Techno-economic analyses of lithium-ion and redox-flow batteries for a 2 MW PV power plant in Germany

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AGENDA

- Classification of redox-flow and lithium-ion batteries
- Economic analyses of a PV power plant in combination with redox-flow and lithium-ion battery systems
- Sensitivity analyses
- Conclusions

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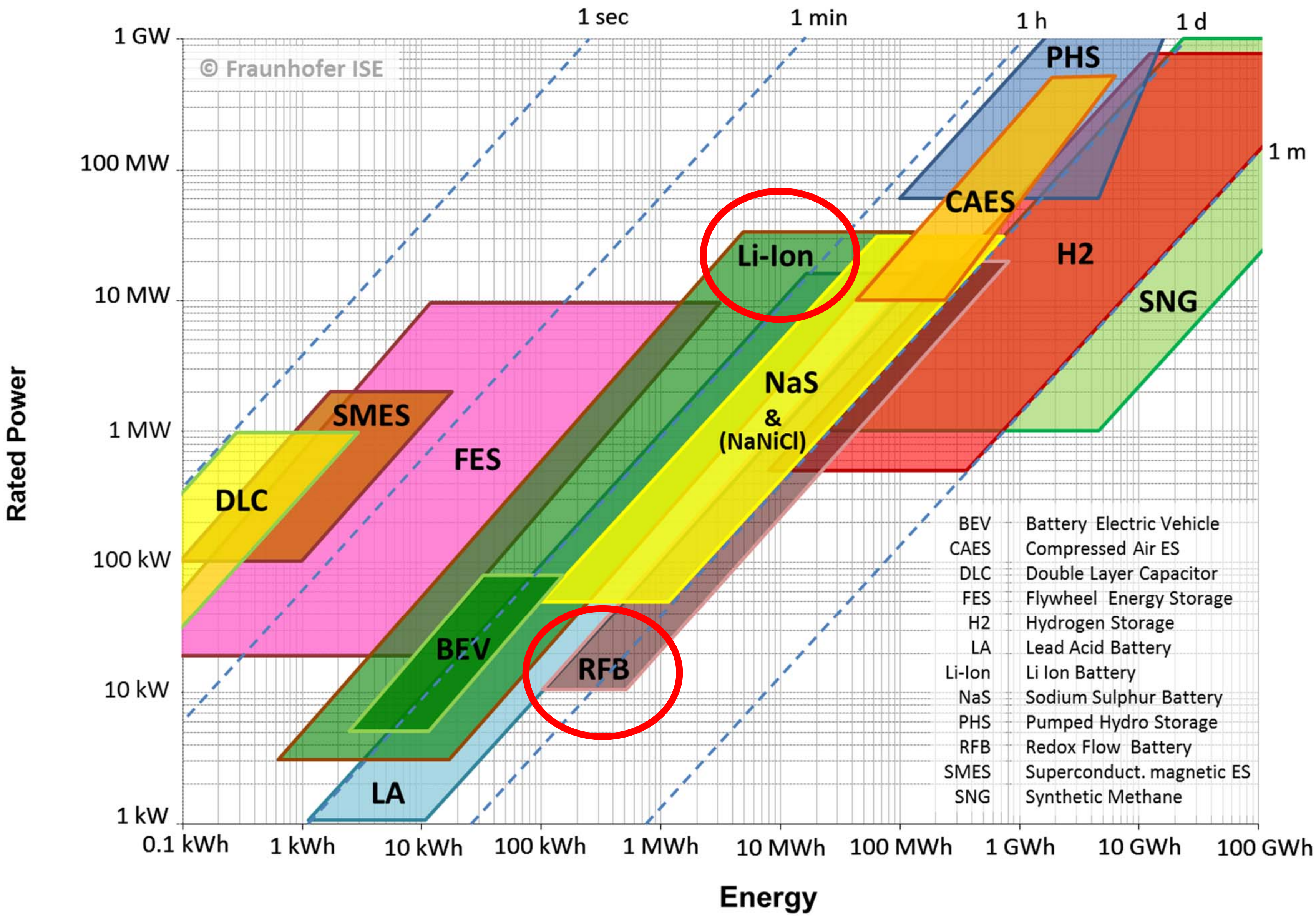
Classification of storages



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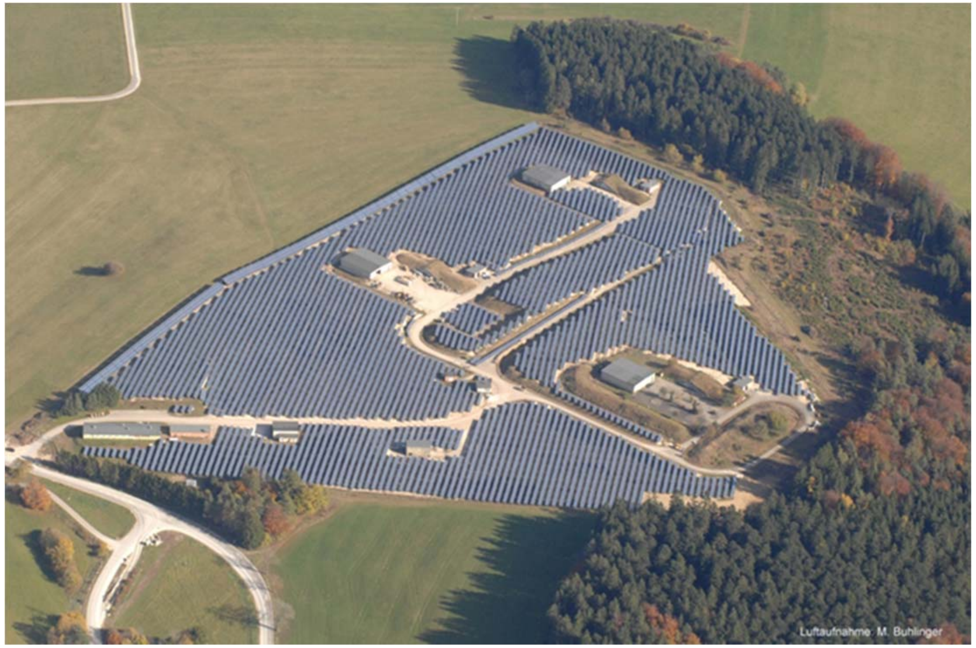
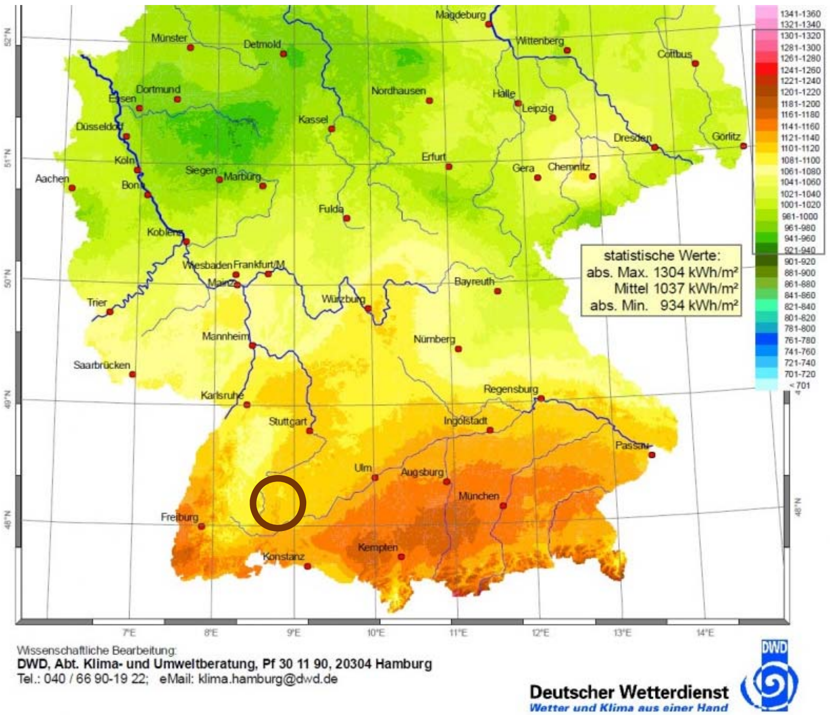
Considered PV power plant in Germany

Installed power	5 101 kWp
2011 generated energy	5 861 000 kWh
Solar modules	22 360
Located	48.072°N / 8.796, 940 üNN Schwäbische Alb
Operation since	01.06.2010
Operating company	BES GmbH, Dürbheim





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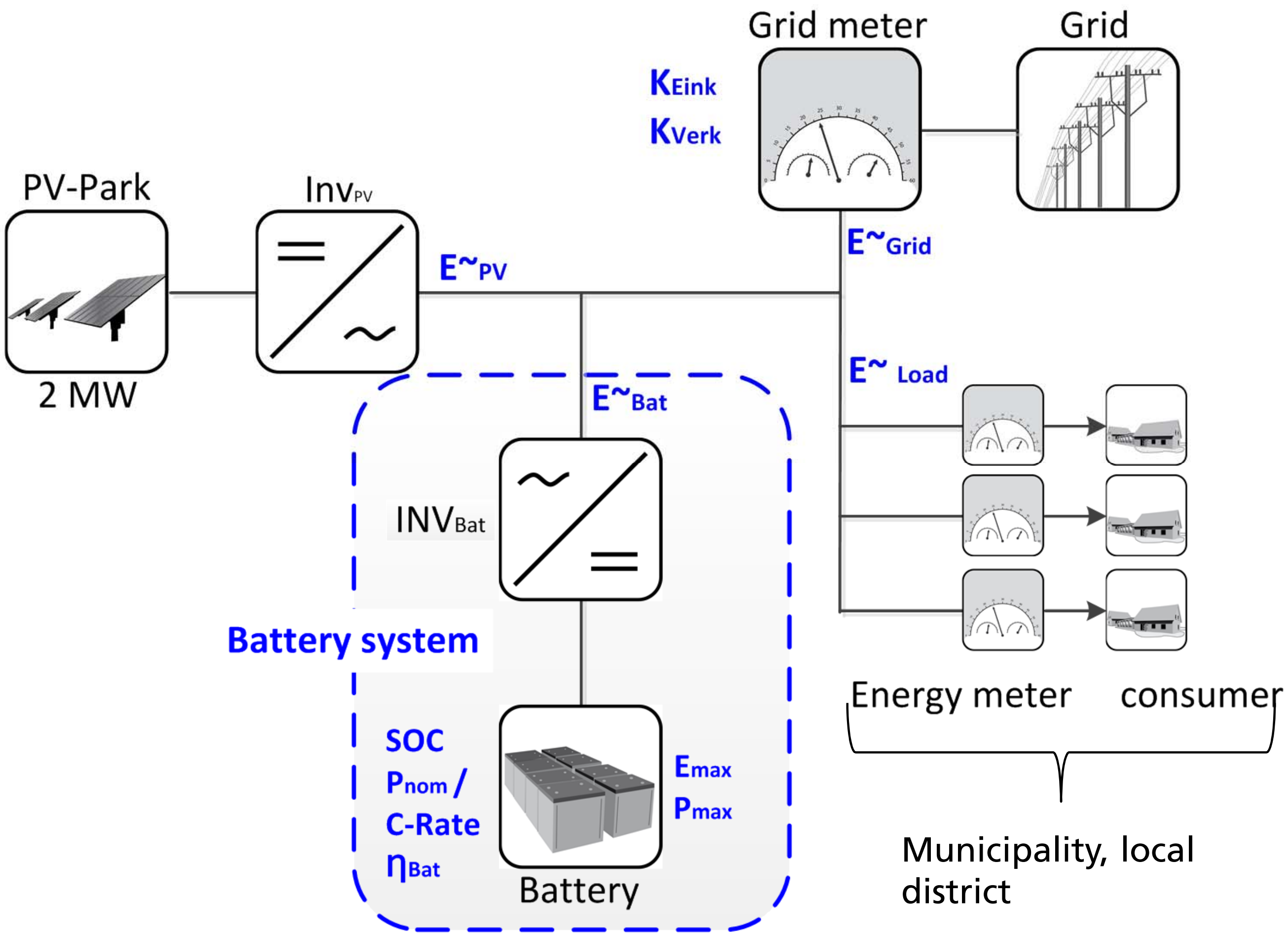
Case study: PV power plant with battery storage

Targets:

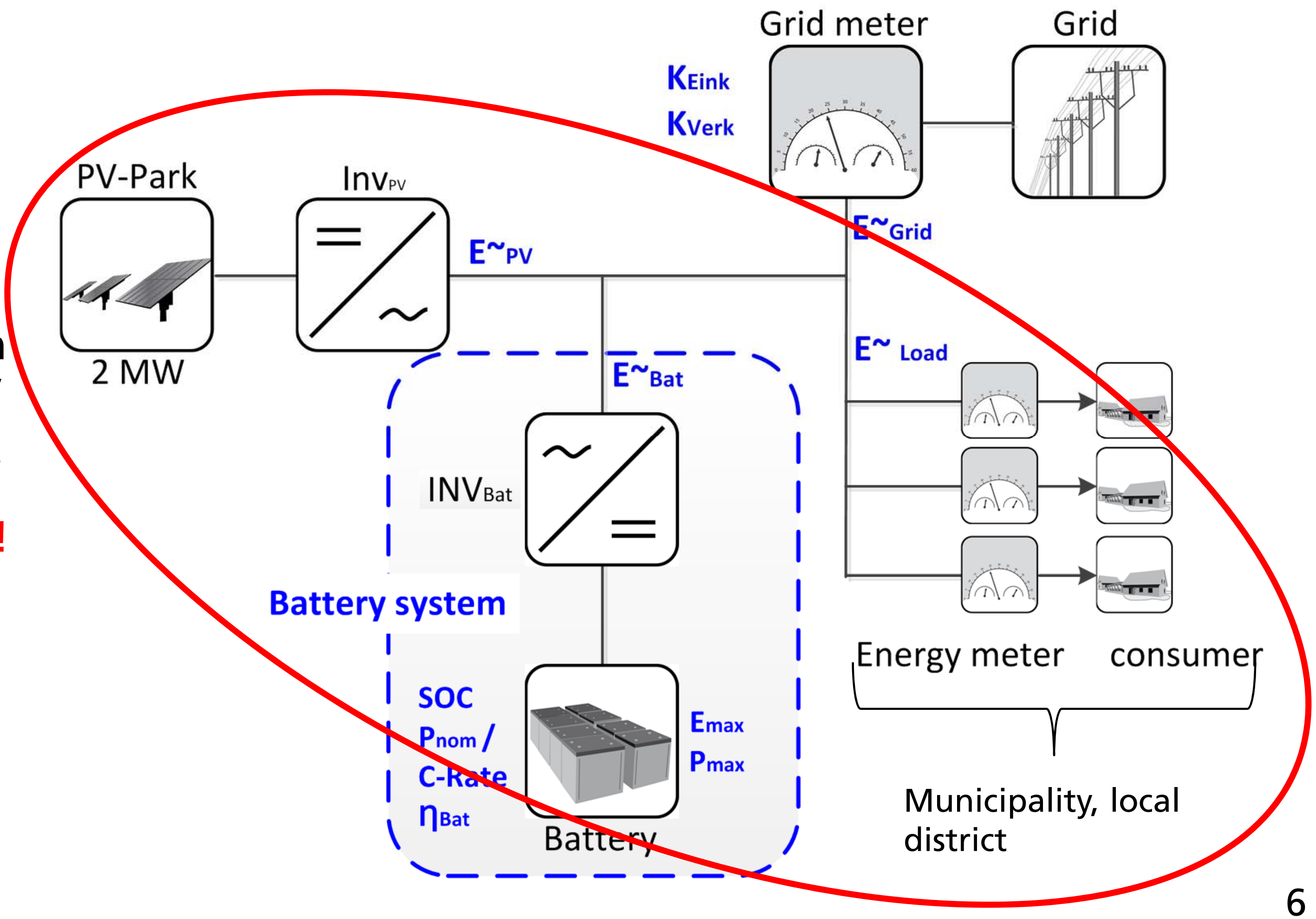
- Maximization of solar fraction
- Minimization of energy purchased from the grid
- Quick amortization time of the battery



Case study: PV power plant with battery storage

Targets:

- Maximization of solar fraction
- Minimization of energy purchased from the grid
- Quick amortization time of the battery
- No additional costs for the local distribution grid !!!



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Case study: PV power plant with battery storage

- Approach:
  - Annual savings → reduction of "external" electricity costs
  - Annual savings → what a battery can cost

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Case study: PV power plant with battery storage

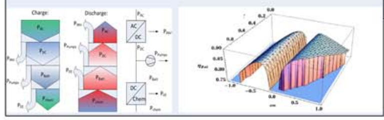
- Approach:
  - Annual savings → reduction of "external" electricity costs
  - Annual savings → what a battery can cost

- Method:
  - Use of input profiles (PV generation and loads)
  - Battery dimensioning
  - Annual simulation
  - Internal rate of return (IRR)

Battery dimension:
Power & Energy

- Load profile
- Generation profile
- EEX – stock market prices
- Consumer tariff

Battery model



- Annual savings
- Optimized battery design for the application

LCC

$$I_0 = \frac{L_n}{(1+i)^n} + \sum_{t=0}^{n} \frac{e_t - a_t}{(1+i)^t}$$

$$I_0 = k \cdot e \qquad k = \left(\frac{i \cdot (1+i)^n}{(1+i)^n - 1} + x\right)^{-1}$$

- factor of proportionality (project time, operation costs, discount rate)

- Specific storage costs
- Specific investment costs for the battery

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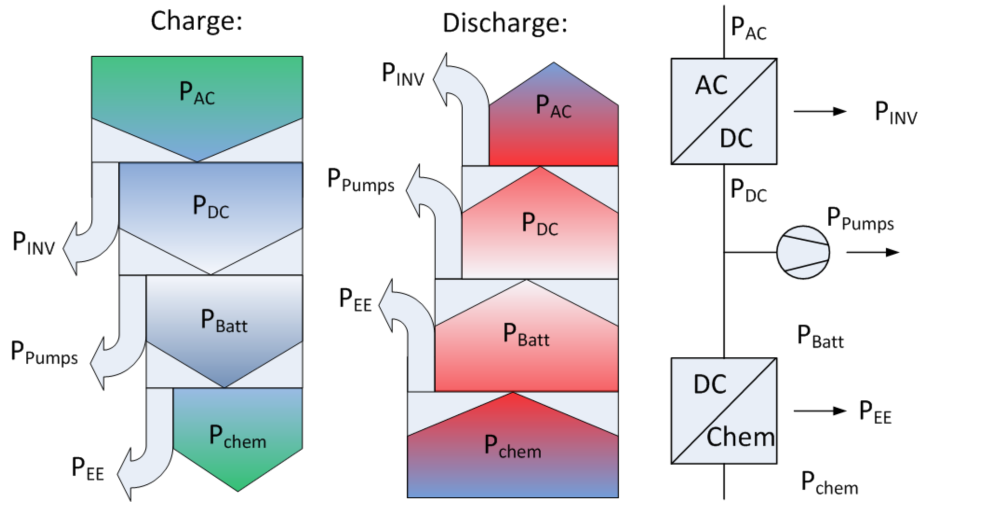
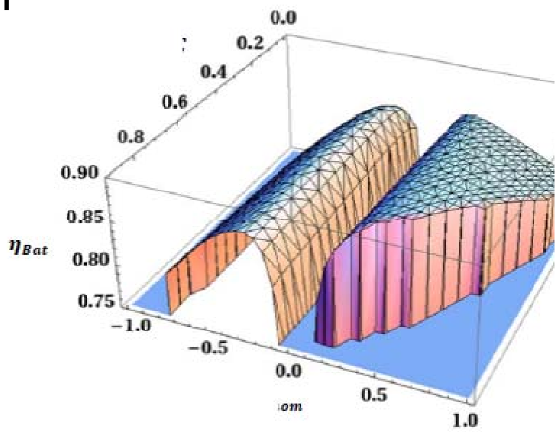
Simulation models

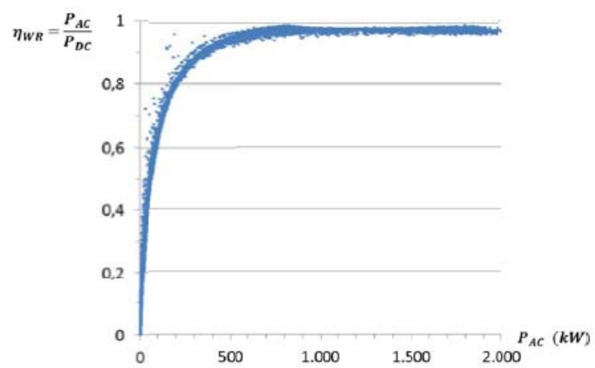
- Energy flux models
- Battery model
  - Efficiency according to power and SOC
- Inverter model
  - Efficiencies depending on requested power
- AC round-trip efficiency
  - Redox-flow approx. 66 %
    - Inverter: 95 %
    - Battery: 73 %
  - Lithium approx. 81 %
    - Inverter: 95 %
    - Battery: 90 %



Efficiency losses for a redox-flow battery



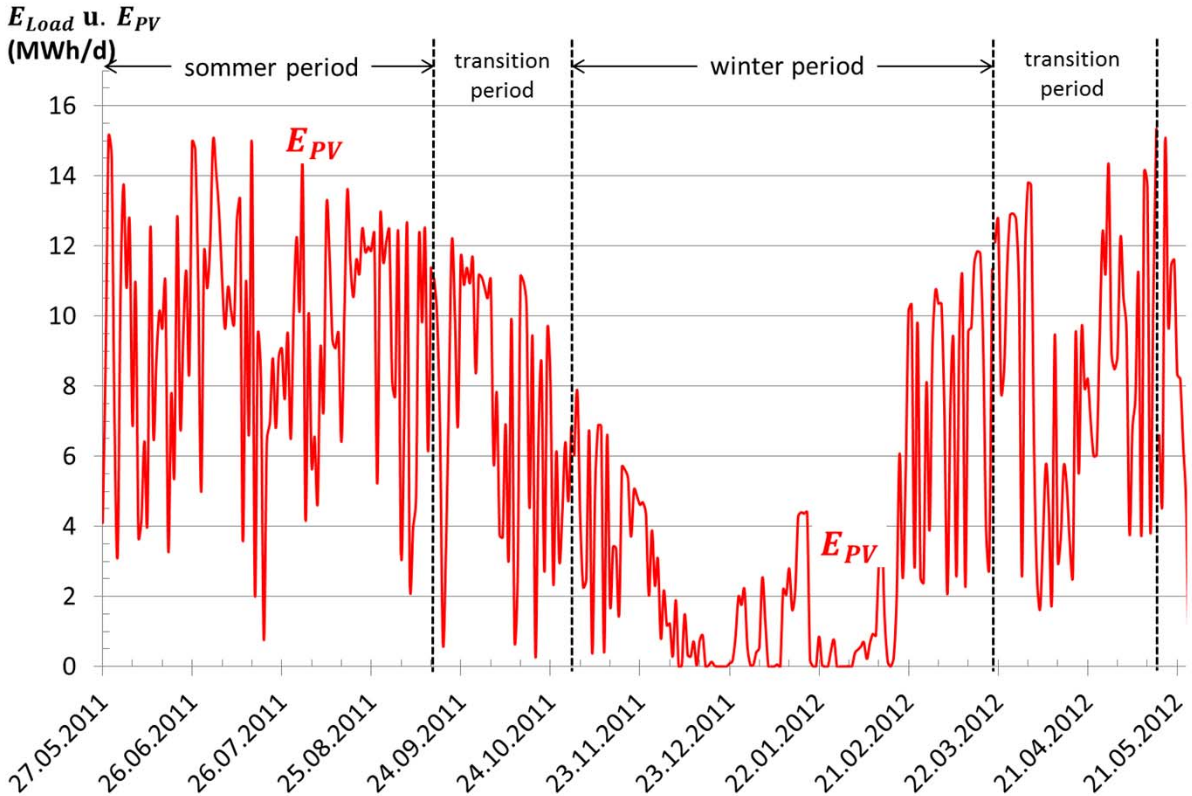
Efficiency of a redox-flow battery according to SOC and requested power



Efficiency of an inverter according to requested power

Input data: Energy fluxes

- PV generation profile
  - 27.5.2011 to 21.5.2012
- Load profile divided into three periods
  - Summer
  - Transition
  - Winter



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Input data: Energy fluxes

- PV generation profile
  - 27.5.2011 to 21.5.2012
- Load profile divided into three periods
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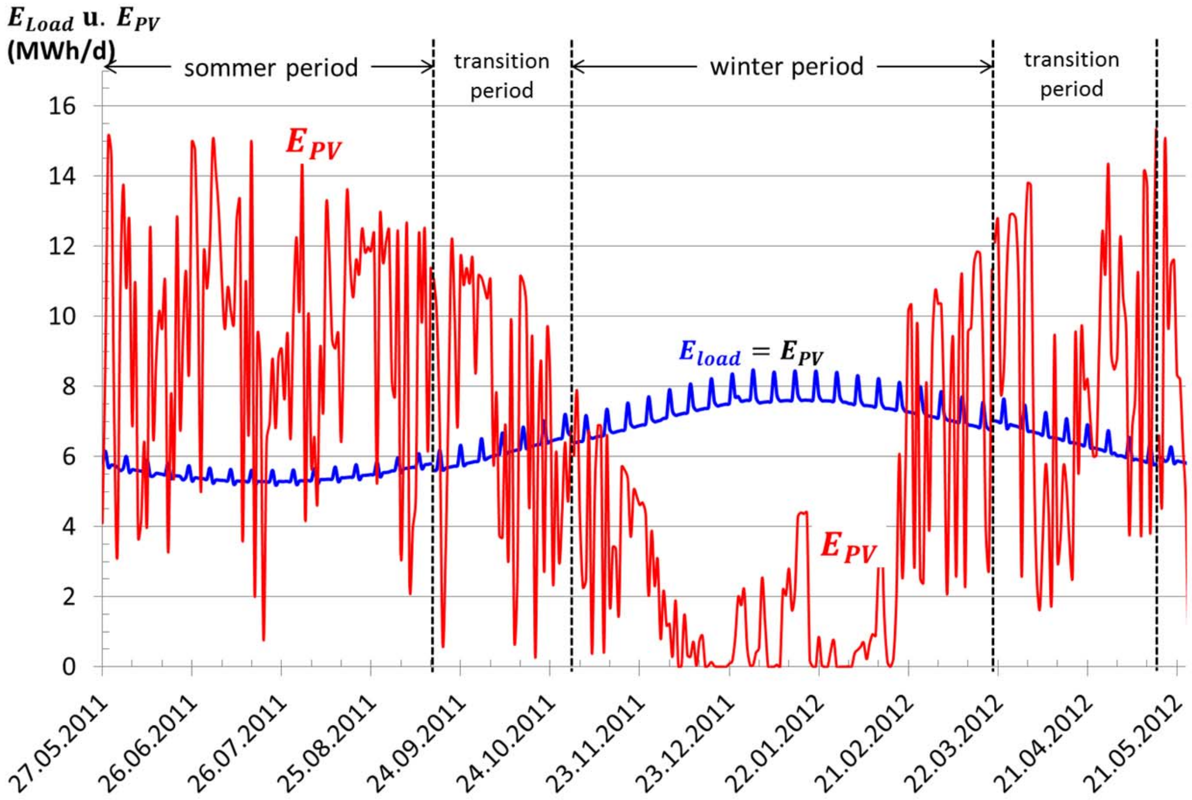
  - Winter
- Variation of the considered load profile
  - Transition time: $E_{load} = E_{PV}$



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Input data: Energy fluxes

- PV generation profile
  - 27.5.2011 to 21.5.2012
- Load profile divided into three periods
  - Summer
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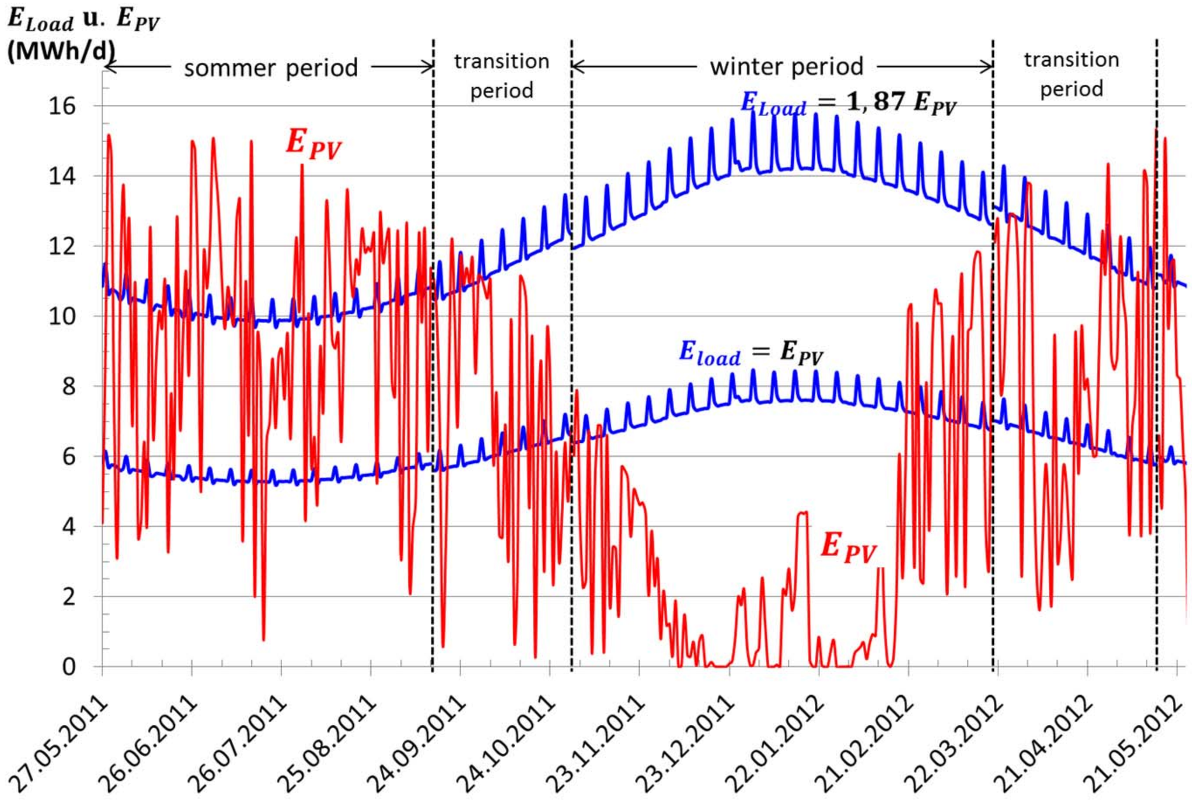
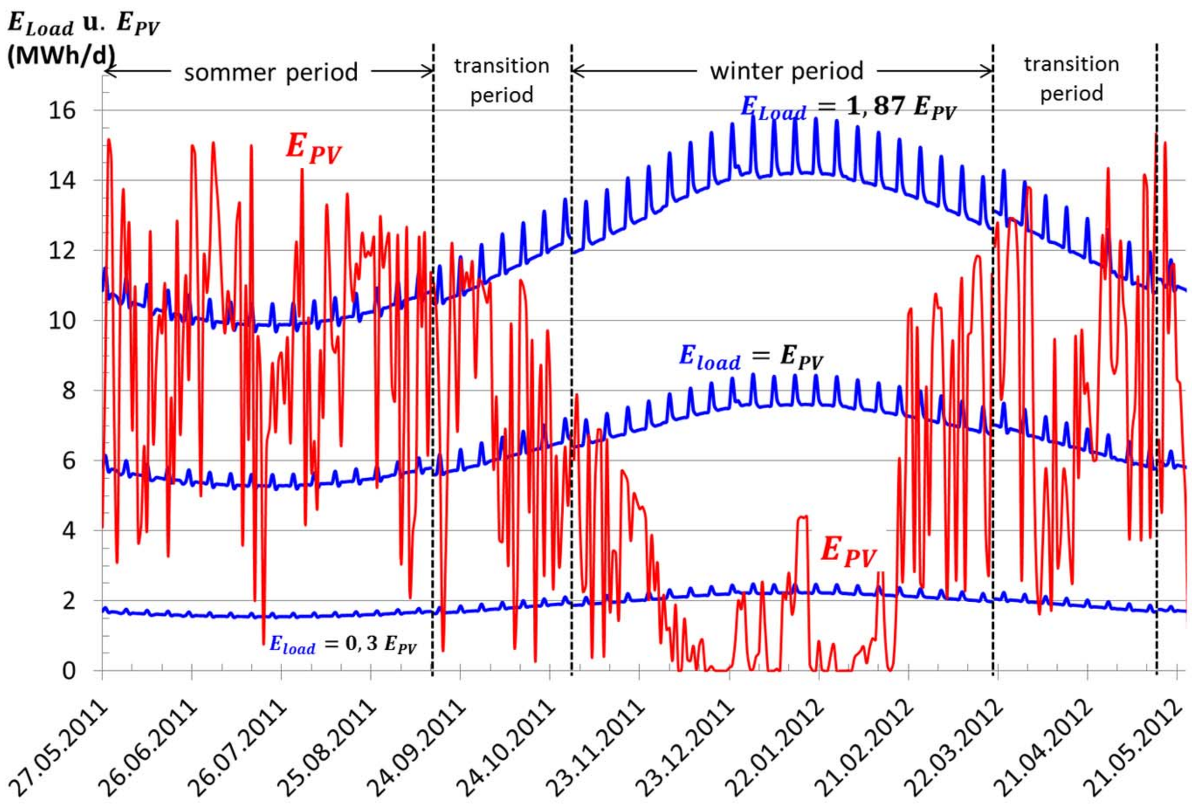
- Variation of the considered load profile
  - Transition time: $E_{load} = E_{PV}$
  - Summer time: $E_{load} = 1.87 * E_{PV}$



Input data: Energy fluxes

- PV generation profile
  - 27.5.2011 to 21.5.2012
- Load profile divided into three periods
  - Summer
  - Transition
  - Winter
- Variation of the considered load profile
  - Transition time: $E_{load} = E_{PV}$
  - Summer time: $E_{load} = 1.87*E_{PV}$
  - Winter time: $E_{load} = 0.3*E_{PV}$



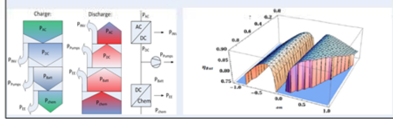
First step: Annual savings and optimized battery design

First step

Battery dimension:
Power & Energy

- Load profile
- Generation profile
- EEX – stock market prices
- Consumer tariff

Battery model



- Annual savings
- Optimized battery design for the application

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- factor of proportionality (project time, operation costs, discount rate)

- Specific storage costs
- Specific investment costs for the battery

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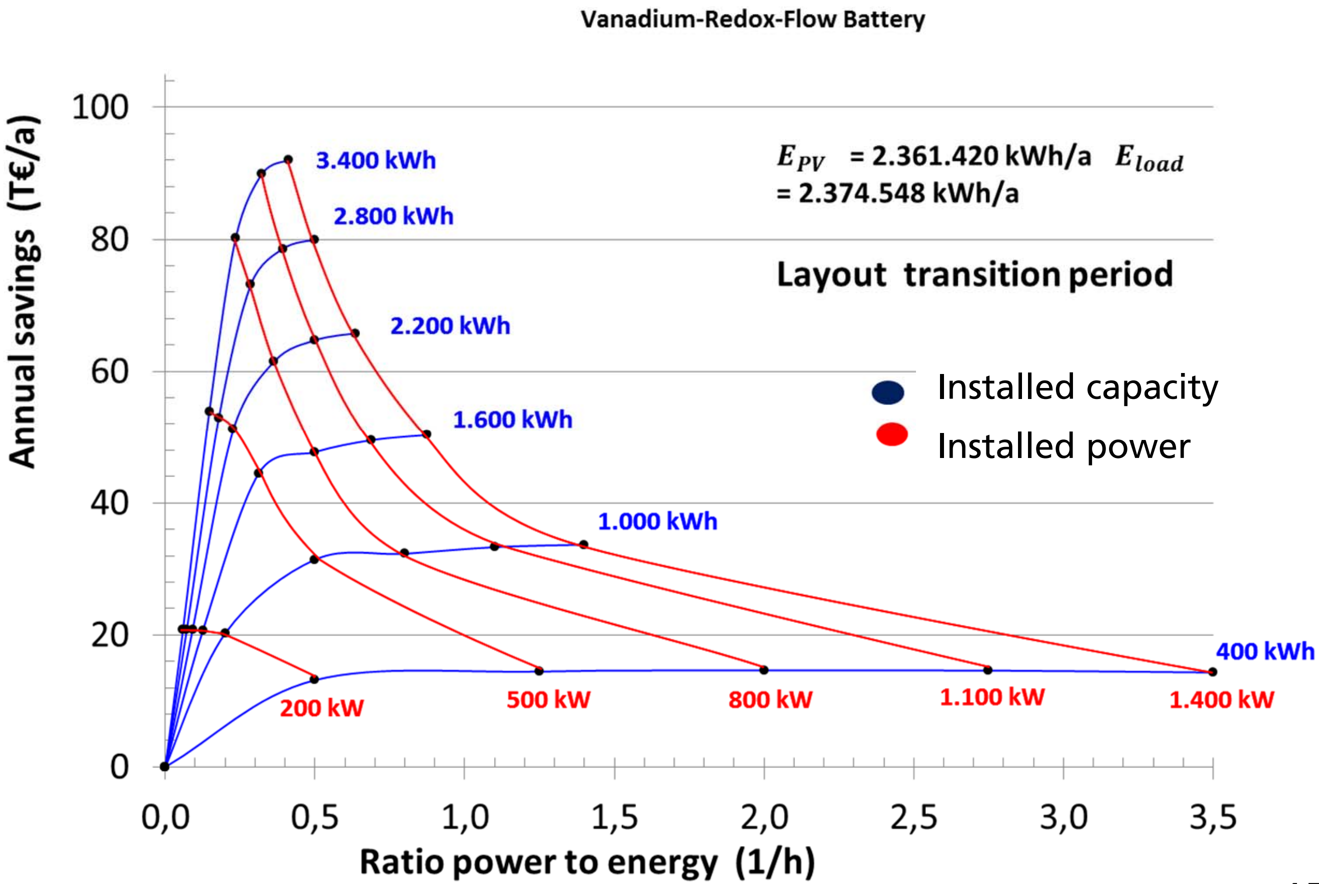
Annual savings in dependence of the battery layout
Example vanadium redox-flow battery

- Variable dimensioning of
  - Installed power
  - Installed capacity
- Case: “Transition time”
- Annual savings increase linear with the power to energy ratio up to a factor of approx. 0.3



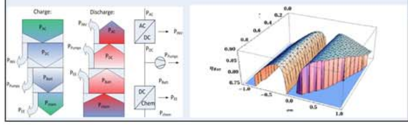
Second step: Specific storage and investment costs

Second step

Battery dimension:
Power & Energy

- Load profile
- Generation profile
- EEX – stock market prices
- Consumer tariff

Battery model



- Annual savings
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- factor of proportionality (project time, operation costs, discount rate)

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- Specific investment costs for the battery

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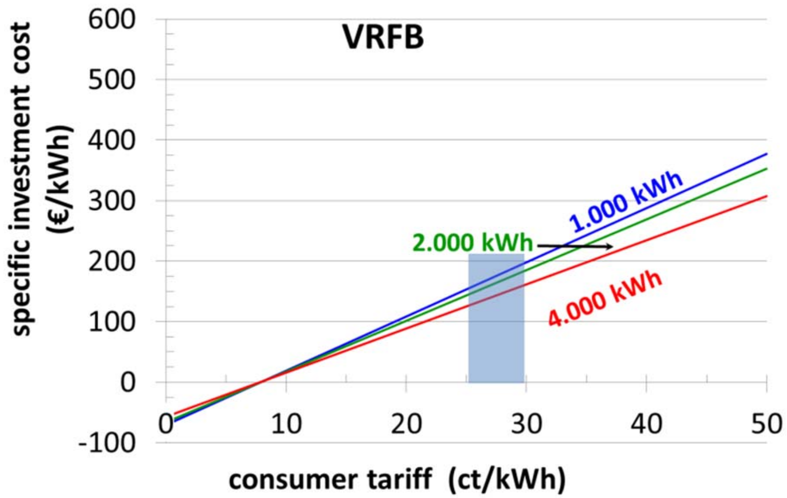
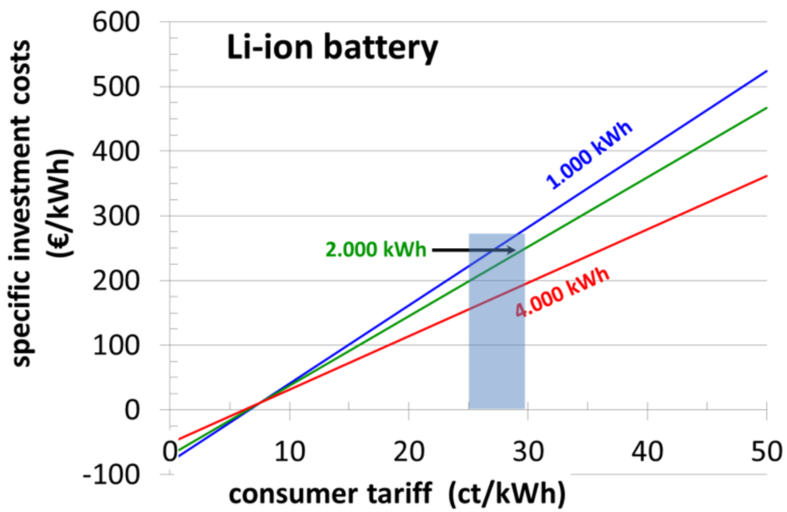
Results: Variation of end-user electricity tariff

Allowed specific investment costs

- Vanadium redox-flow battery:
  Approx. 150 to 200 €/kWh
- Lithium-ion battery:
  Approx. 150 to 260 €/kWh





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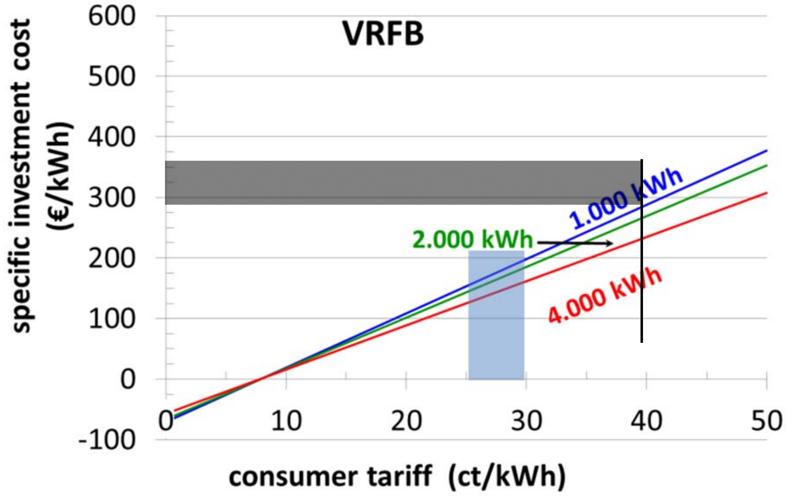
System analysis
Variation of end-user electricity tariff

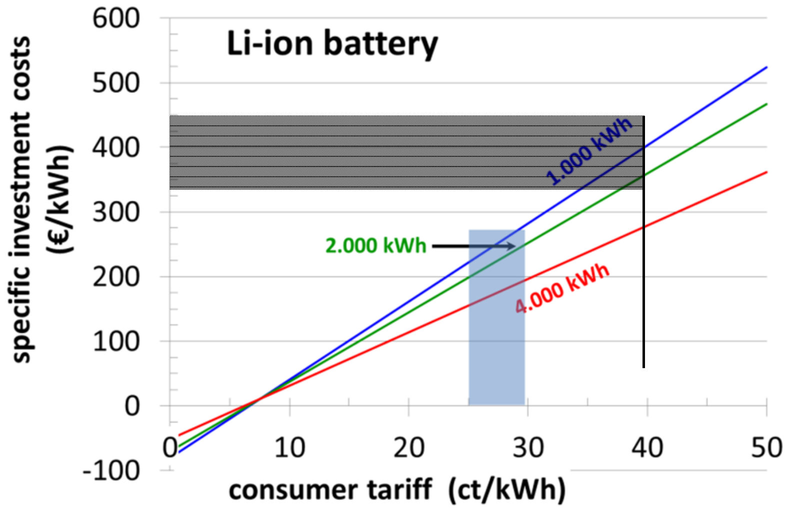
Allowed specific investment costs

- Vanadium redox-flow battery:
  Approx. 150 to 200 €/kWh
- Lithium-ion battery:
  Approx. 150 to 260 €/kWh

Scenario:

- 4 % increase of the end-user electricity tariff every year
- 2020: 0.397 €/kWh
- Vanadium redox-flow battery:
  Approx. 220 to 300 €/kWh
- Lithium-ion battery:
  Approx. 300 to 400 €/kWh





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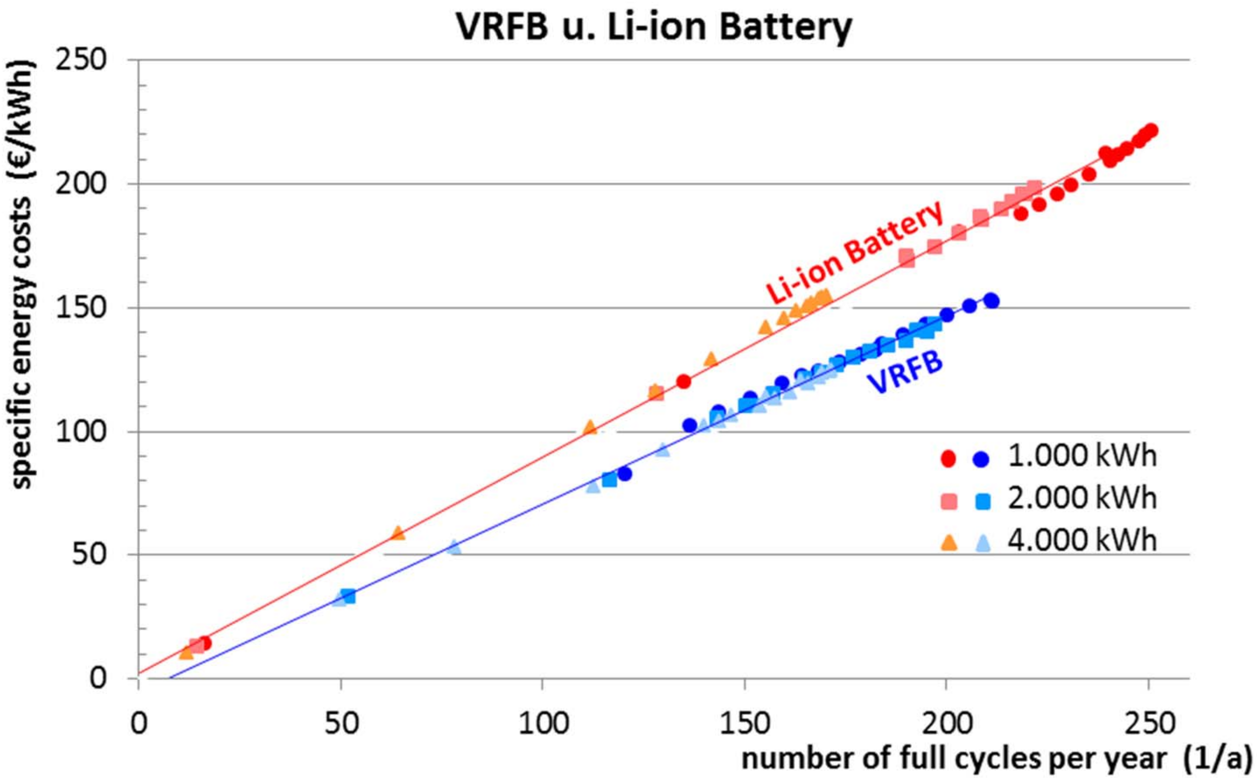
System analysis
Variation of the number of full cycles

- Under German weather conditions number of full cycles per year are limited:
  - Redox-flow: Max. 210 cycles/a year
  - Lithium-ion: Max. 250 cycles/a



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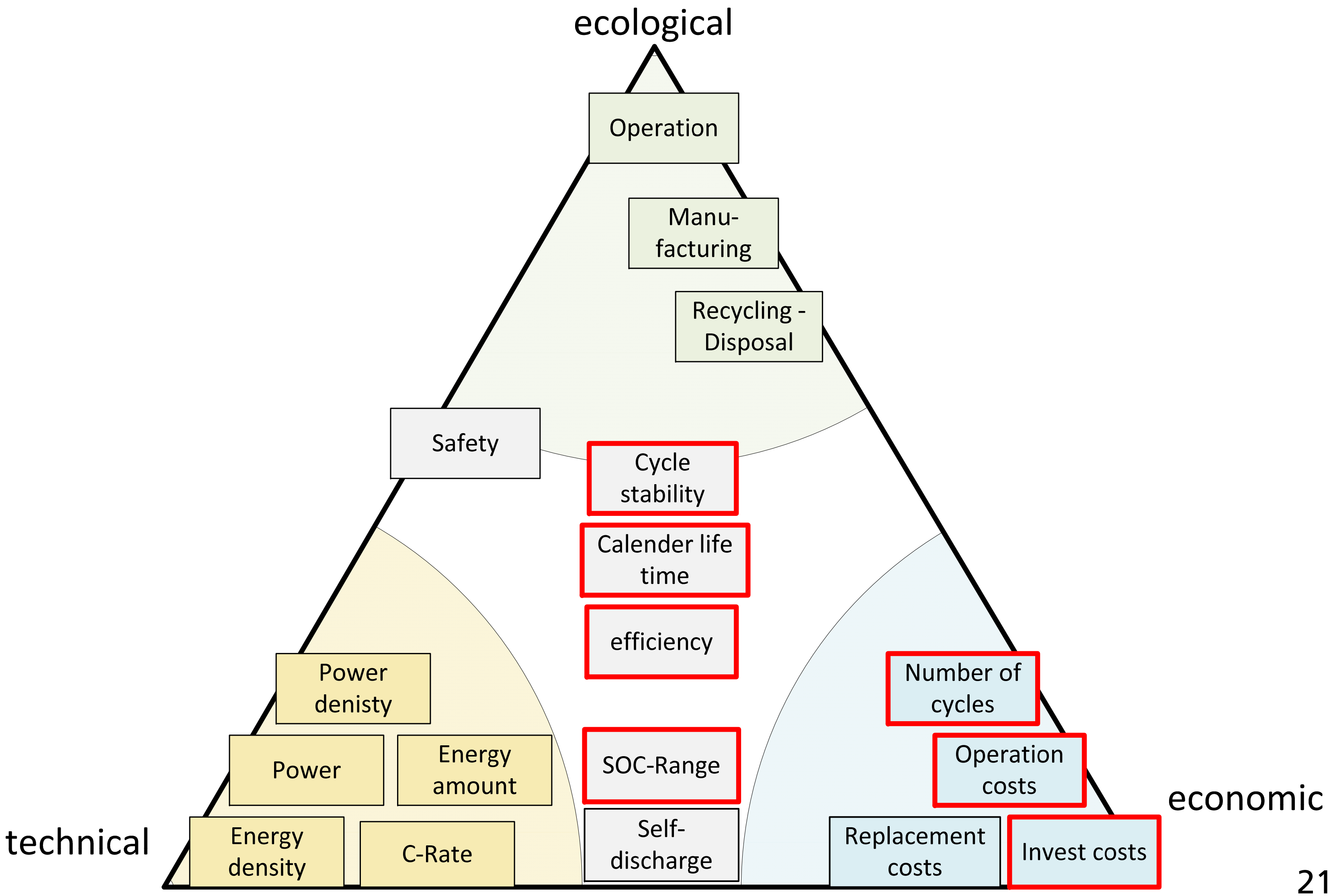
System analysis

- For this case study vanadium redox-flow batteries have to cost below
  - 440 €/kW (stack costs)
  - 40 €/kWh (electrolyte costs)
- Lithium-ion batteries have to cost below 220 €/kWh

- BUT: The actual market prices are higher

- Which are the main cost drivers for vanadium redox-flow batteries and lithium-ion batteries?

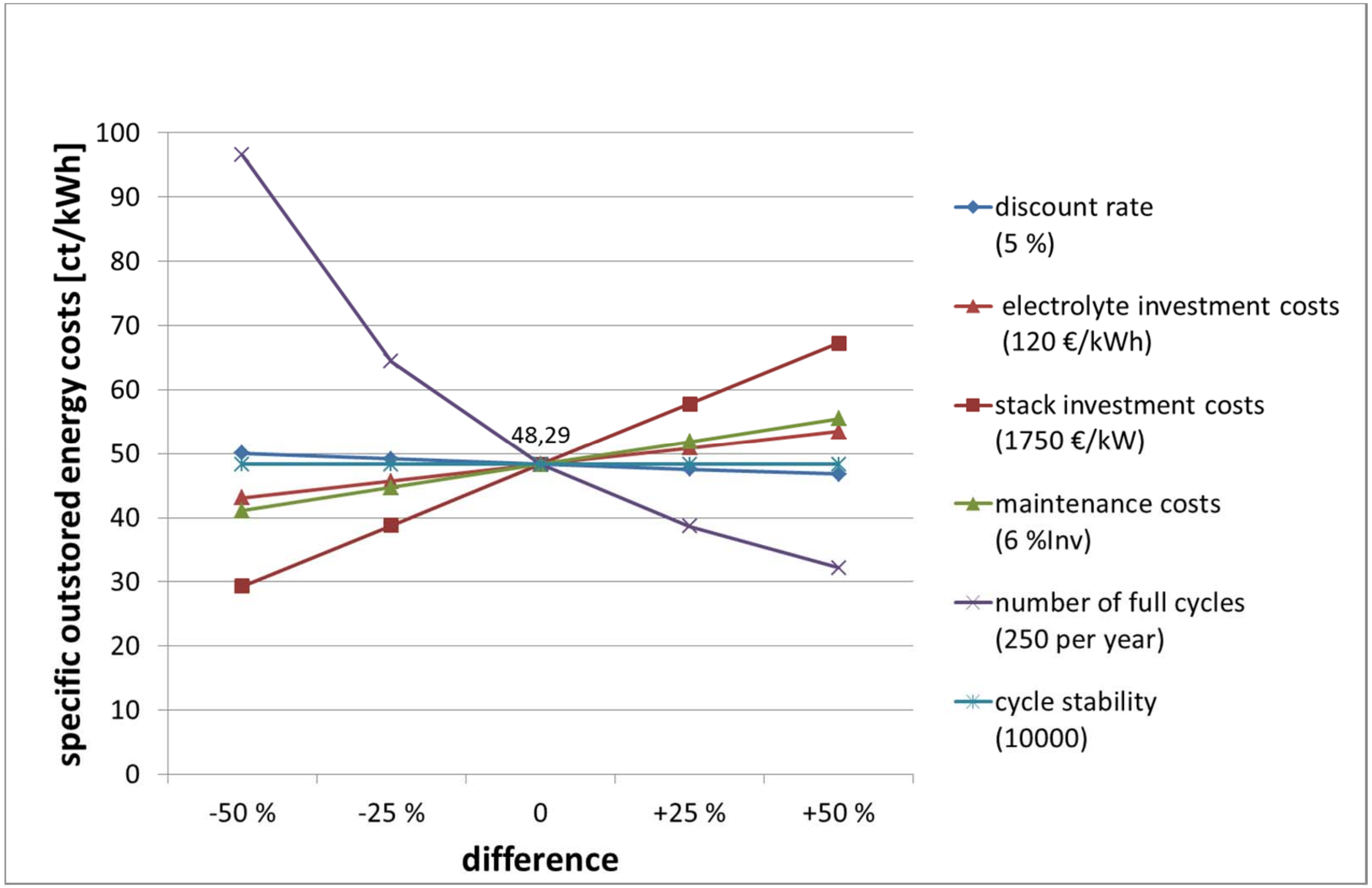
Key parameters



Key parameters – Sensitivity analysis

Vanadium redox-flow battery:

- Project life time: 10 years
- Efficiency: 78 %
- SOC-range: 80 %
- Cycles per year: 250
- Ratio power to energy: 0.25



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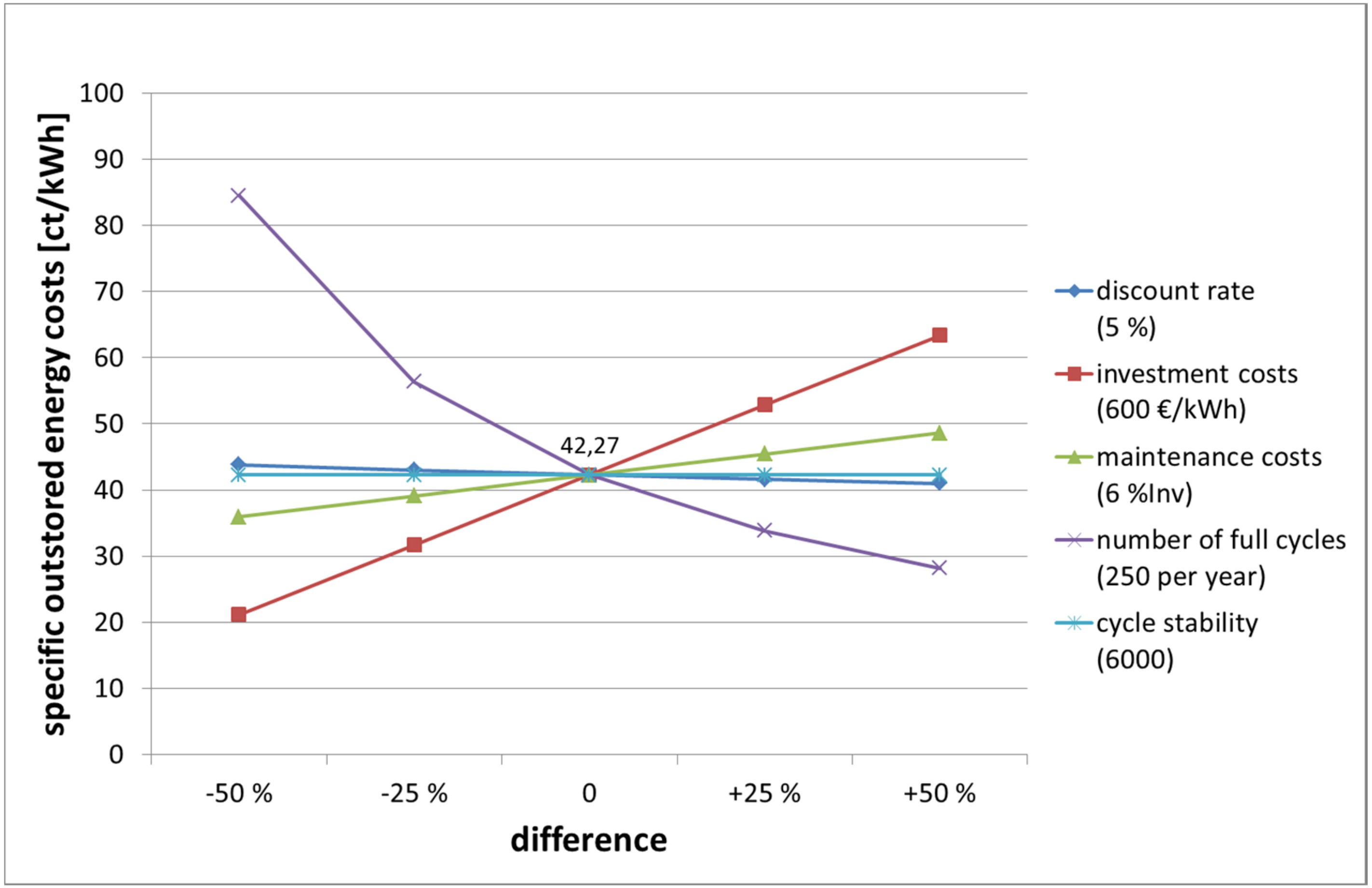
Key parameters – Sensitivity analysis

Lithium-ion battery:

- Project life time: 10 years
- Efficiency: 90 %
- SOC-range: 90 %
- Cycles per year: 250



Conclusions

- Competing battery technologies on the market or close to market entry (e.g. lithium-ion batteries and vanadium redox-flow batteries)
- PV power plants:
  - Lithium-ion batteries suitable as short-term storages
  - Redox-flow batteries suitable as mid-term storages
- The specific investment costs for lithium-ion batteries and redox-flow batteries have to decrease drastically
- Efficiencies affect the justifiable investment costs
- The number of full cycles and the investment costs have a huge influence on the specific storage costs (costs per "out-stored" kWh)
- Multiple use of storage systems enables an economic operation (achieved number of full cycles during the calendar life time)