Hydropower Storage Optimization Considering Spot and Intraday Auction Market

5th International Workshop on Hydro Scheduling in Competitive Electricity Markets

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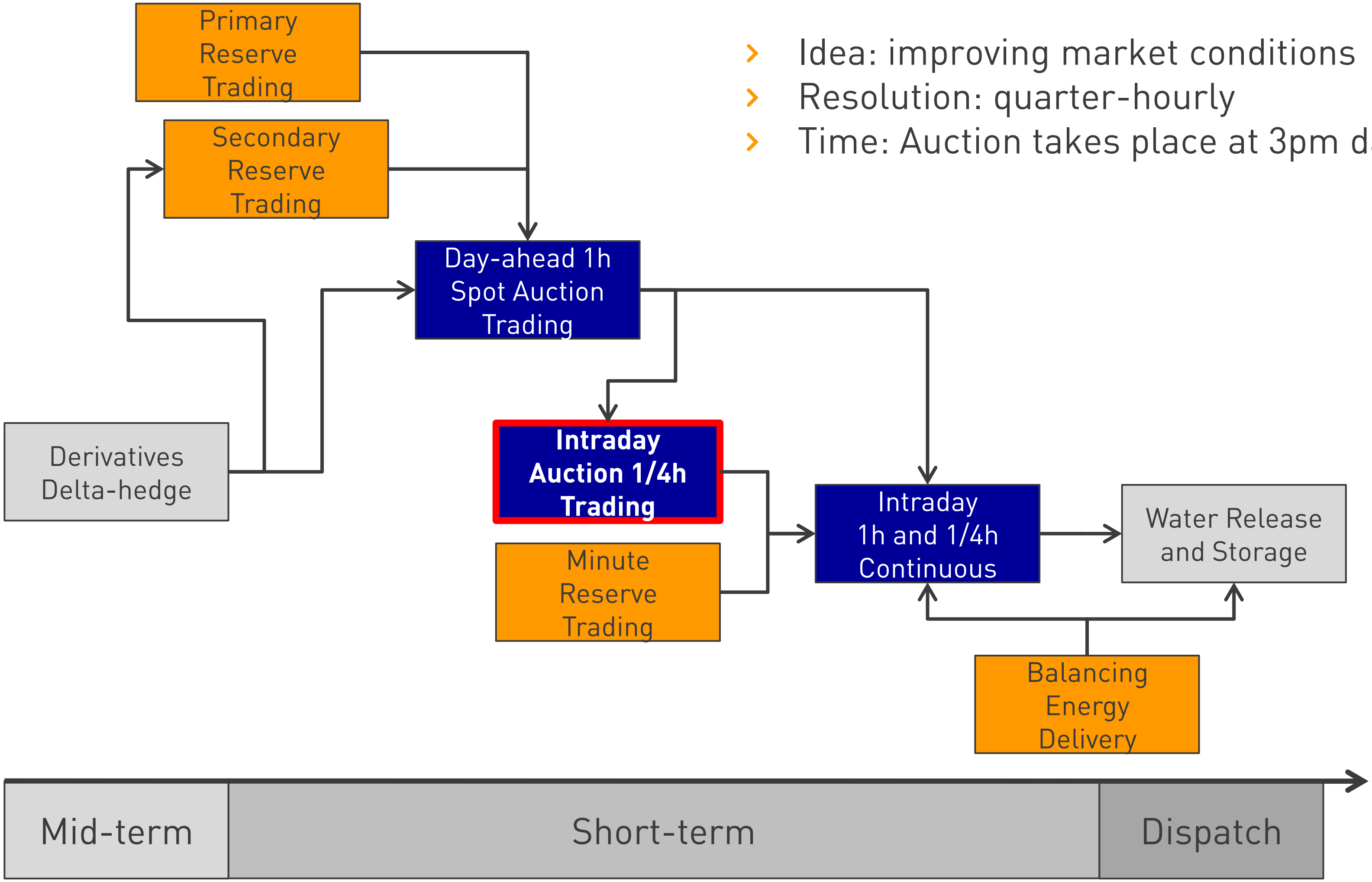
Agenda

1. **Introduction**
   - Quarter-hourly Intraday Auction
   - Market environment
2. **Model**
   - First stage: Spot optimization
   - Second stage: Intraday Auction considering liquidity
3. **Example**
   - Trading hydro storages on the Spot and Intraday Auction market
4. **Conclusion/Questions**

Introduction

Quarter-hourly Intraday Auction

- Idea: improving market conditions
- Resolution: quarter-hourly
- Time: Auction takes place at 3pm day-ahead

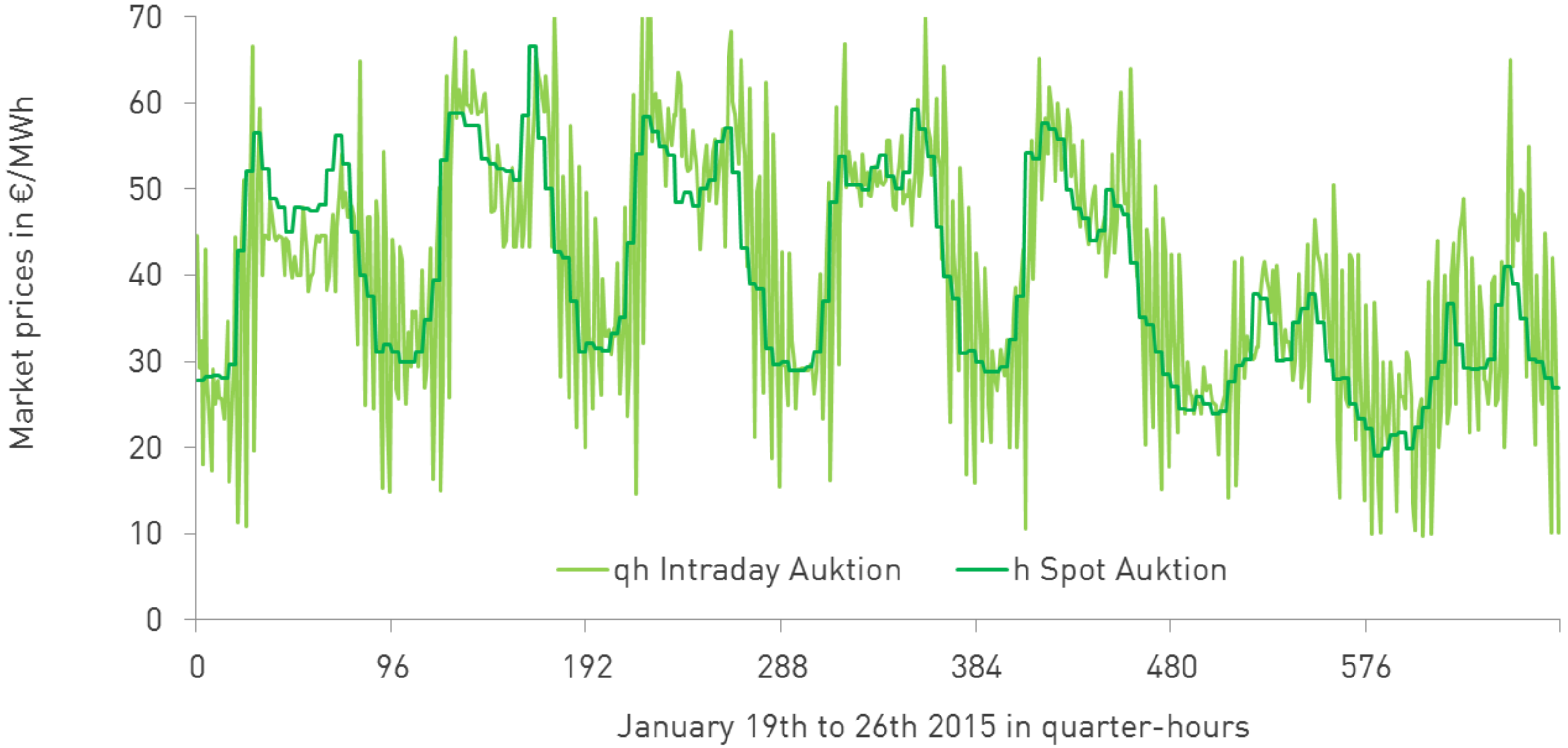


Price development on the German energy markets

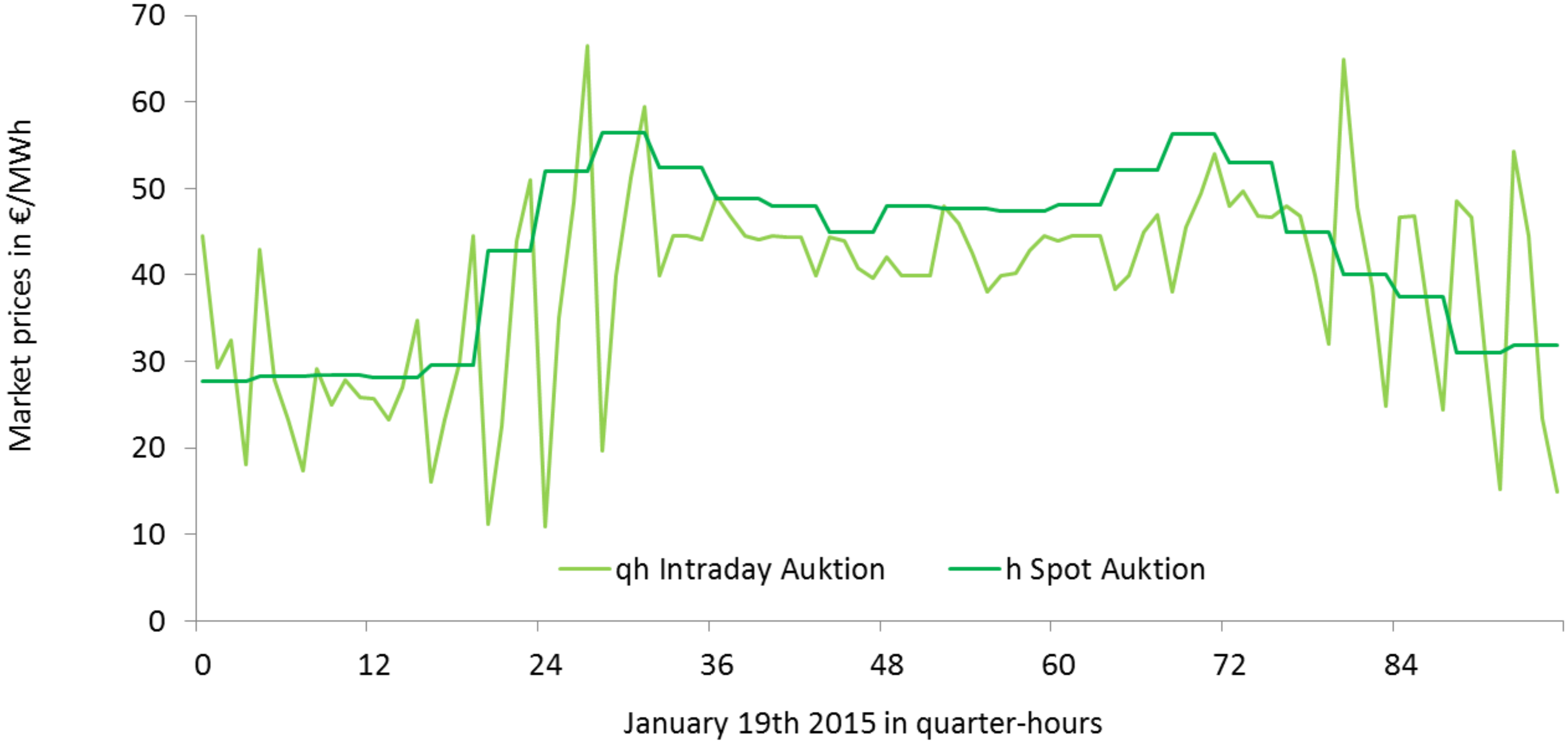
1. **Energy prices dropped because RES (Renewable Energy Sources) with low variable costs entered the Merit Order**
2. **Classical peak-off-peak price profile fluctuates as photovoltaics (PV) feed-in cuts midday peaks**
3. **Long periods with substantial wind feed-in are causing low-price periods with increasing frequency.**

		Spot Auction 1h	Intraday Auction 1/4h	Intraday Continuous 1h	Intraday Continuous 1/4h
yearly average prices	2012	42.85 €/MWh		43.87 €/MWh	35.21 €/MWh
	2013	37.78 €/MWh		38.42 €/MWh	37.76 €/MWh
	2014	32.76 €/MWh	27.68 €/MWh	33.01 €/MWh	32.59 €/MWh
	2015	30.46 €/MWh	30.46 €/MWh	30.78 €/MWh	30.95 €/MWh
yearly standard deviation	2012	18.90 €/MWh		20.22 €/MWh	28.79 €/MWh
	2013	16.46 €/MWh		17.98 €/MWh	23.54 €/MWh
	2014	12.77 €/MWh	17.83 €/MWh	13.72 €/MWh	18.81 €/MWh
	2015	12.61 €/MWh	15.56 €/MWh	13.01 €/MWh	16.93 €/MWh
average volume traded	first 200 days of 2015	25,554 MWh	429 MW	2,882 MWh	474 MW

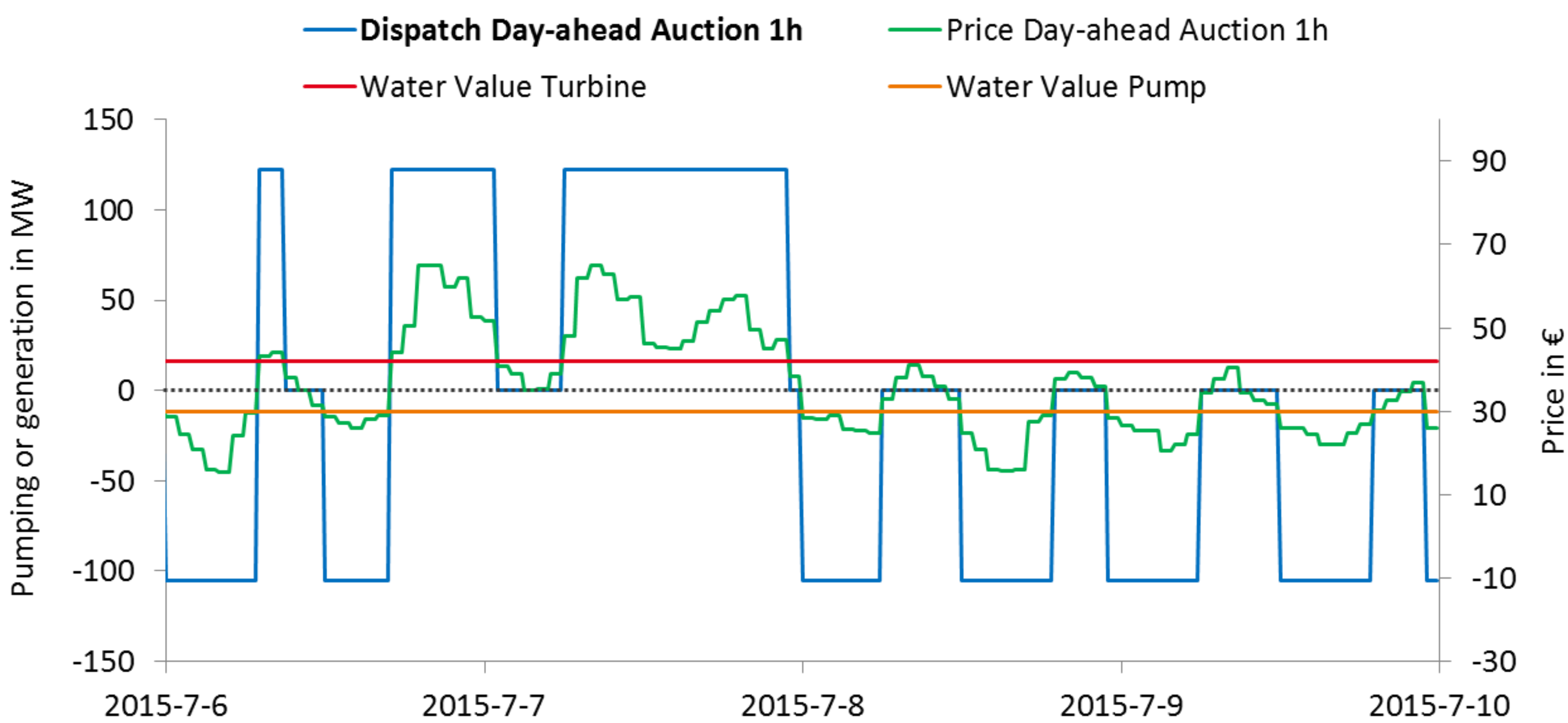
Prices January week



Prices January day

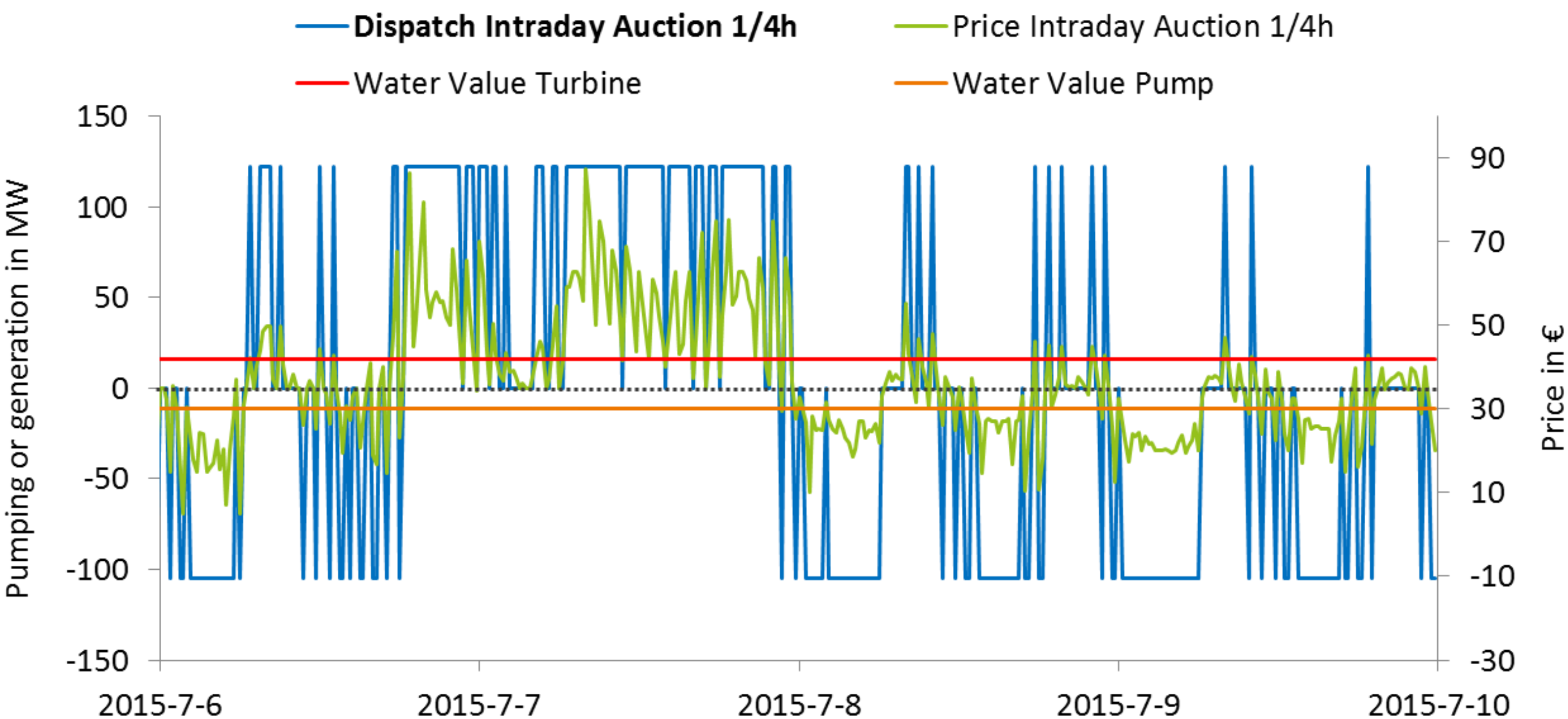


Hourly dispatch of pumped hydro storage



- Machines are switched 17 times from pump to generation mode for hourly Spot market

Quarterly dispatch of pumped hydro storage



- Machines are switched 17 times from pump to generation mode for hourly Spot market
- Machines are switched 129 times when used on quarter-hourly Intraday Auction market

Why post-optimization?

1. **Assuming: perfect markets (full liquidity, no-arbitrage), infinite reservoirs**
   - water values for both markets should be the same
   - either, energy should be sold just on the quarter-hourly Intraday Auction market,
   - or energy should be sold on the hourly Spot market and in a post-optimization on the quarterly Intraday Auction market

2. **Obstacle:**
   - a perfect market does not exist -> no full liquidity
   - reservoir limits

3. **Approach:**
   1) marketing everything on the Spot market
   2) perform a post optimization for Intraday Auction considering liquidity

Multistage quadratic optimization model

First Stage Optimization

1. Objective function:

$$\max_{\substack{turbine\ power \\ pump\ power}} Profit$$

$$\text{Profit} = \sum_{\substack{w \in W \\ t \in T}} \text{PFC}_{\text{t}} \cdot \left(\text{turbine } power_{\text{t,w}} - pump\ power_{t,w}\right) - \text{grid charges}_{t,w}$$

2. Constraints

- Reservoir balancing equations
- Start and end filling level
- Max and min filling level
- Max and min turbine and pump capacity
- Grid charges
- Spillage

3. Symbols

- w∈W=1,...,W: machines
- t∈T=1,...,T: hourly time stages

Second Stage Optimization

1. Objective function:

$$\text{Profit} = \sum_{\substack{w \in W \\ t \in T}} \Big[\big(PFC_t^{short-term} - liquidity\ reduction_t \big) \cdot turbine\ power_{w,t}^{short-term}$$

$$- \big(PFC_t^{short-term} + liquidity\ markup_t \big) \cdot pump\ power_{w,t}^{short-term}$$

$$- \text{grid charges}_{t,w} \Big]$$

2. Additional constraints

- Trading equation

$$final\ turbine\ production_{\ w,t} - final\ pump\ production_{\ w,t}$$
$$= Sell_{w,t} - Buy_{w,t} + turbine\ power_{w,t}^{short-term} - pump\ power_{w,t}^{short-term}$$

- Liquidity

$$liquidity\ reduction_t = turbine\ power_{w,t}^{short-term} \cdot liquidity\ factor$$

$$liquidity\ markup_t = pump\ power_{w,t}^{short-term} \cdot liquidity\ factor$$

Example

Hydro portfolio

Wehr reservoir

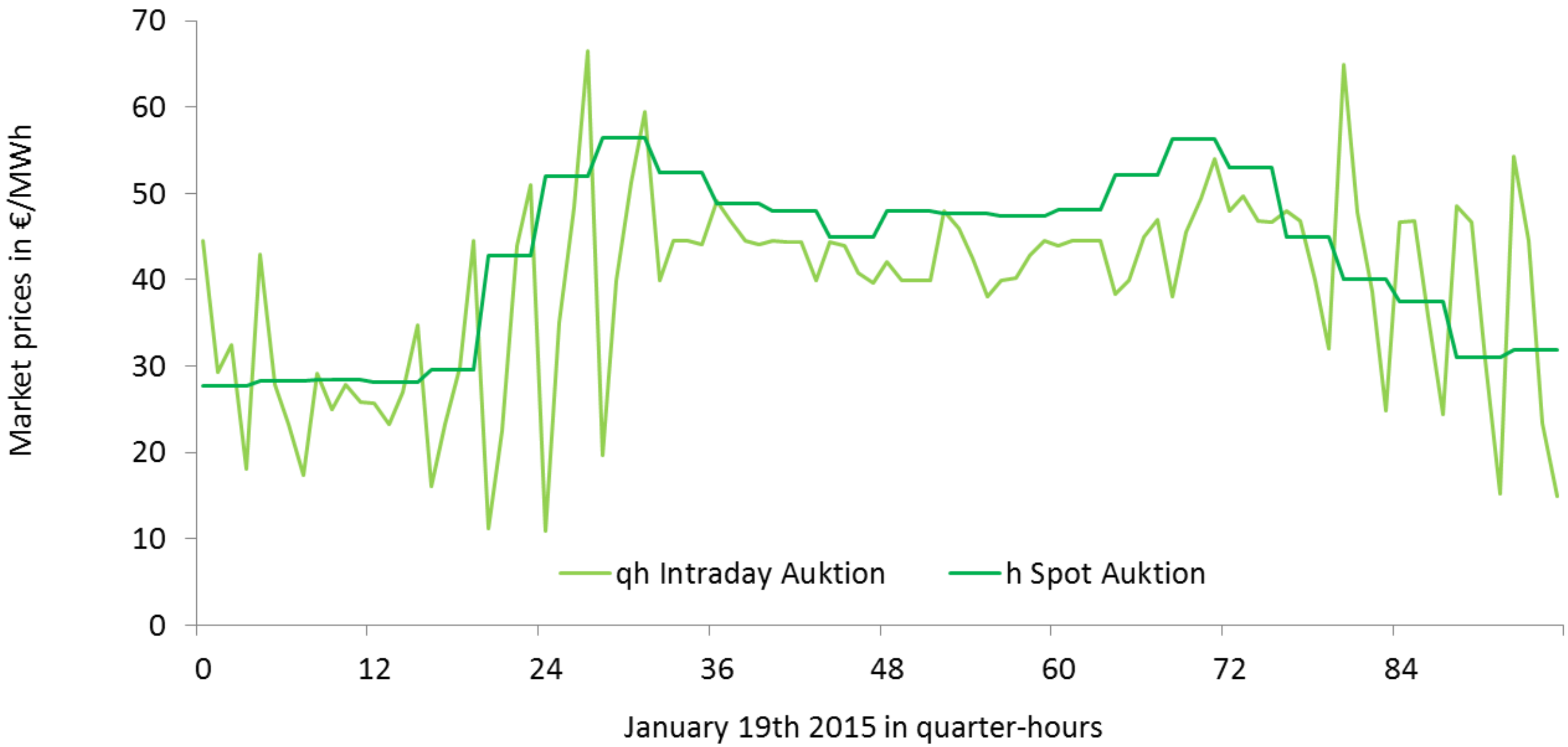
Silvretta reservoir

Kops reservoir

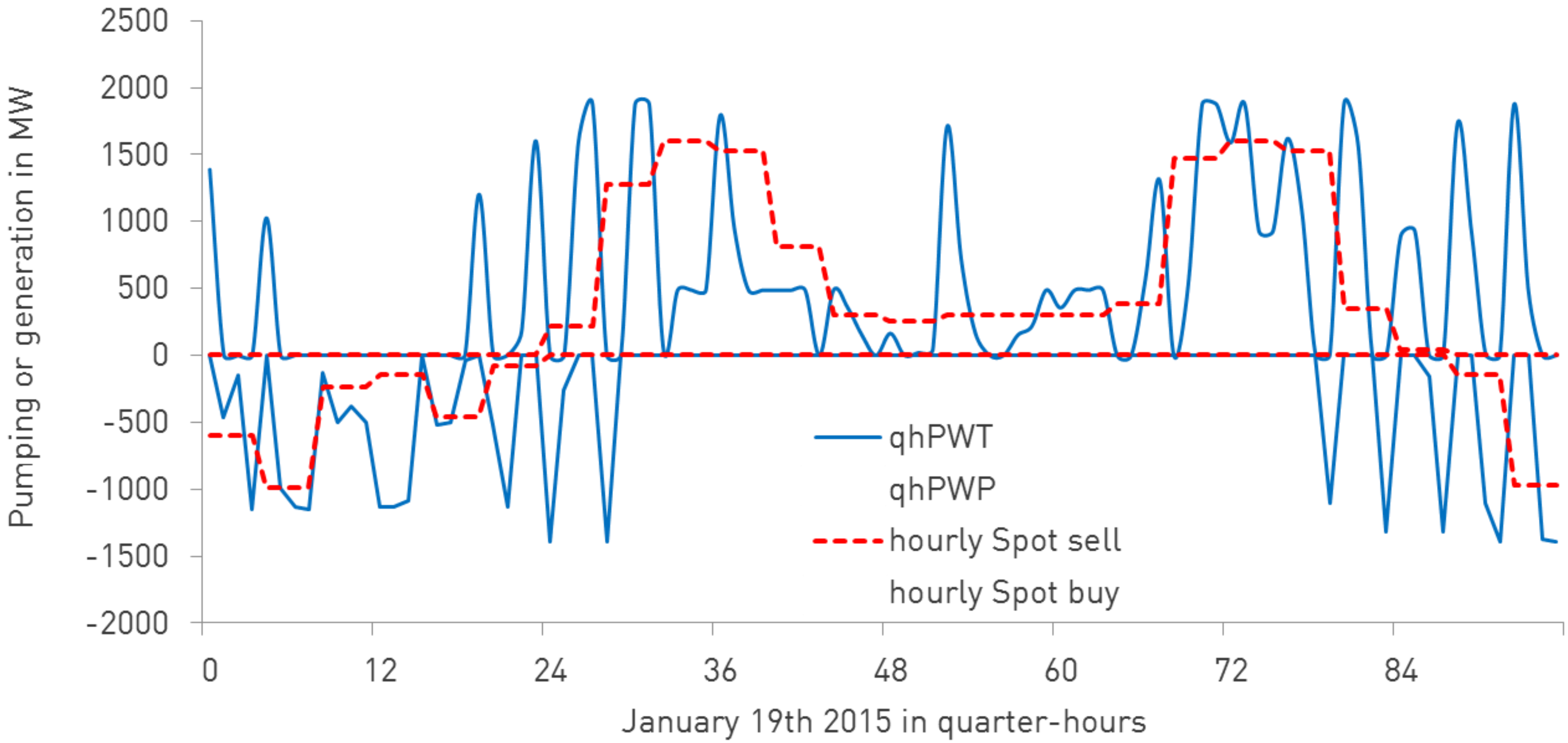
Forbach reservoir

1. **> 2.5 GW generation power**
2. **> 2 GW pumping power**
3. **> 20 reservoirs**
4. **Seasonal and daily pumped hydro storages**

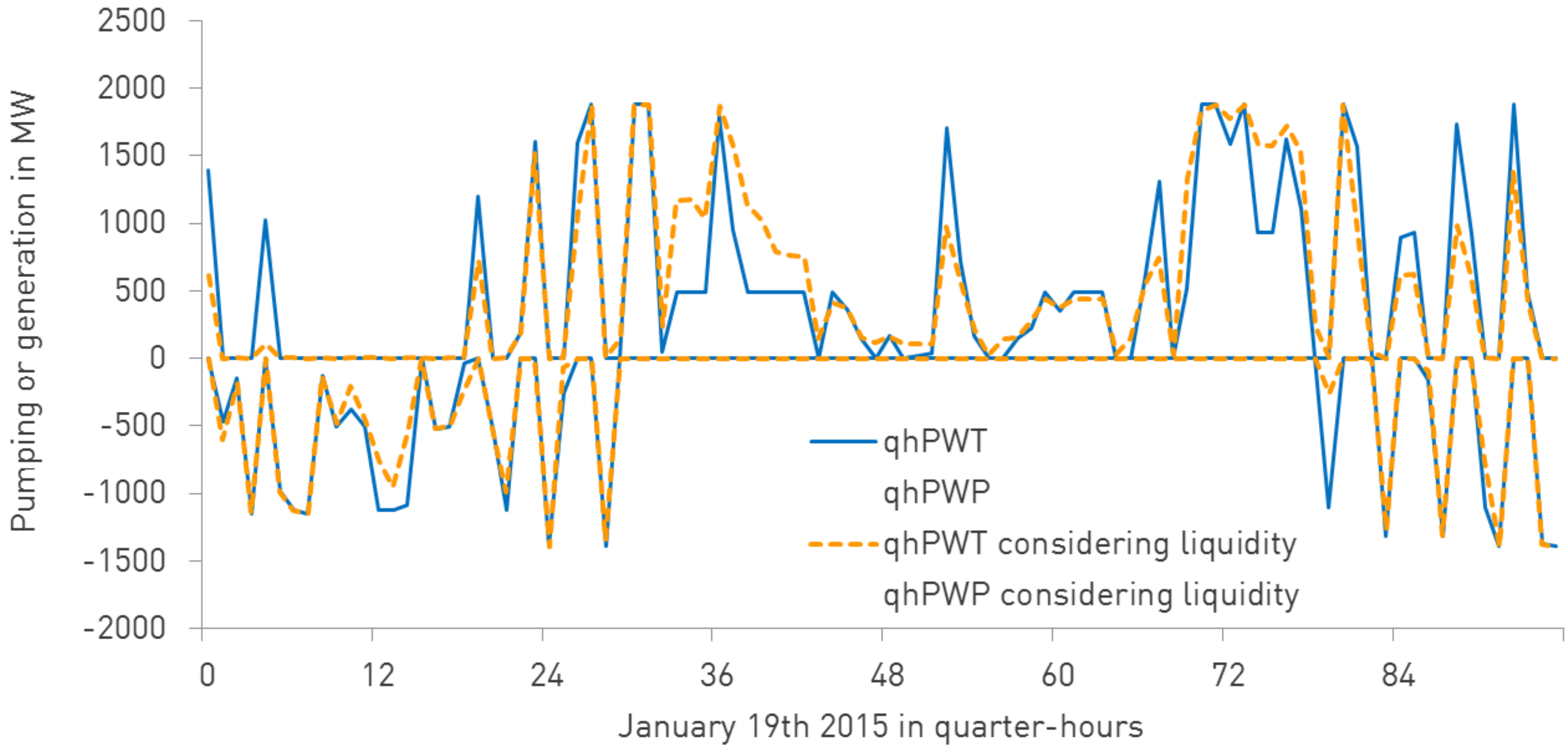
Prices January day



Production Schedule



Production Schedule considering market liquidity



Results

1. **Assuming perfect markets (full liquidity, no-arbitrage) and infinite reservoirs**
   - water values for both markets should be the same
2. **Considering reservoir limits:**
   - water values of seasonal hydro storages for the Intraday Auction 2 to 5€/MWh higher as the water values for the Spot Auction
3. **Considering liquidity:**
   - Assumtion: liquidity 1€/MWh
   - the water values decrease about 0.2 to 1€/MWh
   - Profit decreases because amount traded is reduced and the realized price is lower
4. **Practical application**
   - water values for both markets can be used in short-term position management in every-day's business

Contact

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Questions and Discussion

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