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Systems Analysis and Technology Evaluation (IEK-STE)

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Model-based economic assessment of stationary battery systems providing primary control reserve

16 March 2016 | Johannes Fleer, Sebastian Zurmühlen, Julia Badeda, Peter Stenzel, Jürgen-Friedrich Hake, Dirk Uwe Sauer

Introduction

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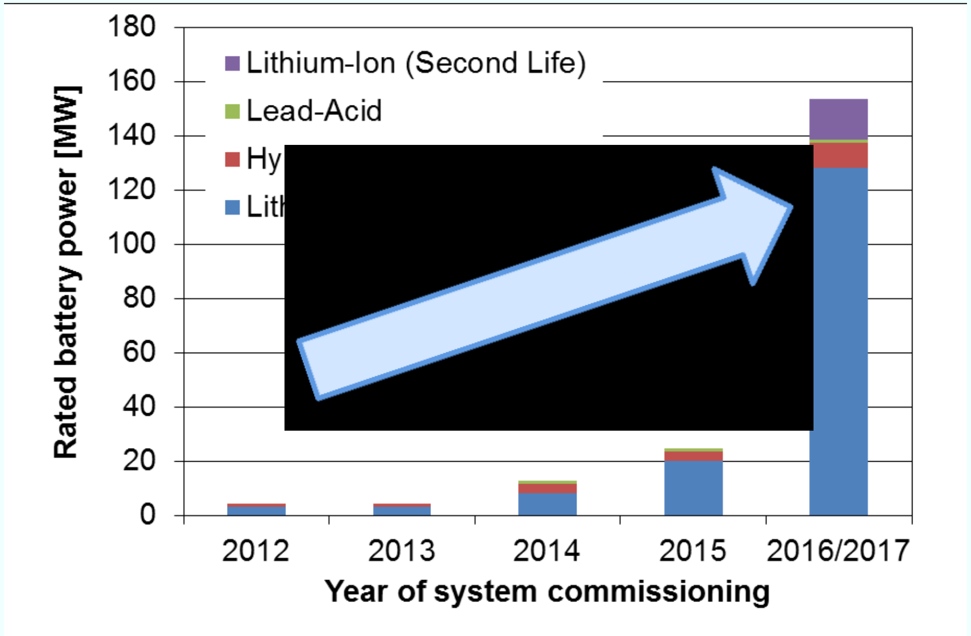

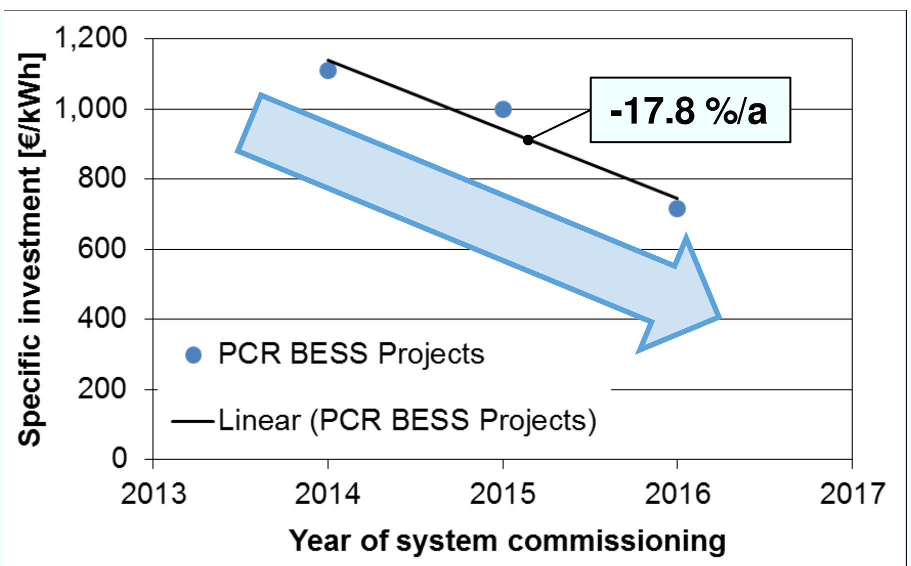

increasing amount of primary control reserve (PCR) supply through stationary BESS

- BESS may reach a market share of 27% on the German PCR market by 2017
- largest project: 90 MW at six different locations (by German utility STEAG)

significantly decreasing system prices

Approach

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Methodology	Data used
▪ simulation model of a battery energy storage system (BESS) providing primary control reserve	▪ grid frequency time series
▪ battery aging model	▪ experimental data on NMC cells
▪ economic assessment using net present value (NPV) approach	▪ BESS prices and price projections ▪ 2015 PCR capacity prices ▪ 2015 EPEX intraday market electricity prices

two case studies in the current German regulatory framework

a 2 MWh BESS providing → 1 MW of PCR (1:2 dimensioned)
→ 2 MW of PCR (1:1 dimensioned)

Model outline

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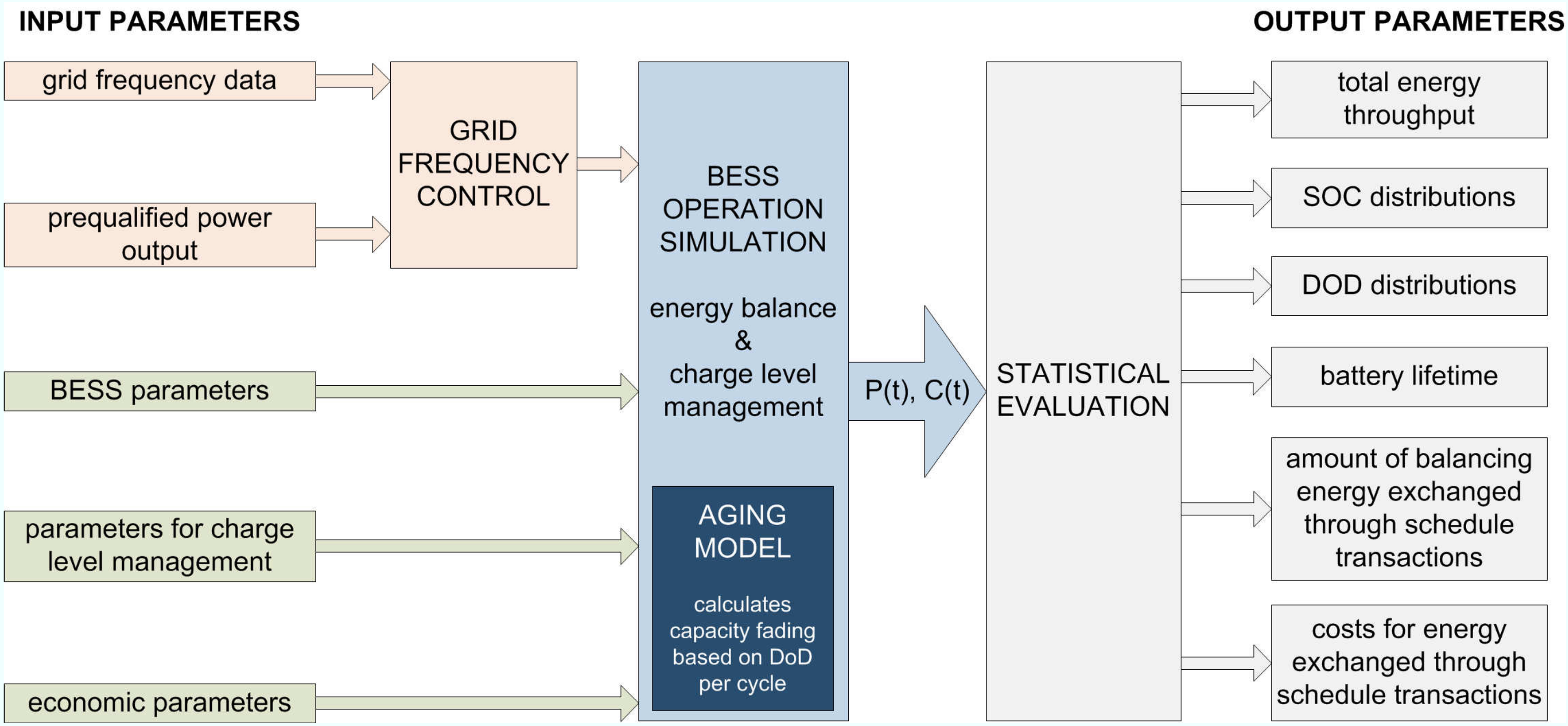

- temporal resolution: one second
- options for charge level management:
  - overfulfillment
  - deadband utilization
  - schedule transactions

- energy flows considered:
  - energy for PCR provision
  - energy for charge level management
  - losses
  - self-consumption

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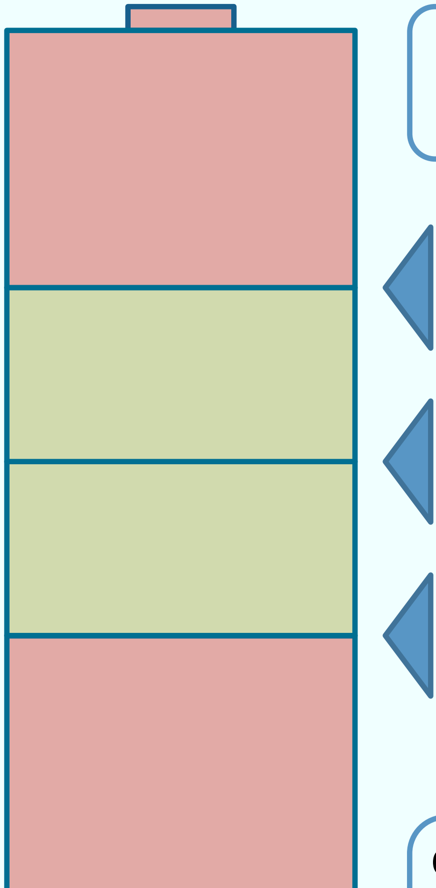
Charge level management implemented in the model

lead time for a schedule transaction (quarter-hourly contract) on the intraday electricity market: 30 to 45 minutes



70% SoC — trigger value for schedule transactions
➔ **discharging process**

50% SoC — set point for overfulfillment and deadband utilization

30% SoC — trigger value for schedule transactions
➔ **charging process**

overfulfillment and deadband utilization are selectively used to

- reduce charging when SoC > 50%
- reduce discharging when SoC < 50%

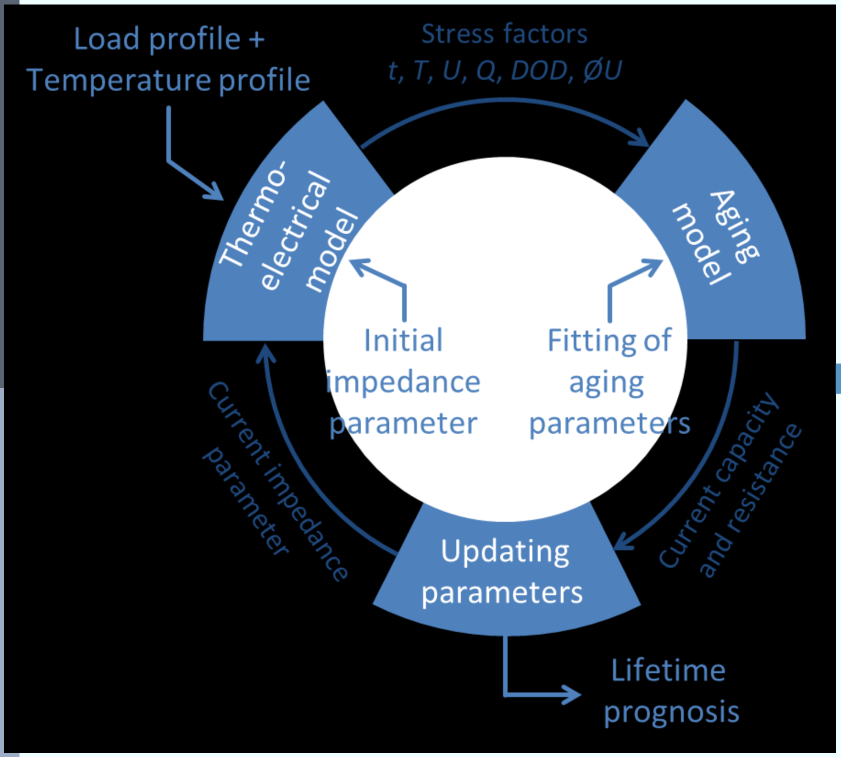
Modeling of battery aging

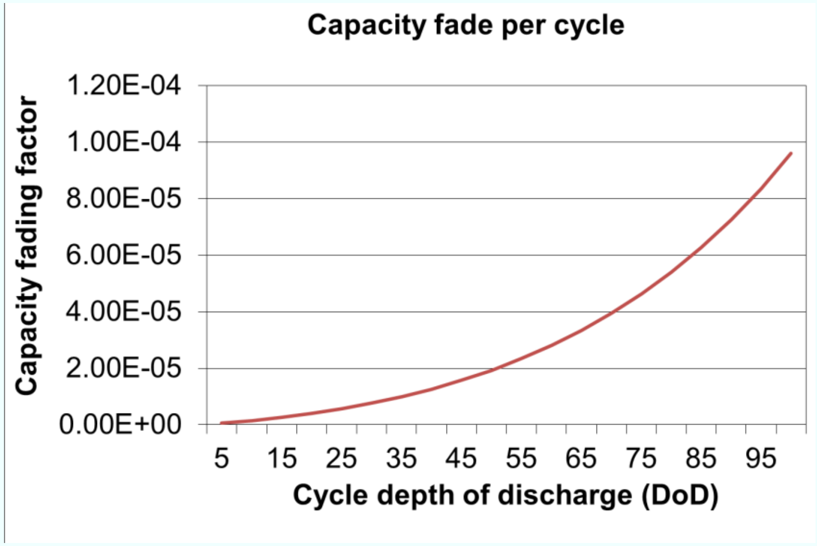
Detailed aging model

- Result of impedance based battery model, originating from EIS measurements
- Extensive aging tests on NMC Li-ion cells for parameter fitting

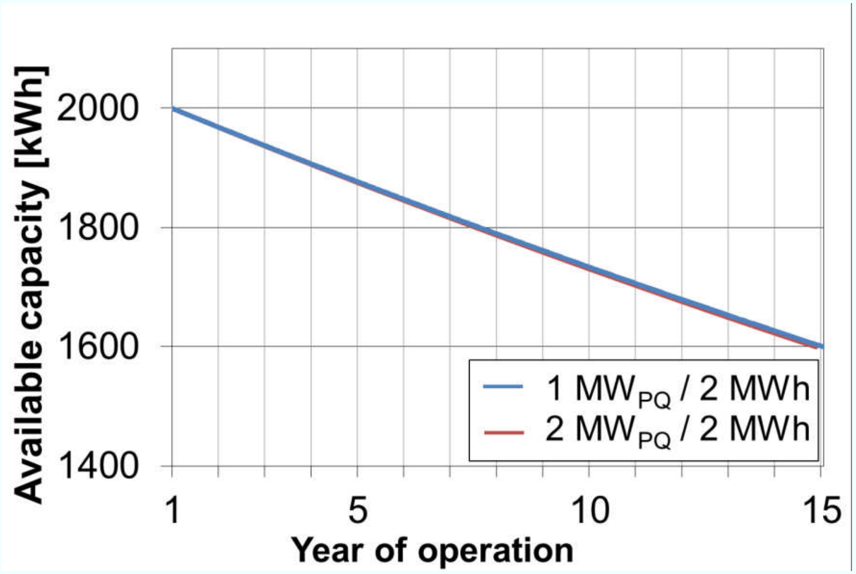
Simplified aging curve

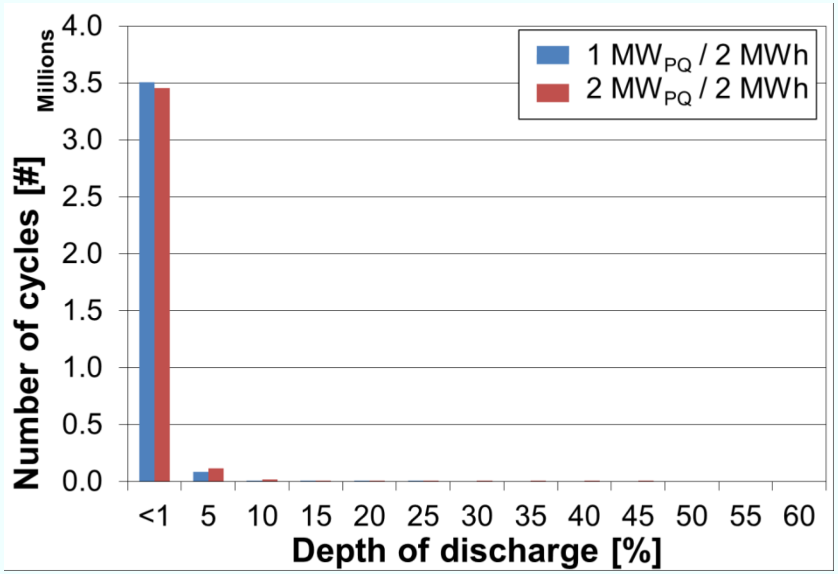
- Derivative from detailed model to be implemented into BESS operation simulation tool
- Wöhler-curve with superposition of calendar aging effects





Battery aging results





- Both systems are expected to reach their end-of-life (80% of initial capacity) after approx. 15 years of operation
- More than 99% of occurring cycles have a DoD < 5%
- A more detailed aging model is required for further investigation

NPV analysis

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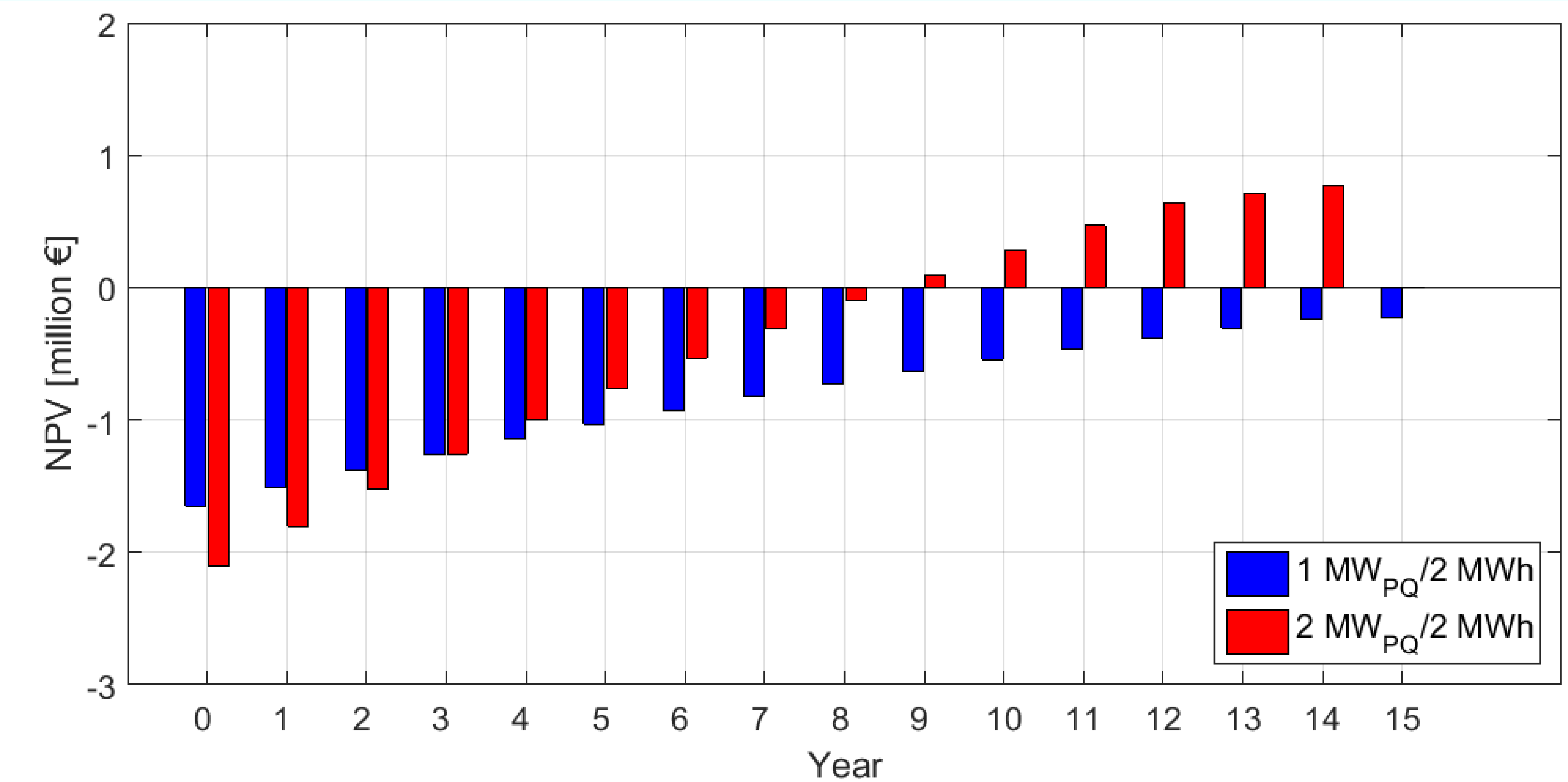
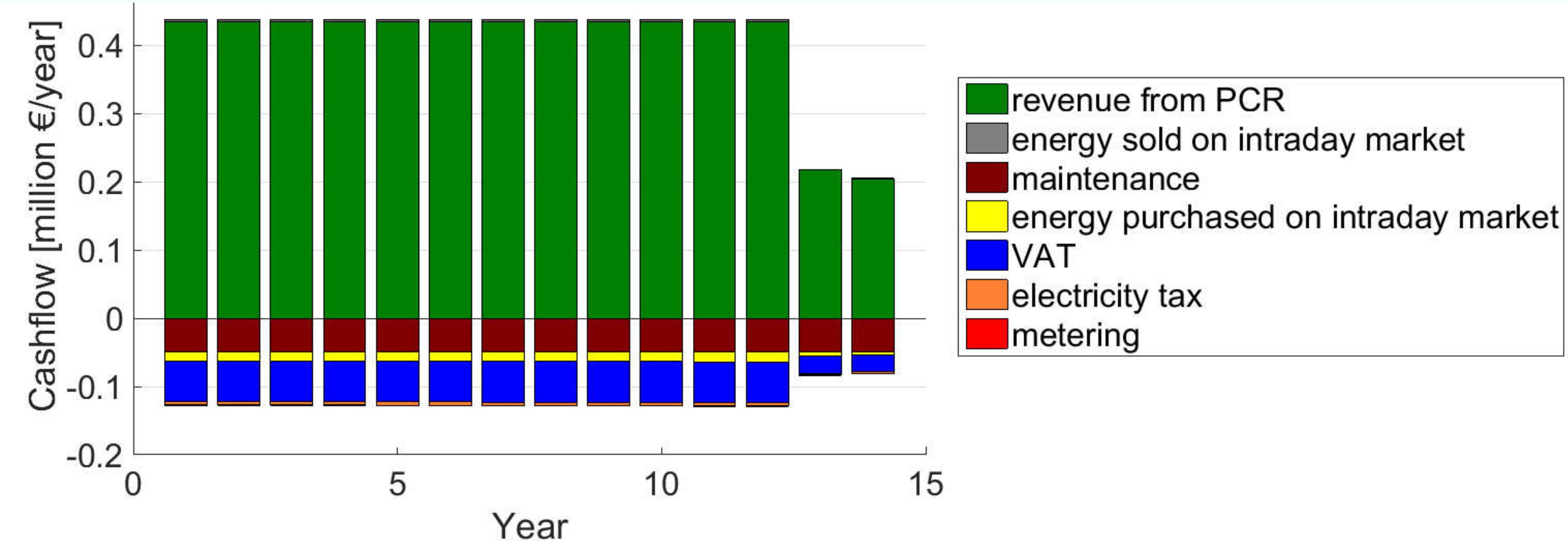


- The 1 MW/2 MWh system is not a business case under current market conditions
- The ammortisation time of the 2 MW/2 MWh system is approx. 9 years, but the tendered PCR capacity had to be reduced to 1 MW after 12 years

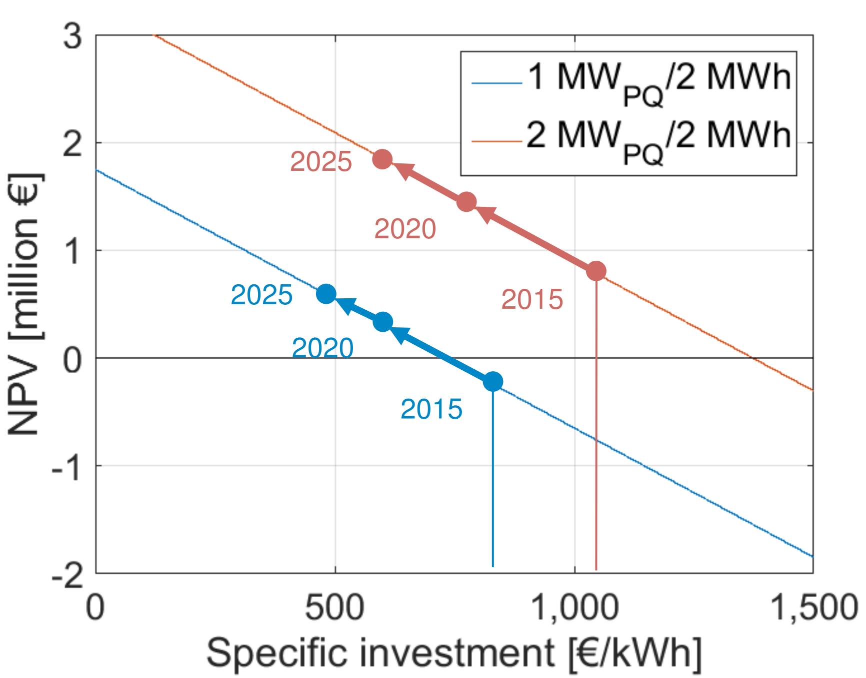
Cashflows

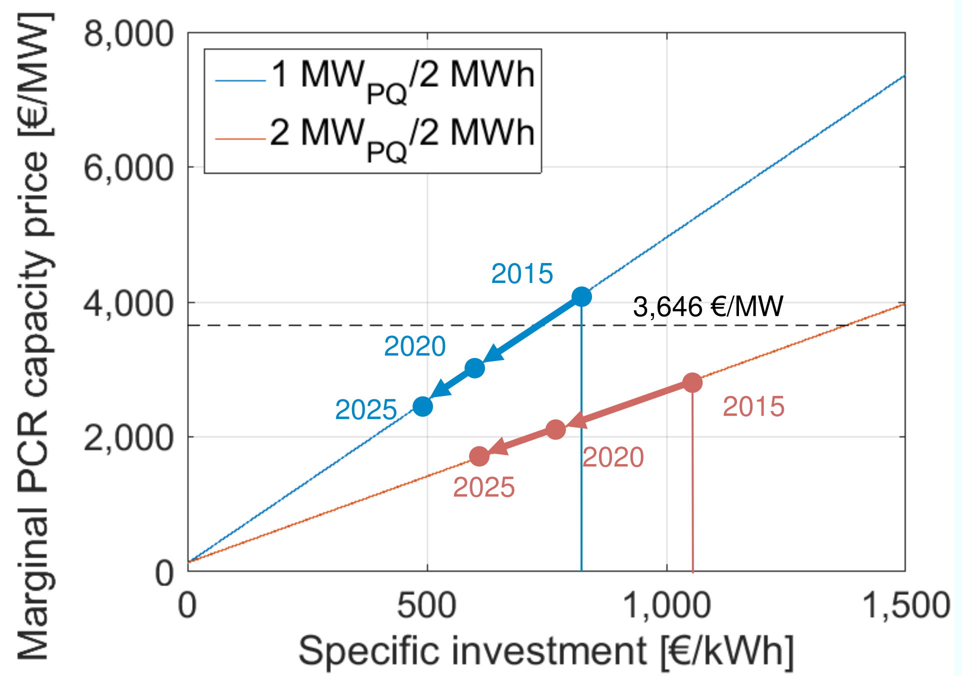
2 MW PCR / 2 MWh BESS capacity



- maintenance and value added tax (VAT) make up largest contributions to operational costs
- schedule transactions on the intraday market play only a minor role

NPV trend analysis & marginal PCR capacity price





- Under the assumption of a constant PCR capacity price, profitability of BESS providing PCR would increase

- Marginal PCR capacity price = lowest price, at which a tenderer can bid at the PCR market and still reach a positive NPV at the end of the BESS lifetime

→ Growing number of BESS participating in the PCR market and sinking battery prices will increase price pressure on the PCR market

Conclusion & outlook

Conclusion

- Results indicate no business case for a 1:2 dimensioned system on the PCR market under the given assumptions
- For the 1:1 dimensioned system, the system price is already below the break-even value
- The simple aging approach cannot reveal the difference between the 1:1 and 1:2 dimensioned system
- Purchase of energy on the intraday market plays only a minor role for the system‘s operating costs

Outlook

➔ Implementation of a more detailed aging model

➔ A more detailed consideration of requirements claimed by the TSOs

➔ Analysis of different bidding strategies and price development on the PCR market

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Back up

BESS operation simulation

State of charge at time t_k: $E(t_k)\ [kWh],\ SOC(t_k)\ [\%]$

Charging/discharging of the battery:

$$\Delta E(t_{k+1}) = \int_{t_k}^{t_{k+1}} P_{PCR}(t)dt + \int_{t_k}^{t_{k+1}} P_{CLM}(t)dt$$

Energy balance to calculate the new state of charge:

$$\Delta E(t_{k+1}) = E(t_k) + \eta_{charge} \cdot \Delta E(t_{k+1}) - \Delta E_{SC}, \qquad \text{if } \Delta E(t_{k+1}) > 0$$

$$\Delta E(t_{k+1}) = E(t_k) + \eta_{discharge} \cdot \Delta E(t_{k+1}) - \Delta E_{SC}, \qquad \text{if } \Delta E(t_{k+1}) < 0$$

State of charge at time t_{k+1}:

$$SoC(t_{k+1}) = \frac{E(t_{k+1})}{C_{Bat}}$$

Check if SOC is inside permissible range to determine measures of charge level management:

$$SoC_{low} < SoC(t_{k+1}) < SoC_{high}$$

Assumptions: Technical parameters

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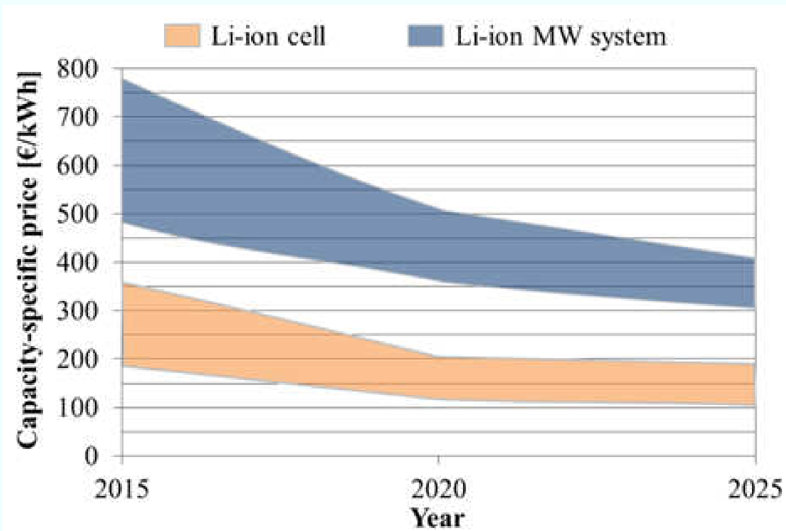
Parameter	Value
prequalified power for PCR supply	1 MW_{PQ} / 2 MW_{PQ}
rated power	1.8 MW / 3.6 MW
nominal capacity at start	2 MWh
charging efficiency	95 %
discharging efficiency	95 %
self-consumption	13.86 kW per MW_{PQ}
SoC set point for overfulfillment and deadband utilization	50 %
upper SoC limit for schedule transactions	70 %
lower SoC limit for schedule transactions	30 %
contract duration for schedule transactions	15 minutes
power rating and energy exchange per schedule transaction for the 1 MW_{PQ}/2 MWh system	0.8 MW 0.2 MWh
power rating and energy exchange per schedule transaction for the 2 MW_{PQ}/2 MWh system	1.6 MW 0.4 MWh
End of Life criterion	80 % C_{nom}

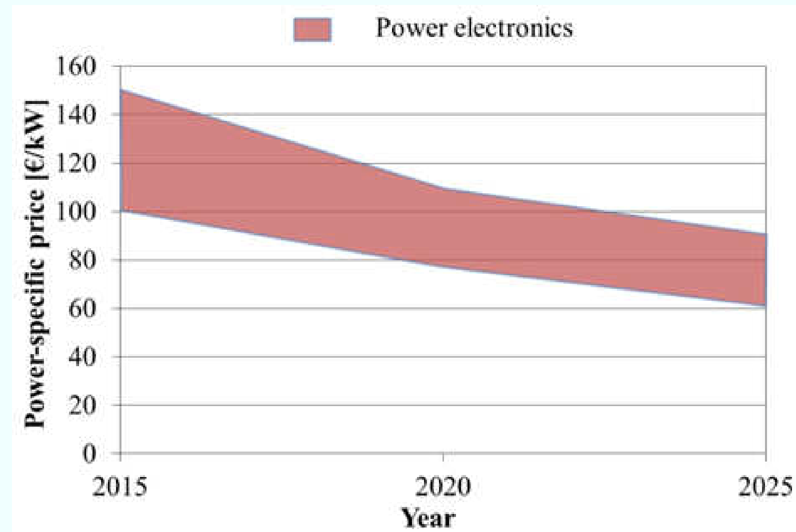
Assumptions: Economic parameters

Parameter	Value
capacity-specific investment (includes battery cells, cell housing, cell connectors, battery module diagnostics, battery management system, cooling system and building)	600 €/kWh
power-specific investment (power electronics, transformers (10 kV), contactors, fuses, control systems and air conditioning)	250 €/kW
discount rate	5%
maintenance	2 % of investment per year
revenues from PCR supply	3646 €/week (see Tab. 2)
costs/revenues from schedule transactions (based on 2015 spot market data)	vary for each transaction
value added tax (VAT)	19 %
tax on electricity (only applied to self-consumed energy)	20.50 €/MWh
charge for electricity metering	631.60 €/year

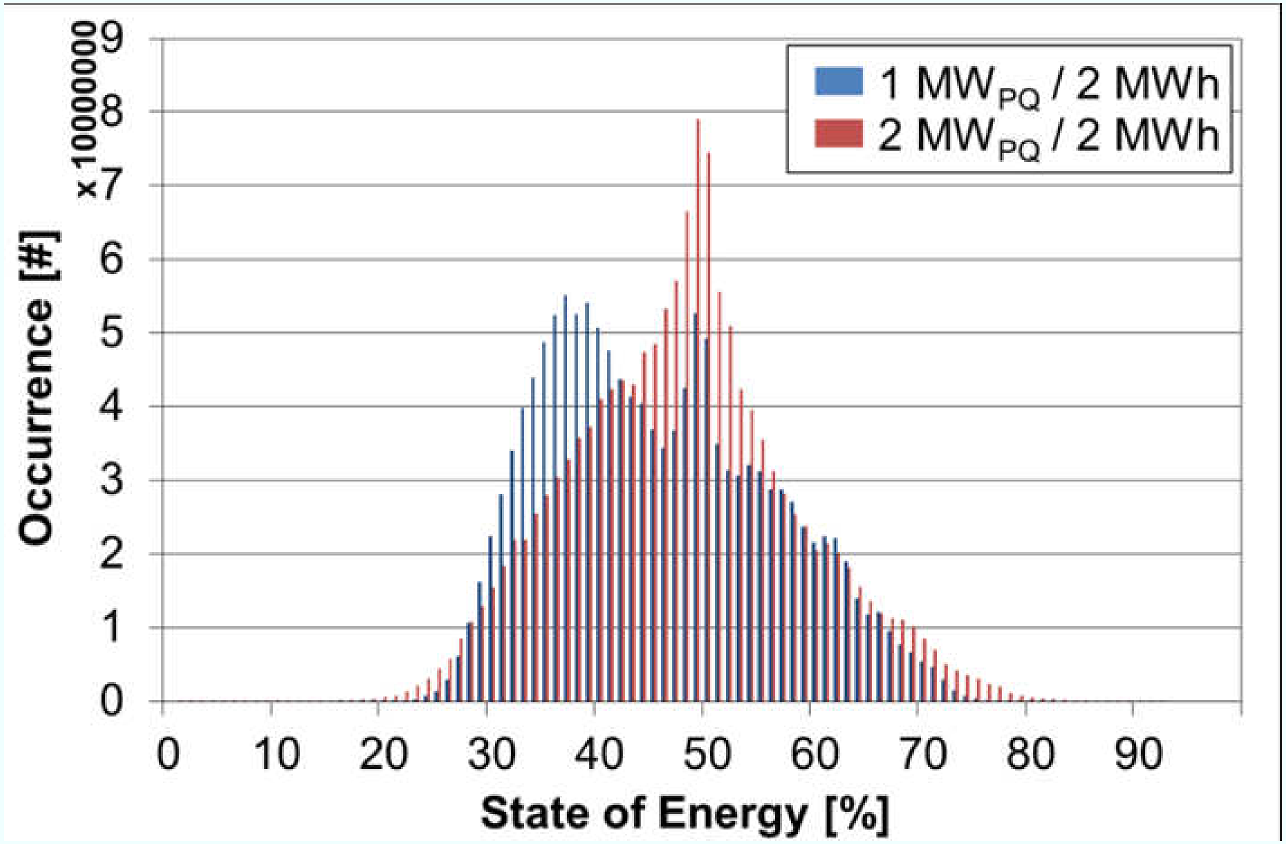
NPV approach: $NPV(i,T) = -Inv_0 + \sum_{t=1}^{T} \frac{R_t}{(1+i)^t},\qquad Inv_0 = Inv_{cap} + Inv_{power}$

Projected battery price development





States of energy histogram



Decreasing PCR prices and decreasing spread in 2016

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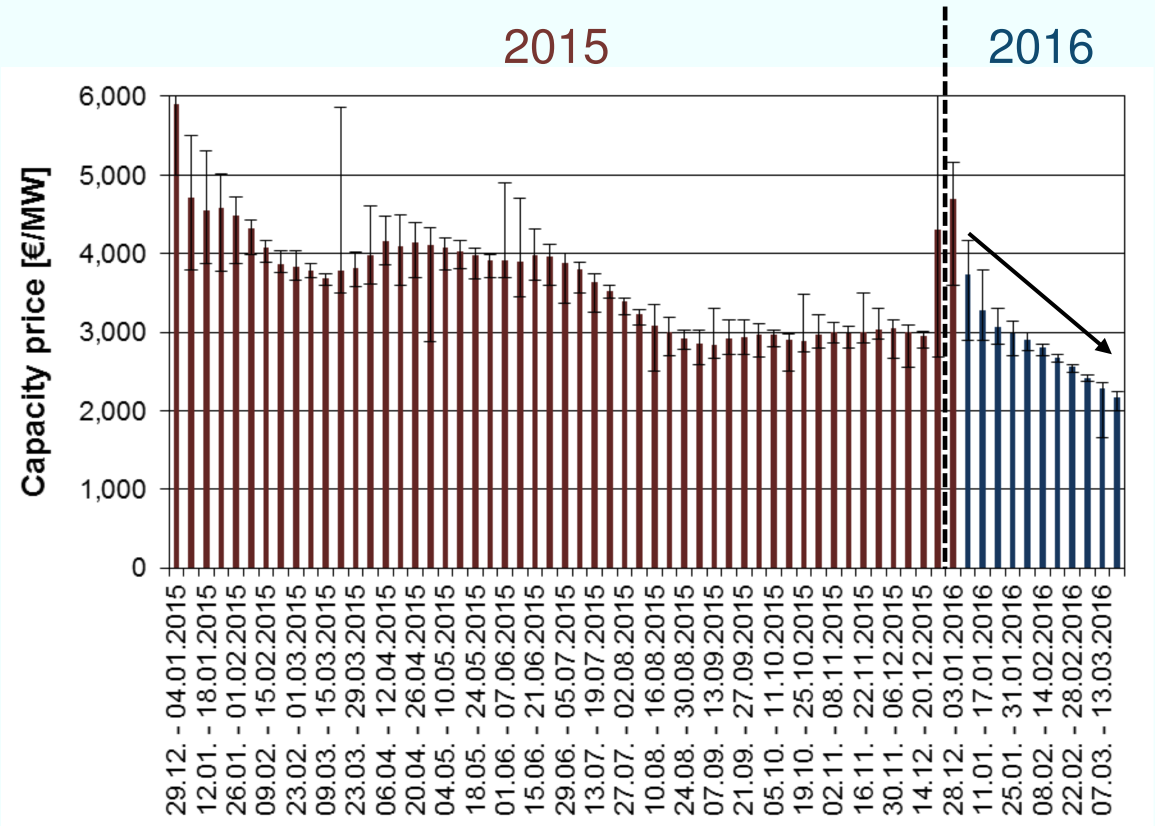

Average capacity price 2015:	3,646 €/MW
Average capacity price 2015 (week 1-12):	4,296 €/MW
Average capacity price 2016 (week 1-12):	2,964 €/MW

DoDs logarithmic