Planning and Scheduling the Electrolyzer in the Austrian Electricity and Balancing Market

Green Hydrogen for Industry – Regulatory Workshop
11th Ferbruary 2021 (VERBUND, CEER, ACER)

Andreas EICHHORN
VERBUND Energy4Business

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735503. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY

H2FUTURE

H2FUTURE
Green Hydrogen for the Steel Industry

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

- **Design and installation of a 6 MW Siemens PEM electrolyzer system** at the voestalpine steel plant in Linz, Austria

- **Two-year demonstration** of the electrolyser system, including grid services by VERBUND and ambitious efficiency target

Verbund
voestalpine
SIEMENS
K1-MET metallurgical competence center
APG
TNO innovation for life

- ❑ Project budget: €18 million
- ❑ Total funding: €12 million from FCH JU
- ❑ Project duration: 4.5 years

Installation and Operation of an Electrolysis System at the Steel Production Site in Linz, Austria

Key Data

- **6 MW PEM electrolyser**
- **Start of pilot plant operation** in 2019
- **Pilot tests** and **demonstration** until 2021

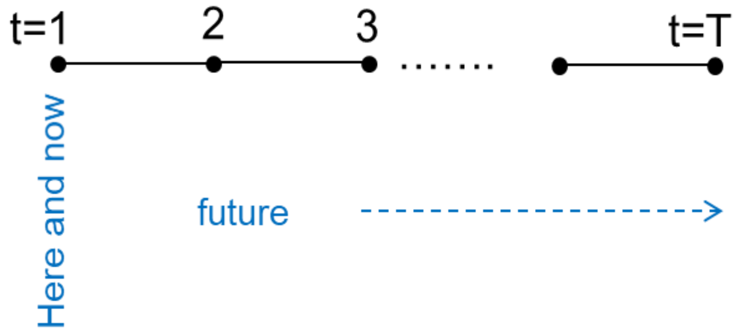
H2FUTURE
Planning and Scheduling based on Optimization Algorithm

Setup:

- **Quasi-commercial operation period:** fall 2020 till end of 2021 min. 3000 full load hours (required by grantor)
- **Goal:** demonstrate **economic feasibility** in a real-world **market environment**
- **Challenge:** H_2 is (for now) only used as a natural gas substitute; usually gas market price < electricity price (in the future H_2 price possibly higher than natural gas price); additional operating costs (e.g., grid fees)
- **However:** Electrolyzer is flexible (can change the consumption of electric power between 1.5 MW and 6 MW) → grid services / control reserve can be provided → additional revenues
- **Relevant markets:**
  - day-ahead spot market → major market, high liquidity, hourly granularity
  - intra-day spot market → very small market in Austria, possible additional revenues
  - FCR / primary control reserve → electrolyzer is only prequalified for +-1 MW
  - aFRR / secondary control reserve → electrolyzer is prequalified for +-4 MW
  - mFRR / tertiary control reserve → smaller revenues than aFRR

H2FUTURE
Planning and Scheduling based on Optimization Algorithm

Optimization model based on hourly time grid →



Planning horizon:
e.g., 1 year (T=8760) (in quasi-commercial operation)
or e.g., 2 days (T=48) (if no long-term constraint)

rolling horizon approach (recalculate every day …)

Input parameters:

- technical specifications of electrolyzer (efficiency, Pmax, Pmin, …)
- electricity spot price expectations for each hourly interval in the future (price forward curve)
- price expectations for control reserve (capacities price and energy price) of different products (FCR, aFRR+, aFRR-, mFRR+, mFRR-) in according time discretization (4h)
  H2 prices (based on gas price forward curve)
- H2 volume still to be produced in the given (remaining) period
- volumes and capacities already sold on the spot and the control reserve markets
- operating costs, start costs, …

H2FUTURE
Planning and Scheduling based on Optimization Algorithm

Decision variables:

- Power consumption [MW] and H_2 production in each hourly interval (hourly schedules)
- Contribution to each type of control reserve (FCR, aFRR+, aFRR-, mFRR+, mFRR-) (4h schedules)

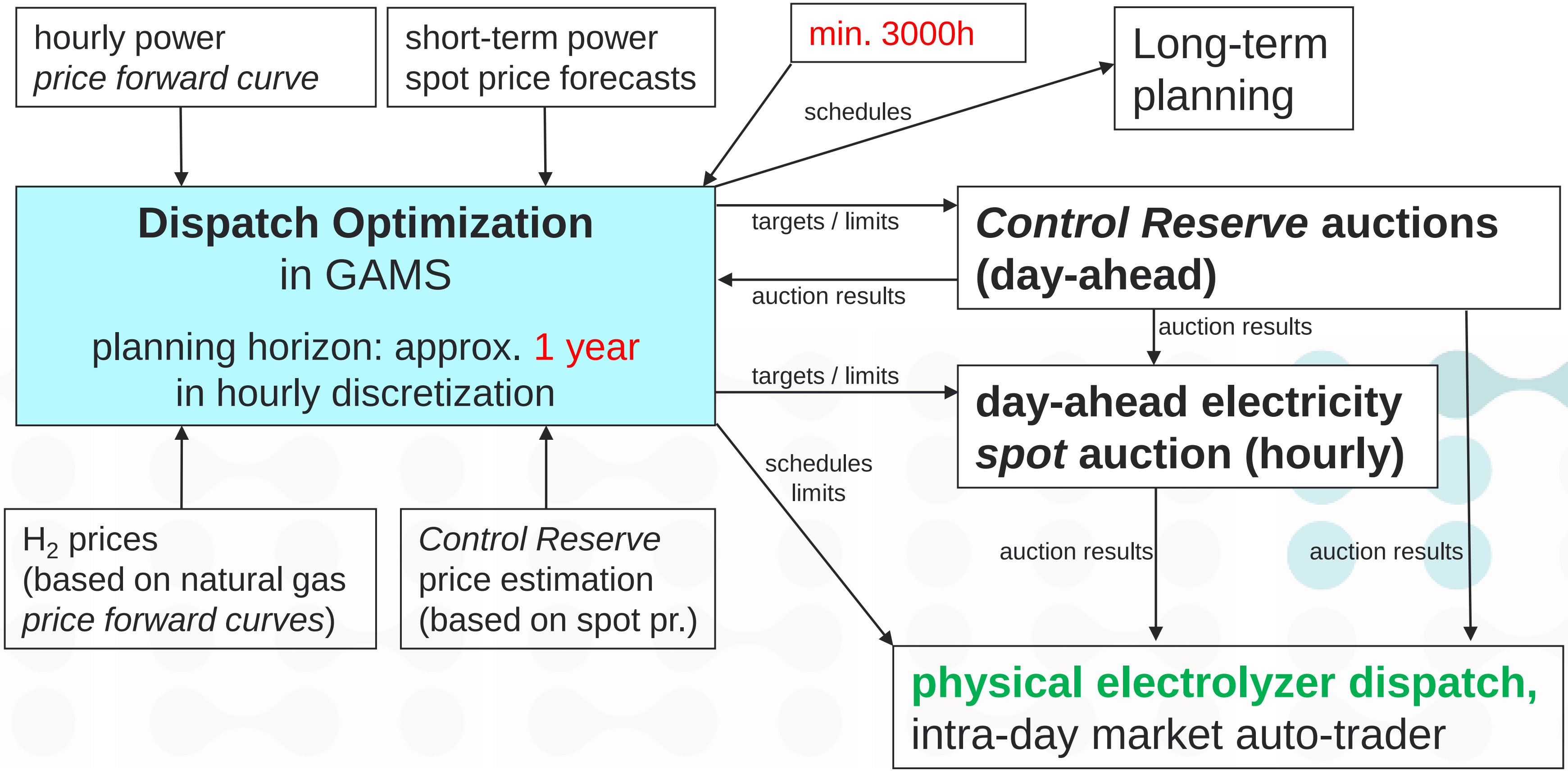
Constraints:

- Power consumption in each interval at 0 MW or between P_{min} and P_{max}
- H_2 production in each interval according to power consumption and efficiency
- Control reserve contributions according to power production and its distance to P_{min} and P_{max}
- Minimum H_2 production in the rest of the period (*time-spanning-constraint*) 3000h

Objective function (to be maximized):
H_2 revenues + control reserve revenues – electricity costs – operating costs
(according to price expectations)

Optimization model solved by optimization algorithm

H2FUTURE
Planning and Scheduling based on Optimization Algorithm



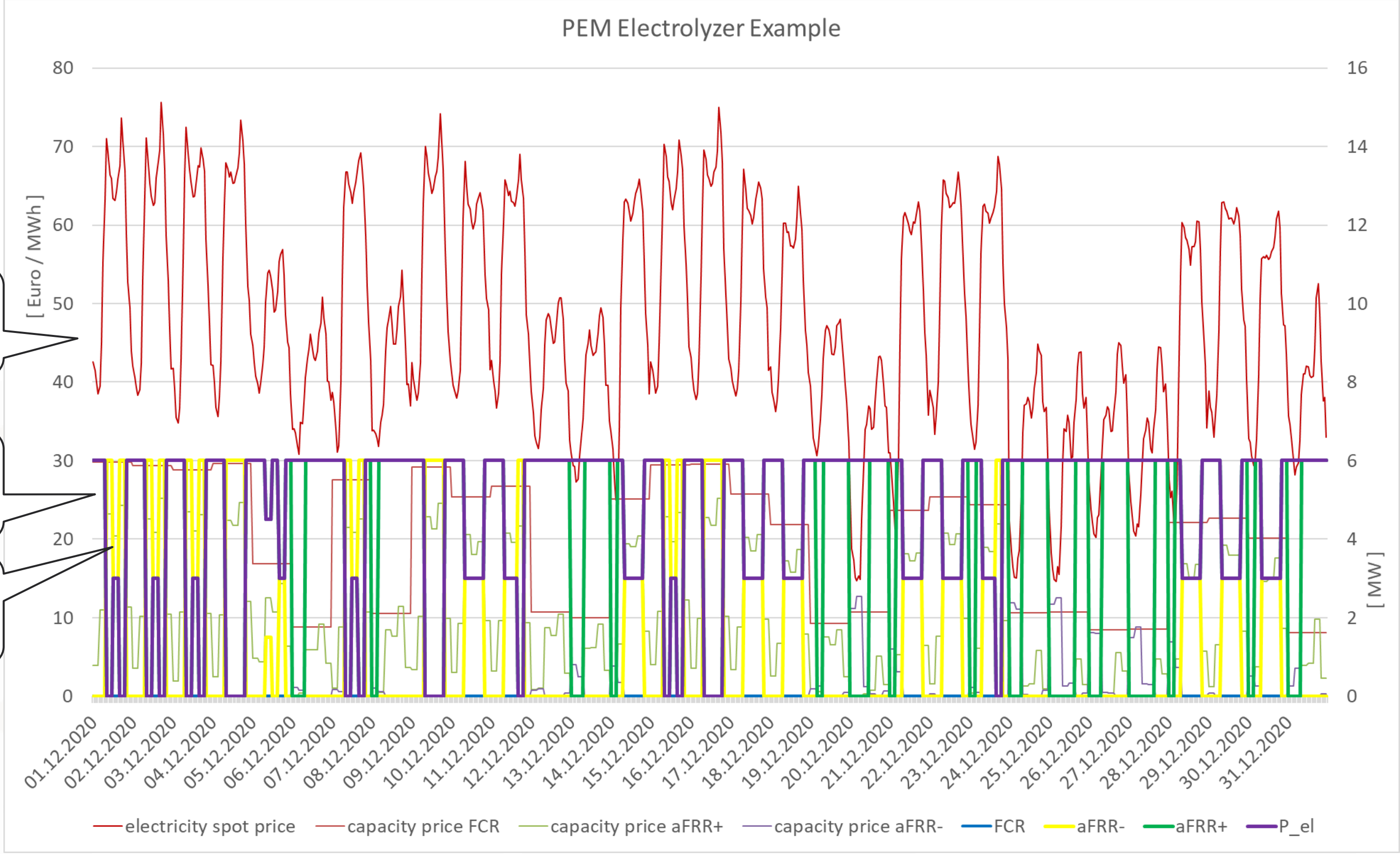
H2FUTURE
Planning and Scheduling based on Optimization Algorithm

Exemplary model run for Dec. 2020:

input: spot price expectation

output: optimal power schedule

output: optimal aFRR- contrib.



rolling horizon approach:

- only use 1st day results
- recalculate the next day!

H2FUTURE
Planning and Scheduling in Practice

Daily routines:

- D-2: Dispatch Optimization
- D-2: final Ancillary Services Pricing and offer in DB *
  - Decision for which ancillary services market (FCR or aFRR) and directions (+/-) for each 4h block

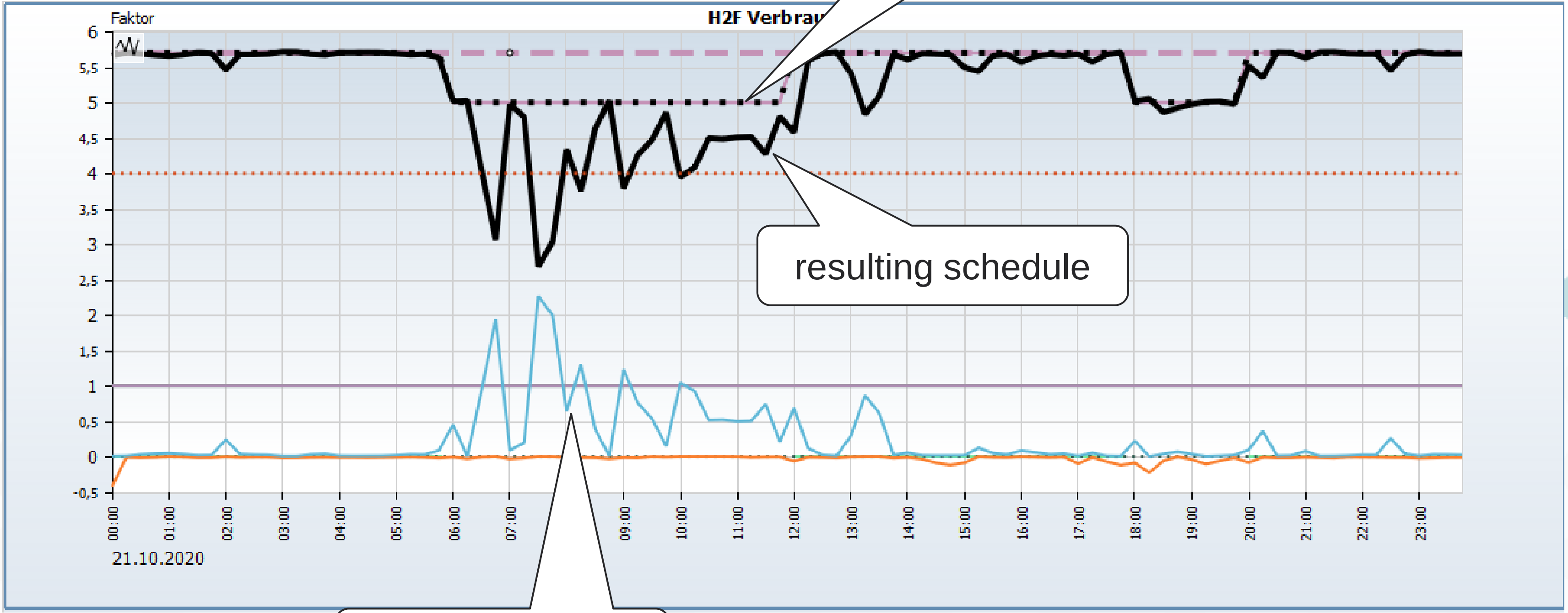
- D-1: 08:00 gate closure FCR auction
- D-1: 09:00 gate closure aFRR auction
- D-1: 12:00 gate closure EPEX spot auction

- D-0: continuous trading on intraday market

H2FUTURE
Planning and Scheduling in Practice

Actual schedule, example day Oct./Nov. 2020:

day-adhead spot

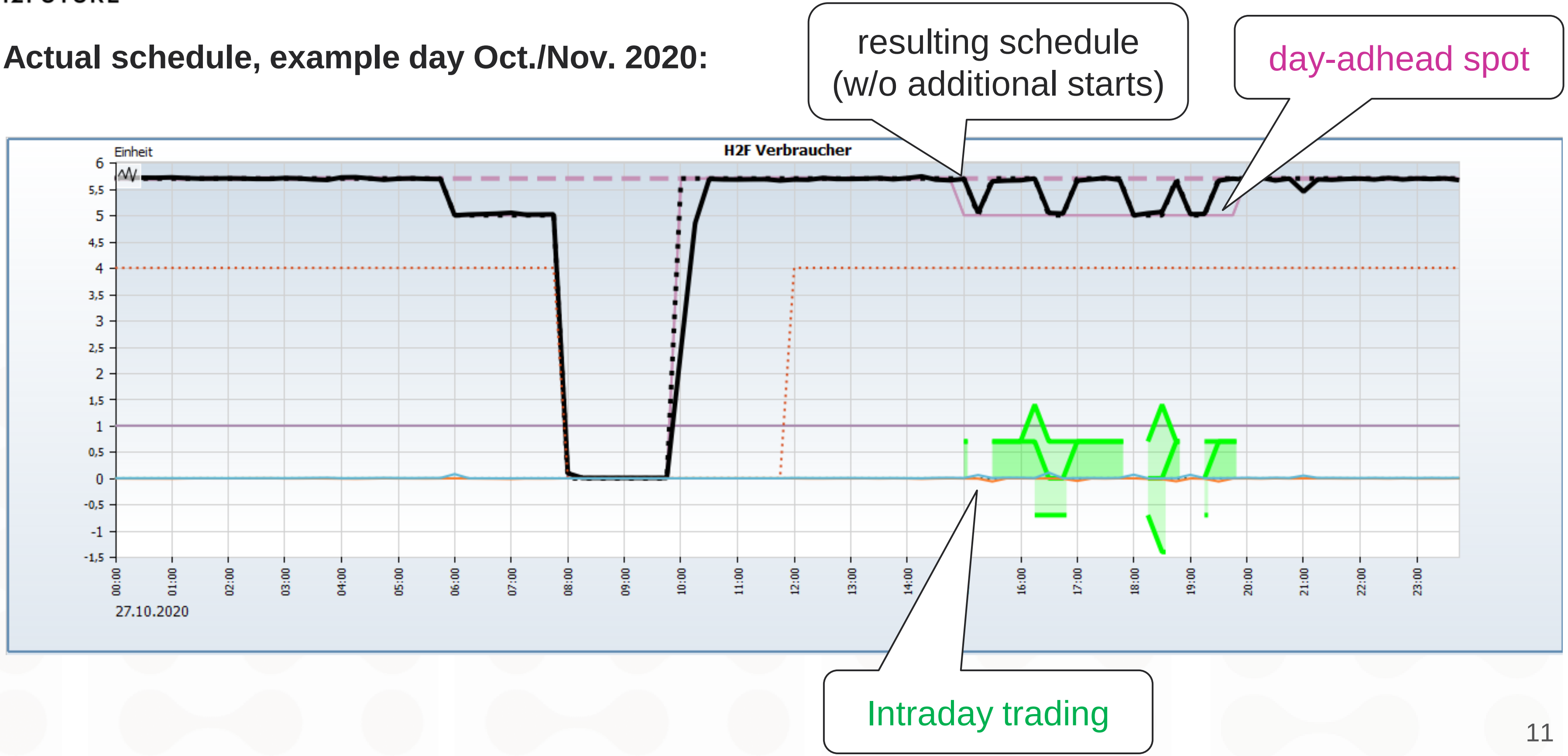


resulting schedule

aFRR+ activation

H2FUTURE
Planning and Scheduling in Practice

Actual schedule, example day Oct./Nov. 2020:



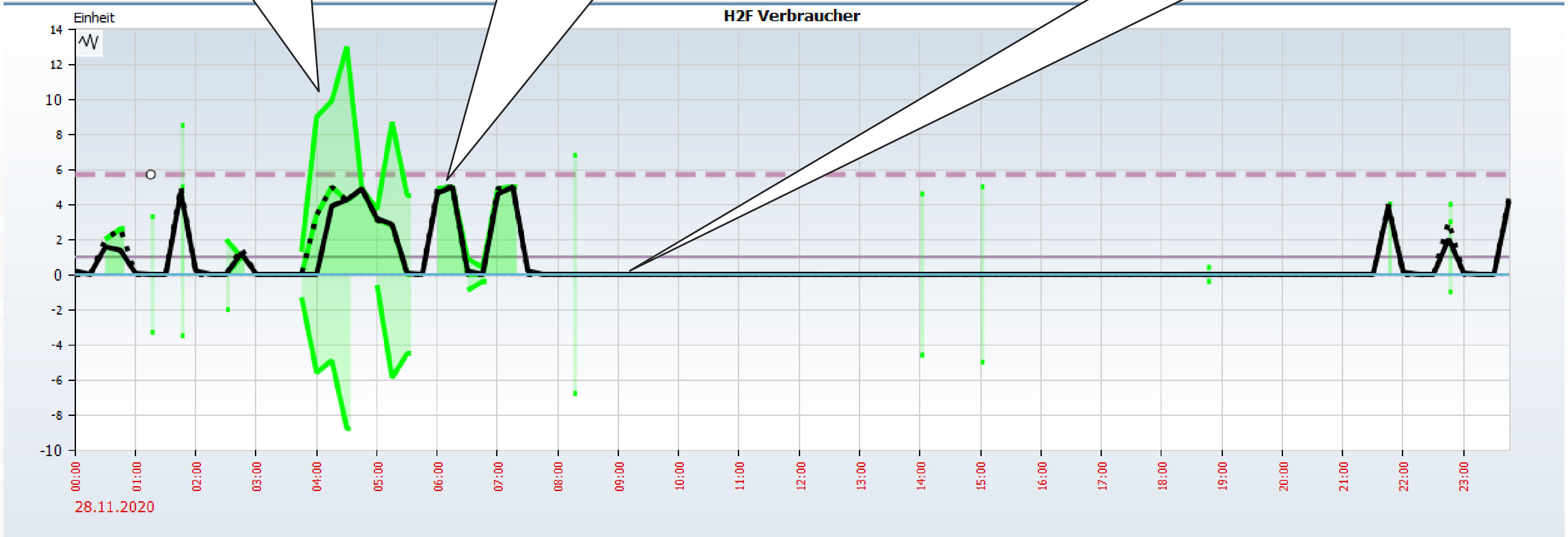
H2FUTURE
Planning and Scheduling in Practice

Actual schedule, example day Oct./Nov. 2020:

Intraday trading

resulting schedule (with additional starts!)

day-adhead spot = 0 MW



H2FUTURE
Challenge: Estimating Revenues of Control Reserve

PEM electrolyzer can provide **control reserve = grid services** and thereby create **additional revenues**; *this has to be anticipated in the medium-term optimization model somehow!*

Particularly relevant:

- **FCR** (frequency containment reserve, primary control reserve)
- **aFRR** (positive <u>and</u> negative automatic frequency restauration reserve / secondary control reserve)

(mFRR also possible but less rewarding)

Challenges:

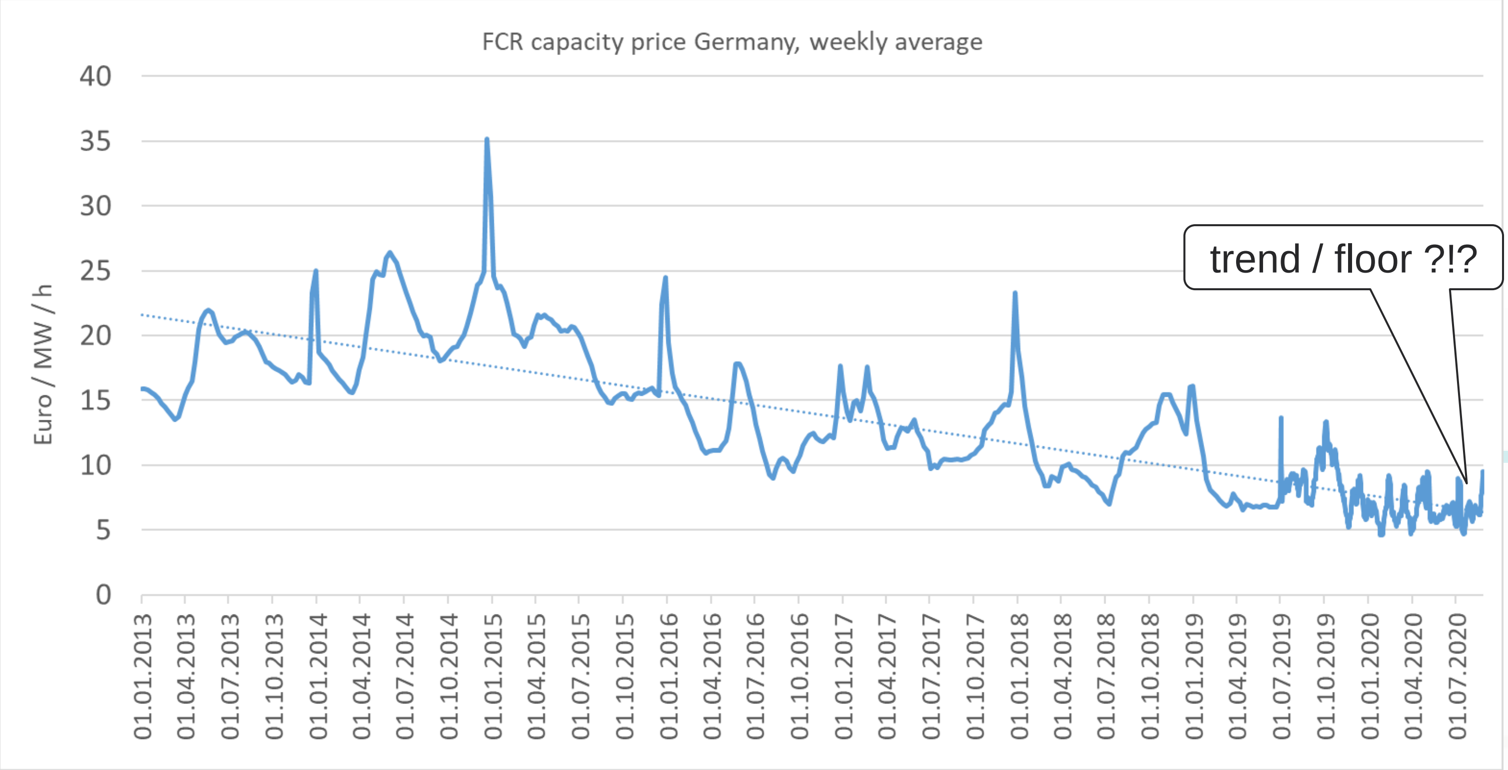
- few market participant in Austria → speculation, bubbles, game theoretic behavior
- market rules are changed relatively frequently

Problem: There are no real forecasts available for control reserve !

- neither for FCR nor for aFRR
- neither within VERBUND nor from external forecast providers
- neither for the short term nor for the medium / long term

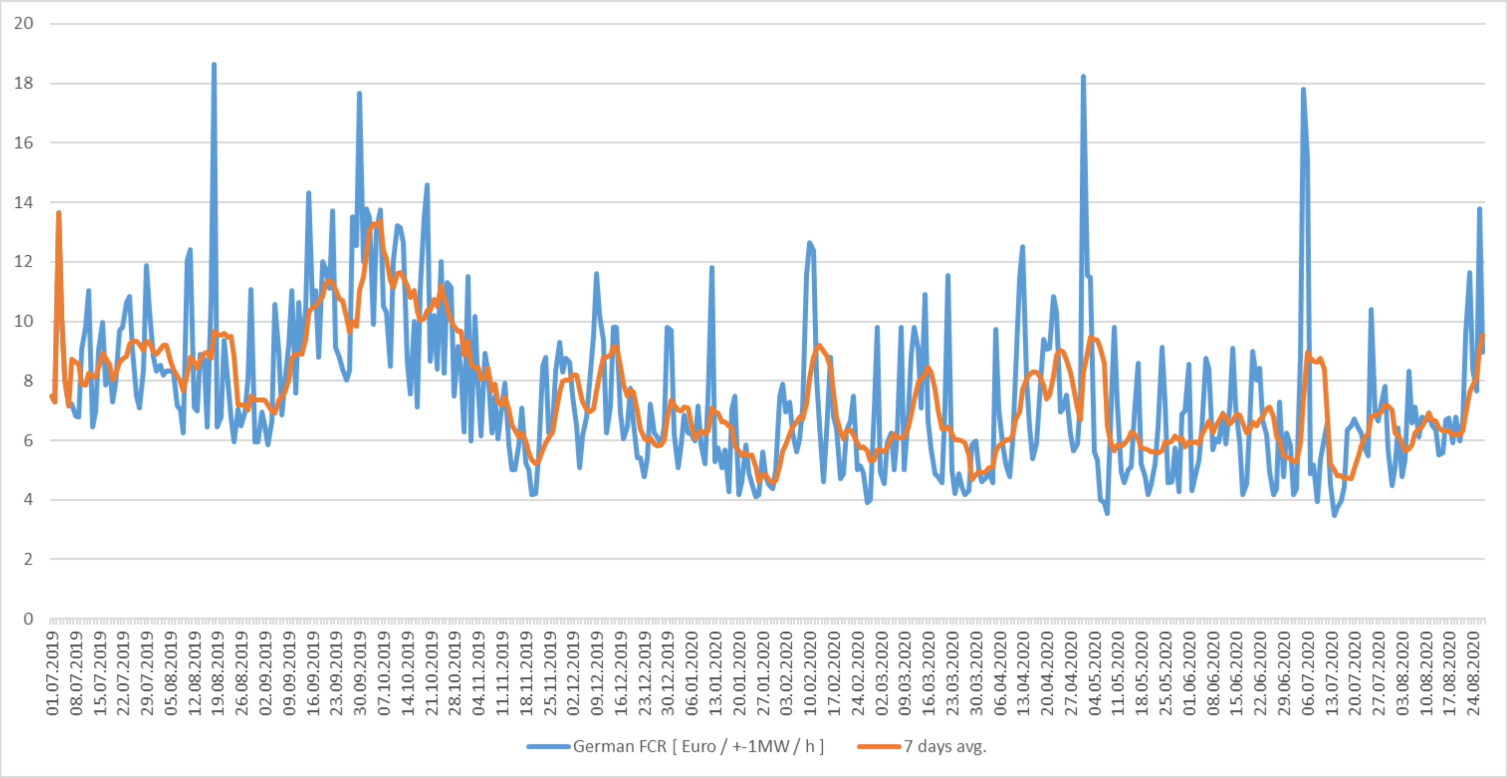
H2FUTURE
Challenge: Estimating Revenues of Control Reserve

FCR: symmetric product (pos/neg), only capacity price, no energy price, descending trend!



H2FUTURE
Challenge: Estimating Revenues of Control Reserve

FCR: daily European day-ahead auction since mid 2019, highly volatile, hardly predictable



H2FUTURE
Challenge: Estimating Revenues of Control Reserve

aFRR: more complex product due to

- asymmetric product (pos/neg separately)
- 4h blocks for each day (0 to 4, 4 to 8, …) → 6*2=12 day-ahead auctions

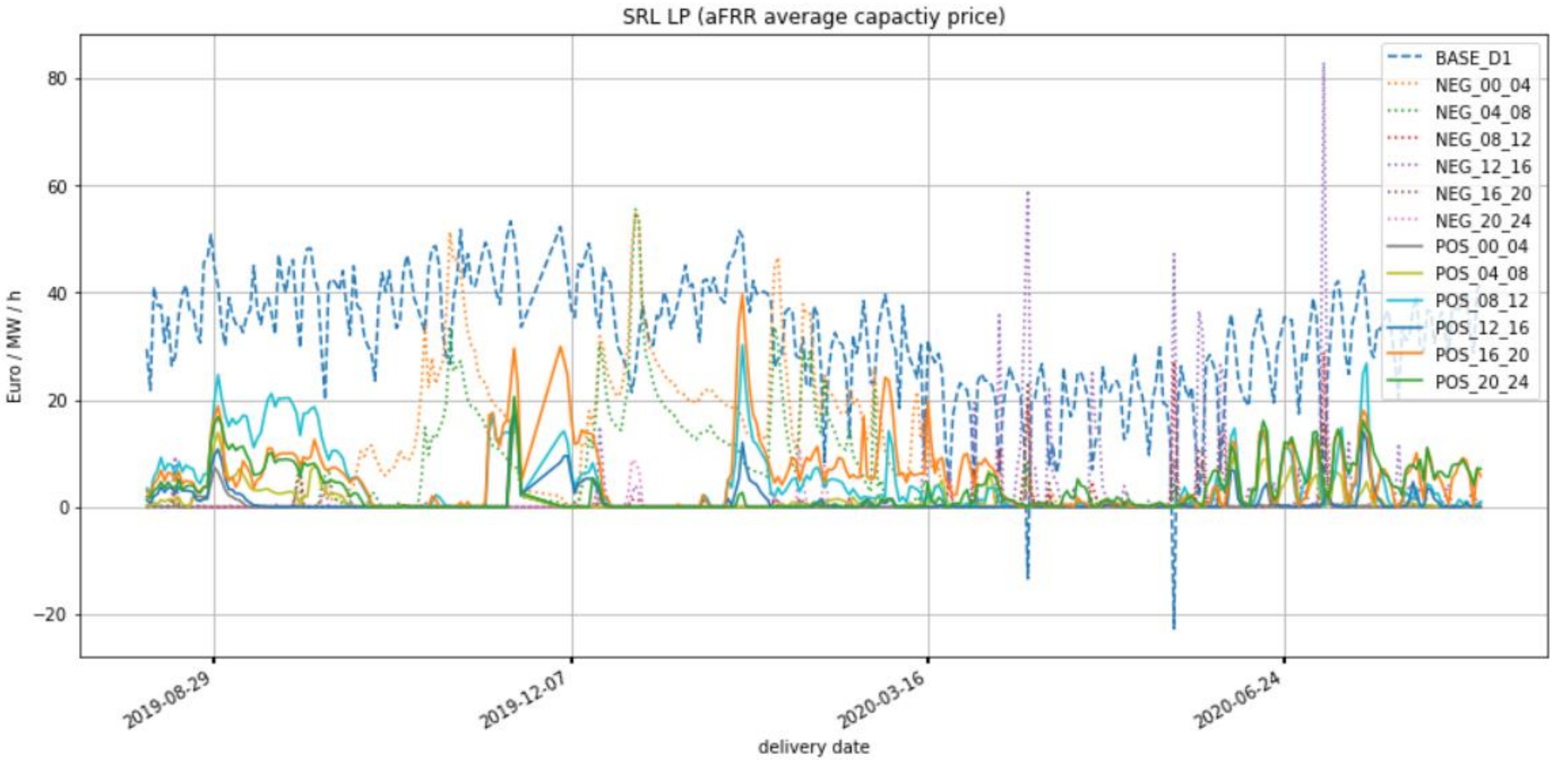
- two sources of revenues, respectively:
  - **capacity price** (1st award criterion), mostly zero!
  - **energy price** (2nd award criterion) for the case of activation, high revenues possible!
- **pay-as-bid** for both, capacity price and energy prices → 24 merit order lists (MOLs) each day

- game theoretic behavior of market participants, esp. in small countries such as Austria
- energy price revenues (main source of revenue!) also depend on your marginal electr. price (in our case: spread between electricity spot price and H2 price)

→ What to predict?!? Even harder …

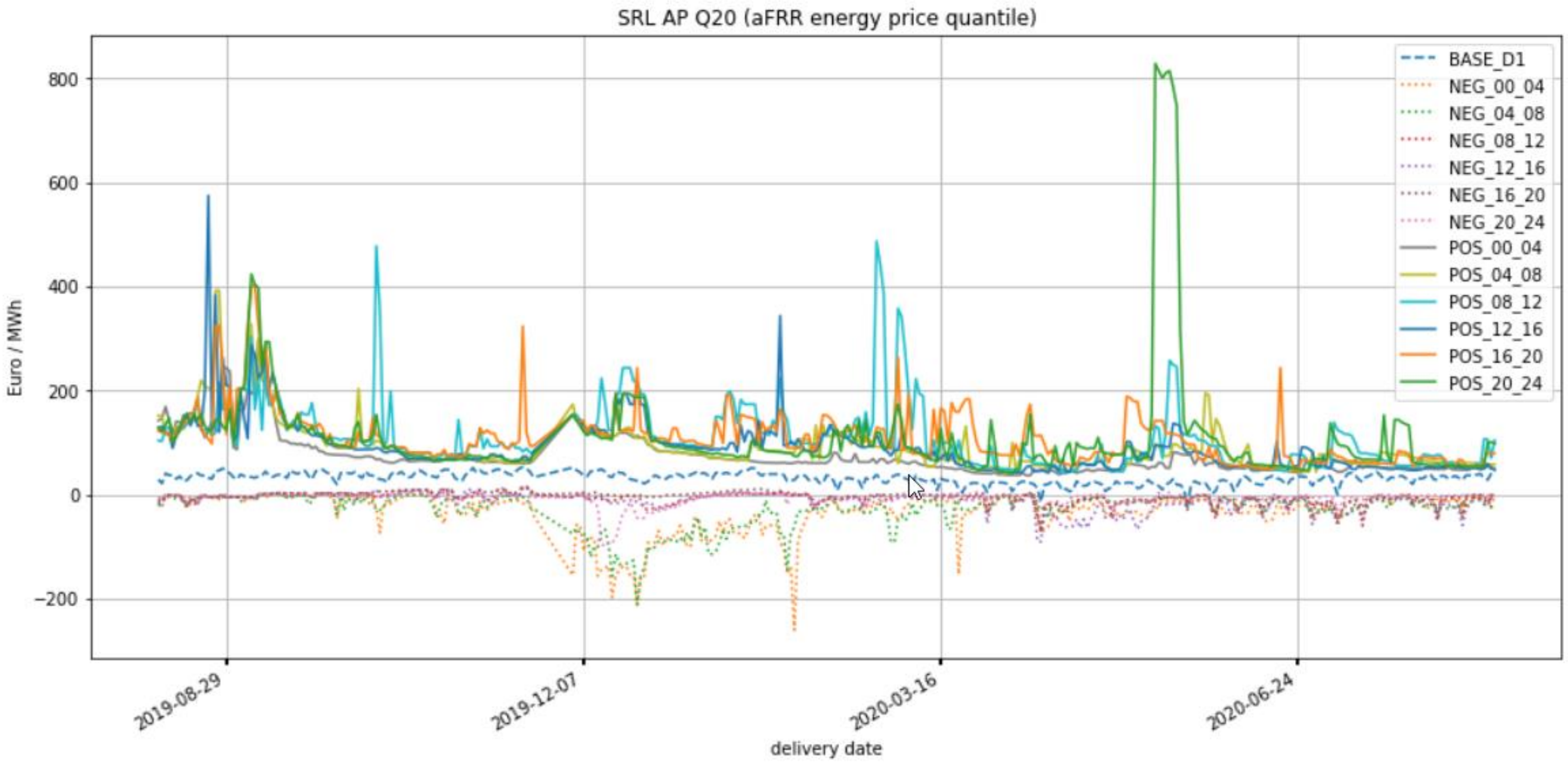
H2FUTURE
Challenge: Estimating Revenues of Control Reserve

Real aFRR capacity prices (MOL average): often zero, sometimes unexplainable market movements…



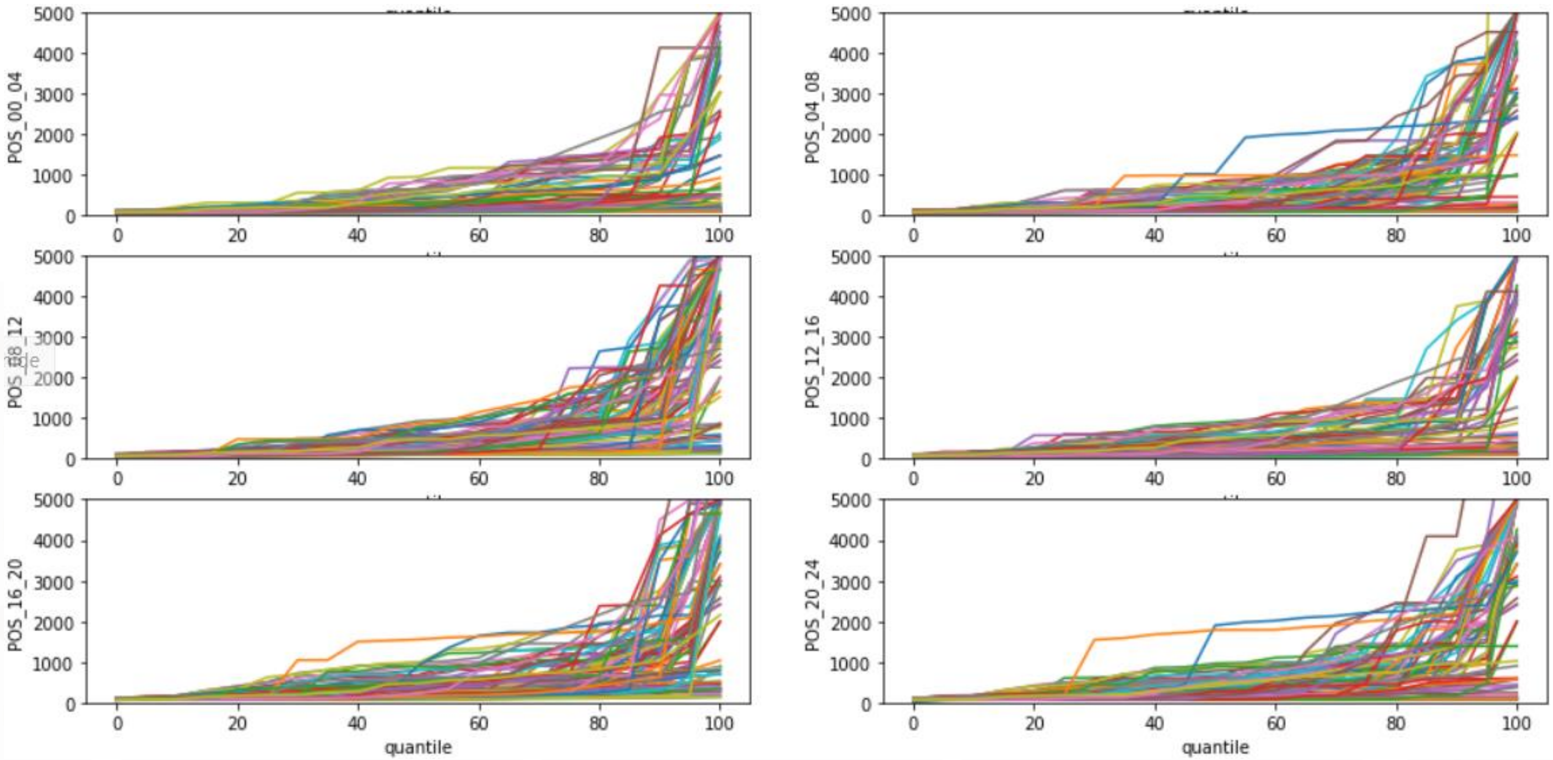
H2FUTURE
Challenge: Estimating Revenues of Control Reserve

aFRR energy prices (20% quantile of MOL): sometimes unexplainable developments …



H2FUTURE
Challenge: Estimating Revenues of Control Reserve

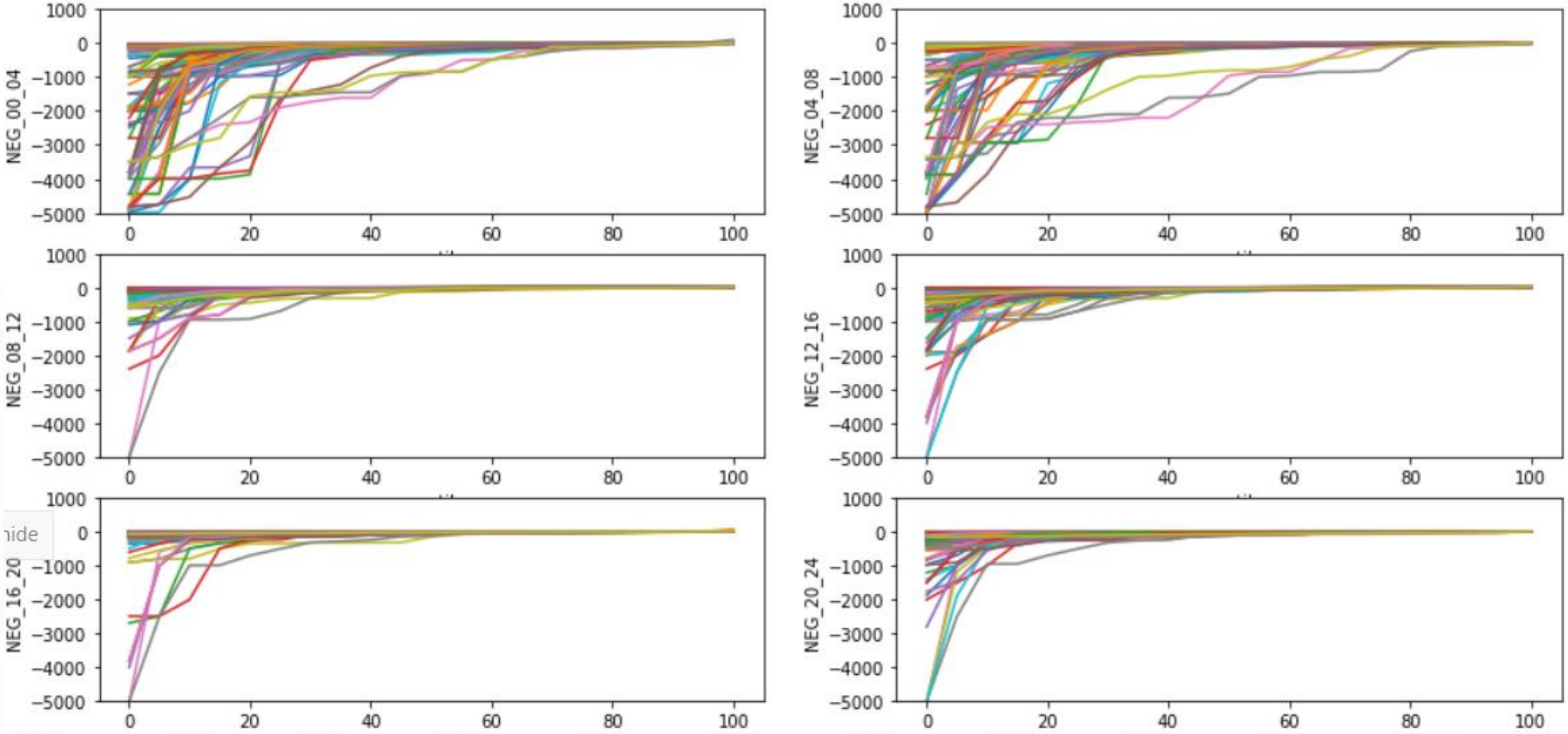
aFRR+ energy prices MOLs: sometimes extremely high prices …



H2FUTURE

Challenge: Estimating Revenues of Control Reserve

aFRR- energy prices MOLs: sometimes extremely negative prices …



H2FUTURE
Challenge: Estimating Revenues of Control Reserve

VERBUND / H2Future approach :

- no explicit forecasted price curves (point forecasts) for FCR, aFRR !
- no trend estimation, no outlier prediction etc.
- estimating medium-term control reserve *price quantiles* based on **regression** on *electricity* spot price expectations / price forward curve and on *gas* PFC
- *nonlinear* regression technique with Random Forests
- aFRR: use regression for capacity price (50% quantile) and whole energy price MOLs (10%...90% quantiles) and calculate revenues based on H_2 / gas price forward curve

→ down-to-earth approach, but coherent planning / optimization setup
→ carrying forward price levels from present / recent history (e.g, 1 year)

H2FUTURE
Summary

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

- planning and scheduling of electrolyzer asset using optimization techniques
  basically like for classical power generation assets (but higher dependence on grid services prices)

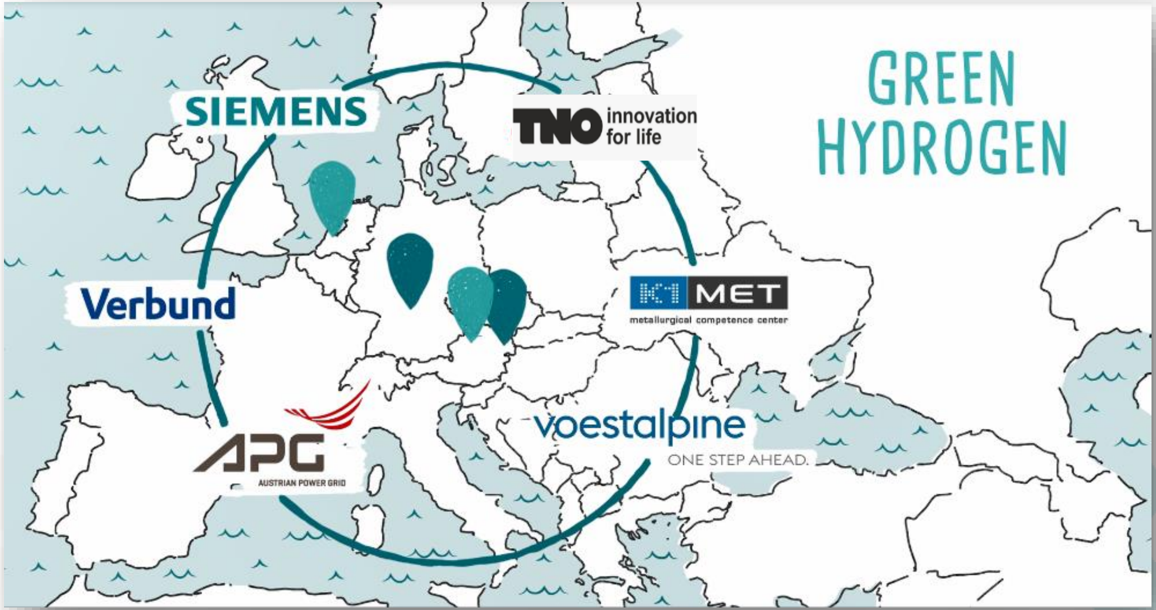
- challenging economic situation (high electricity prices, lower gas / H_2 prices)
  - → use flexibility to provide grid services / control reserve
  - → in the future: obtain higher H_2 prices (higher than just natural gas market price)

- difficulty to forecast / estimate grid services prices, unexplainable market movements due to
  - few market participant in Austria (→ European harmonization)
  - market rules are changed relatively frequently
  - aFRR: pay-as-bid pricing
  - aFRR: duality of capacity price and energy price

  → speculation, bubbles, game theoretic behavior

H2FUTURE

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING



http://www.h2future-project.eu