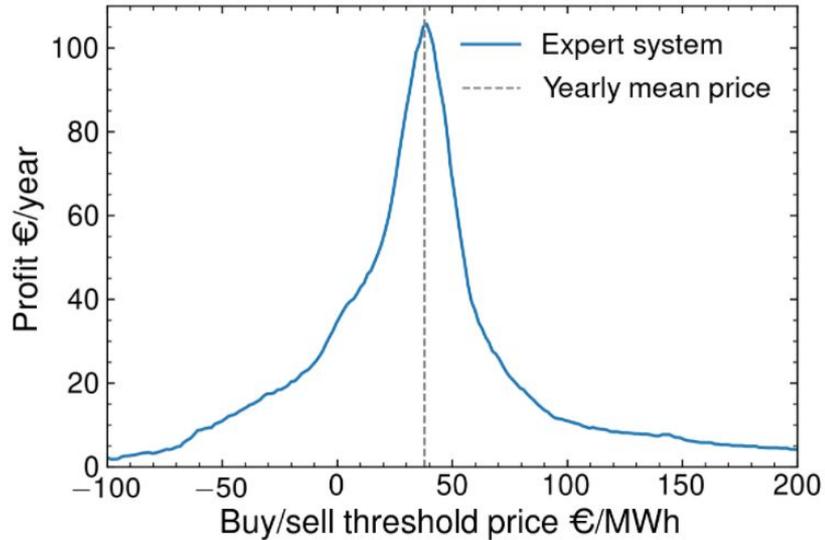
Total energy : 14 kWh

Usable capacity : 13.5 kWh

Roundtrip efficiency : 90%

Warranty : 10 years

Expert system: simple approach to arbitrage



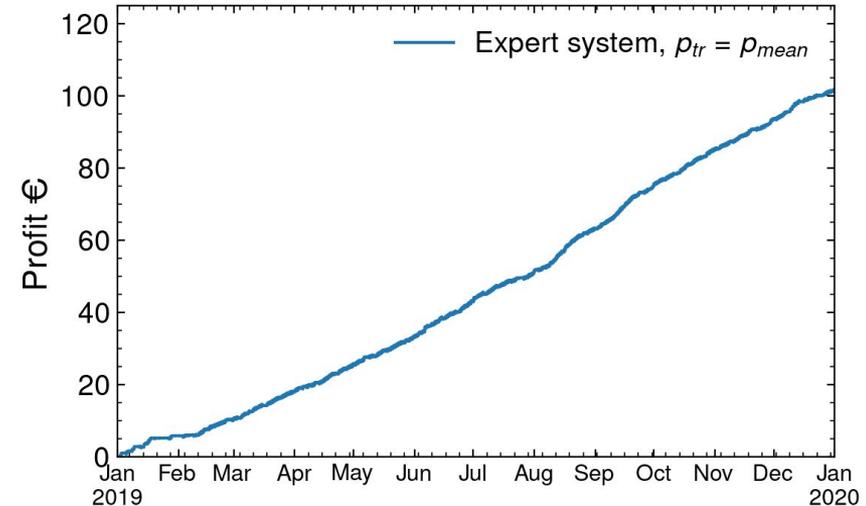
With simple strategy
Tesla Powerwall may profit up to ~100 eur/ year.

Is it possible to improve the strategy?

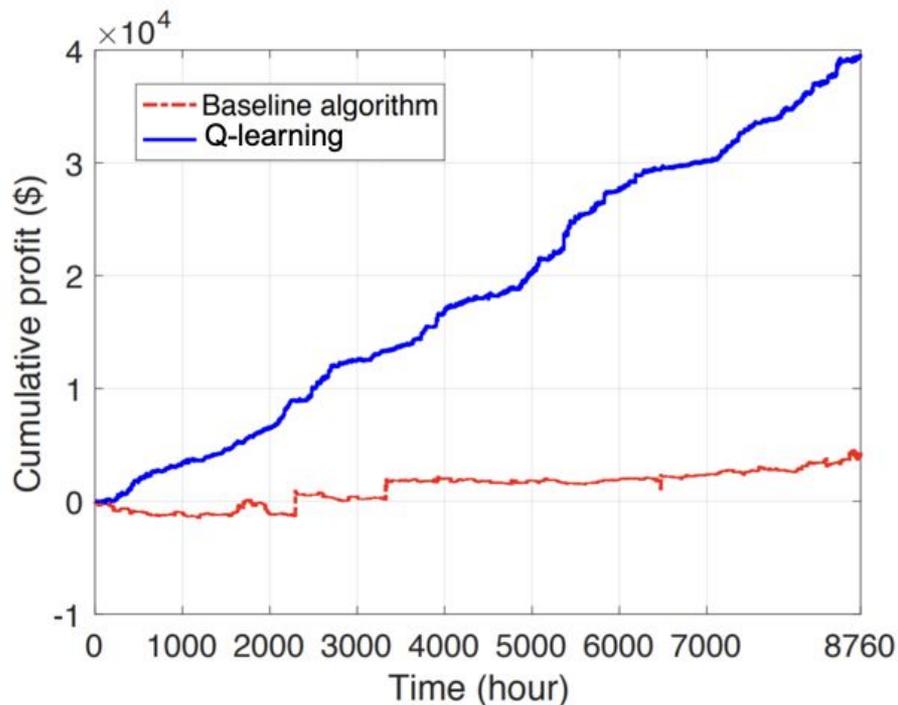
Expert system:

buy @ price < threshold

sell @ price > threshold



Reinforcement learning for energy arbitrage



Reinforcement (Q) learning was used to optimize energy arbitrage on New England energy market using 8MWh batteries (~600xTesla Powerwall).

[Energy storage arbitrage in real-time markets via reinforcement learning](#)

[H Wang, B Zhang](#) - 2018 IEEE Power & Energy Society General ..., 2018 - ieeexplore.ieee.org

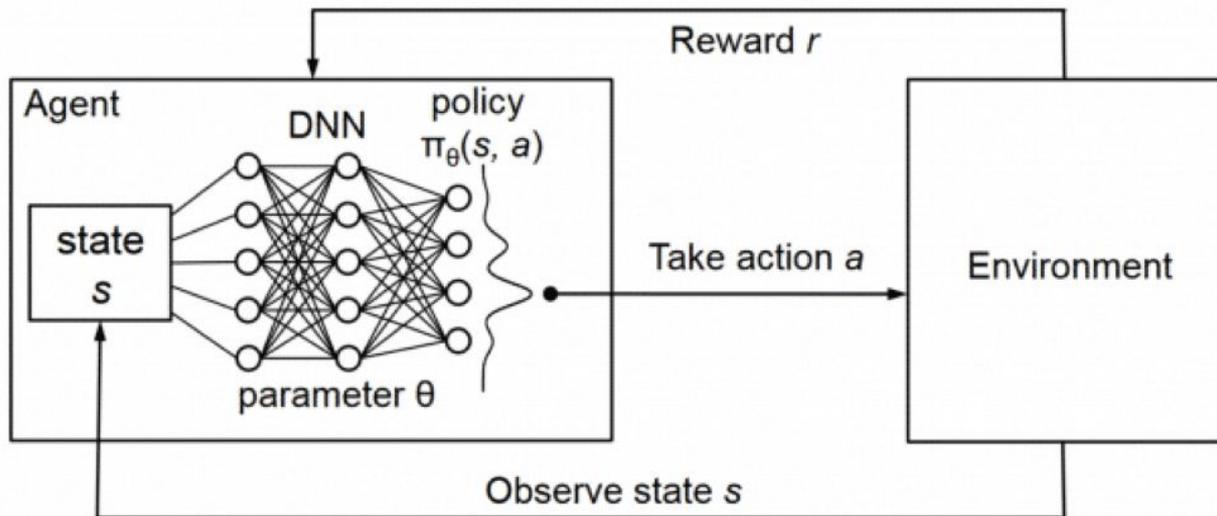
In this paper, we derive a temporal arbitrage policy for storage via reinforcement learning. Real-time price arbitrage is an important source of revenue for storage units, but designing good strategies have proven to be difficult because of the highly uncertain nature of the prices. Instead of current model predictive or dynamic programming approaches, we use reinforcement learning to design an optimal arbitrage policy. This policy is learned through repeated charge and discharge actions performed by the storage unit through updating a ...

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Reinforcement learning: our setup

Learning is performed with the following approach:

 **PyTorch** – open-source machine learning library
Deep Q network is implemented to store the optimal strategy



reward:

$$r_t = (\bar{p}_t - p_t) d_t$$

where

$$\bar{p}_t = (1 - \eta)\bar{p}_{t-1} + \eta p_t$$

d_t — dispatch

p_t — energy price

actions:

buy/sell/hold

environment:

storage

state:

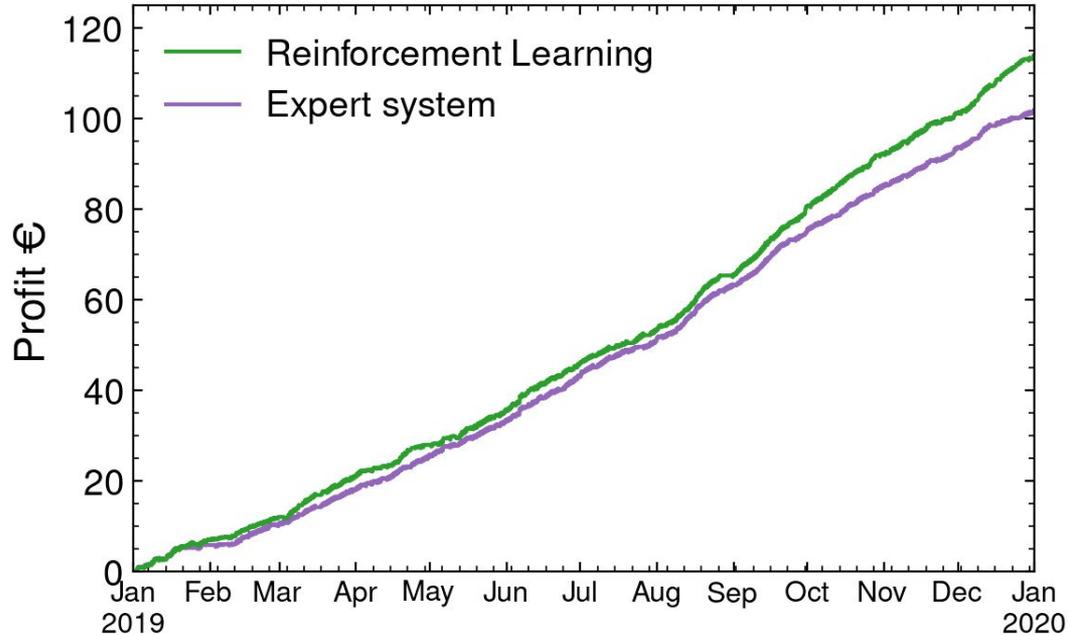
energy price

battery state

previous energy price

Our RL results

Electricity arbitrage with Tesla Powerwall
2019 DE Market



Cumulative reward ES = 100 EUR
Cumulative reward RL = 110 EUR

**RL is only slightly better than
the Expert system**

Exploring the maximal possible profit

- Does the RL and expert system coincide because of reaching the maximal profit?
- The limit in profit can be explored by optimizing the arbitrage problem.

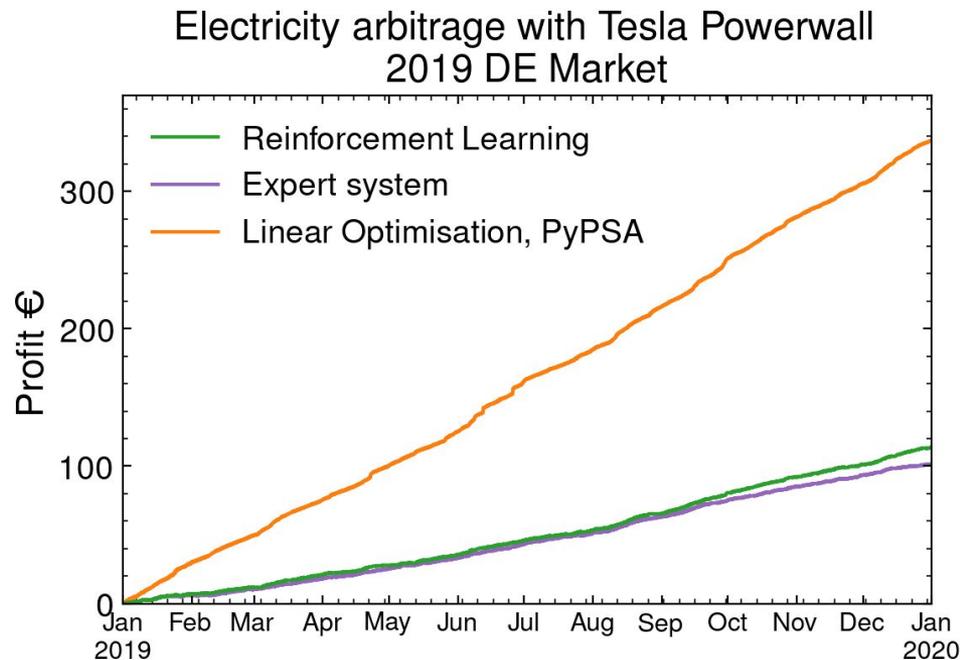
Can be done by PyPSA - Python for Power System Analysis



<https://github.com/PyPSA/PyPSA>

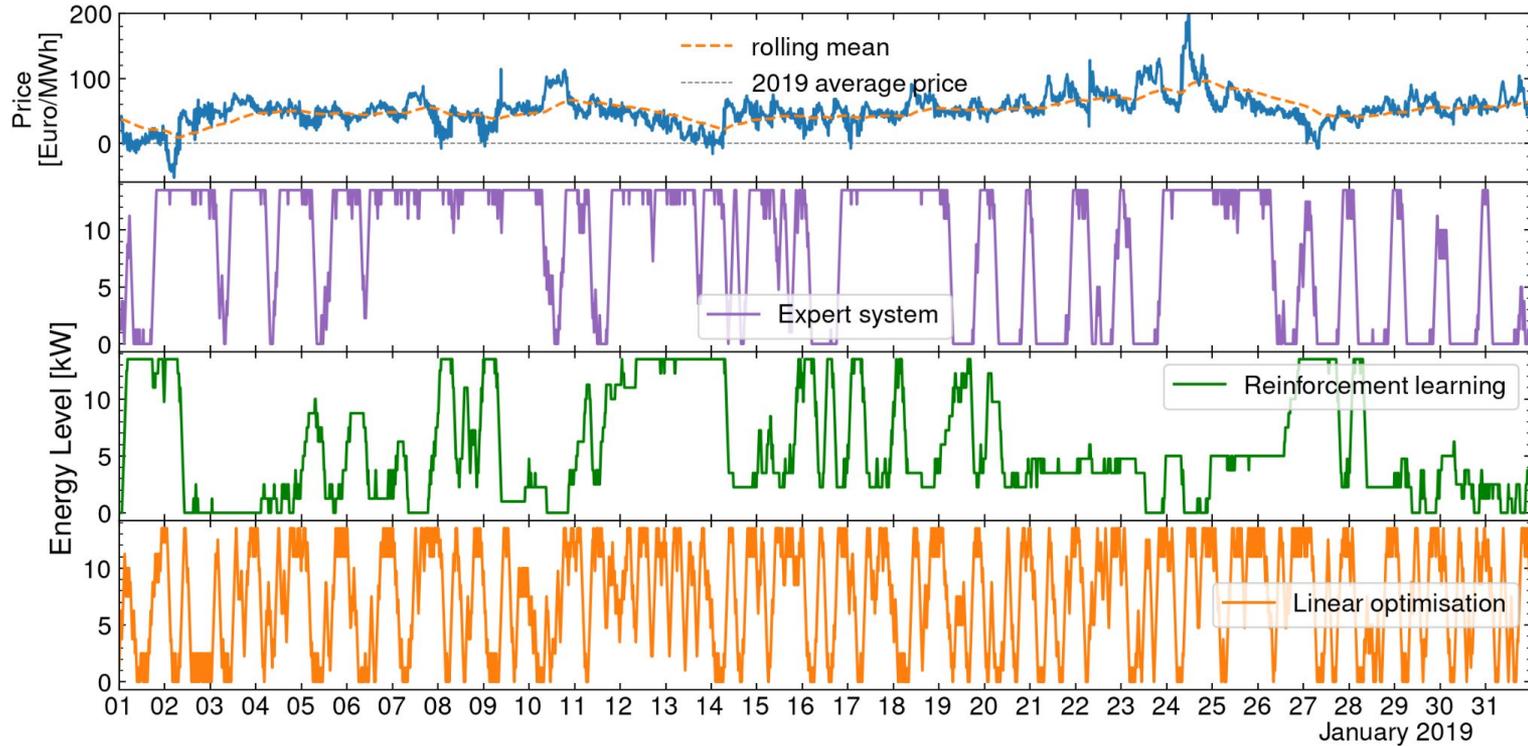
*“a toolbox for simulating and optimising modern power systems that include features such as conventional generators with unit commitment, variable wind and solar generation, **storage units**, coupling to other energy sectors, and mixed alternating and direct current networks.”*

Exploring the maximal possible profit



Maximal possible profit is ~3 times larger than the RL and ES result.
A possible room for improvement for AI agents with another structure ...

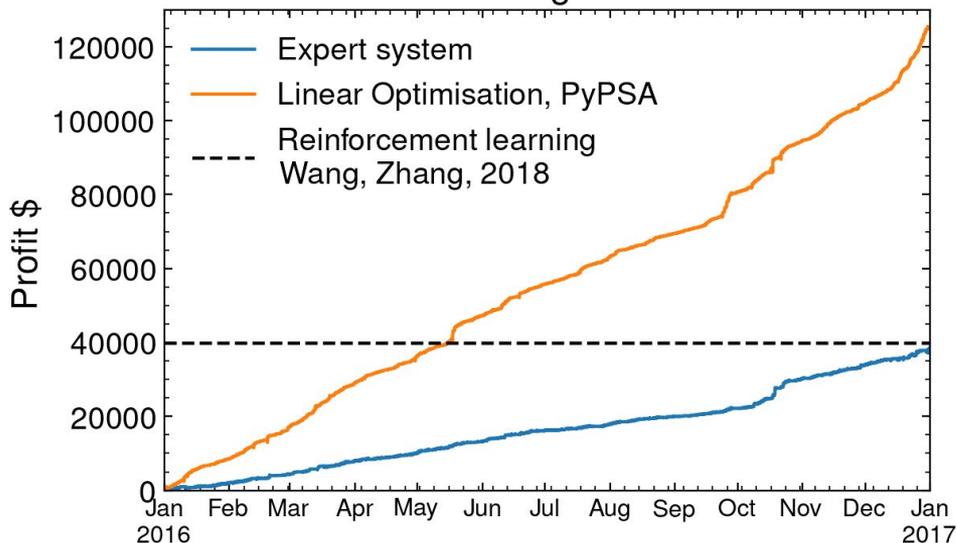
Energy dispatch for different strategies



In order to maximise profit the storage should always respond to price dynamics.

Comparison with previous studies

8MWh 2MW storage
2017 New England Market



Energy storage arbitrage in real-time markets via reinforcement learning

H.Wang, B.Zhang - 2018 IEEE Power & Energy Society General ..., 2018 - ieeexplore.ieee.org

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Expert system provides similar to RL results at the NE market:

Reinforcement learning in current setup is not better than simple expert system!

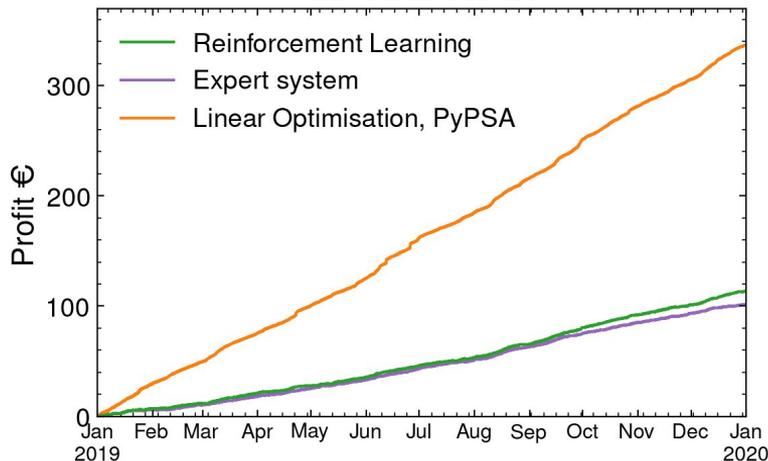
Summary

- Energy arbitrage at German electricity market is possible.
- Simple expert system (but/sell at fixed threshold) provides ~110EUR/year with Tesla Powerwall.
- DQN performs slightly better than expert system. Possible ways for improvement should be studied.
- Previous estimates of Deep Q-learning performance were over-optimistic.

Outlook:

- How to improve the performance of the agent?
- Consider other (automotive) batteries.
- Backreaction of electricity network on massively done arbitrage.

Electricity arbitrage with Tesla Powerwall
2019 DE Market



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Thank you for the attention!

