ON THE ECONOMICS OF DECENTRALIZED BATTERY-SUPPORTED PHOTOVOLTAIC SYSTEMS

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Agenda

- Research question
- Methods & Assumptions
- Results
- Interpretation
- Conclusion
Research question

- What are the maximum additional investment costs for battery systems to be profitable in combination with decentralized photovoltaic systems?
  - Lithium based vs. lead based
Methods and assumptions

Linear optimization model (MATLAB, time resolution: 1/4h):

- "Yalmip" toolbox and "Gurobi" solver are used
Methods and assumptions

- Linear optimization model:
  - Time horizon: 25 years
  - Load profile: Standardized household load profile (4000 kWh/a)
  - Degradation of the PV system: 80% of original capacity after 20 years
  - DoD: Lithium 80%, Lead 50% → 3000 load cycles
  - Lifetime of the battery: 12 years (250 load cycles per year) "end of life"
  - Battery efficiency: Lithium 0.9, Lead 0.7
Methods and assumptions

Objective function:

\[
\min \sum_t \left( q_t^{\text{grid\,battery}} + q_t^{\text{grid\,demand}} \right) * c_t^{\text{electricity\,purchase}} - \left( q_t^{\text{PV\,feedin}} + q_t^{\text{battery\,feedin}} \right) * p_t^{\text{feedin}}
\]

Demand equation:

\[
q_t^{\text{demand}} = q_t^{\text{net\,demand}} + q_t^{\text{PV}} + q_t^{\text{battery}}
\]

Battery equations:

\[
q_t^{\text{charge}} = (q_t^{\text{PV\,battery}} + q_t^{\text{net\,battery}}) * \eta^{\text{charge}}
\]

\[
q_t^{\text{discharge}} = -\frac{q_t^{\text{battery\,demand}} - q_t^{\text{battery\,feedin}}}{\eta^{\text{discharge}}}
\]

\[
\text{storage\,Level}_t = \text{storage\,Level}_{t-1} + q_t^{\text{charge}} + q_t^{\text{discharge}}
\]

PV equation:

\[
q_t^{\text{PV\,output}} = q_t^{\text{PV\,battery}} + q_t^{\text{PV\,demand}} + q_t^{\text{PV\,feedin}}
\]
Methods and assumptions

- Economic calculation:

\[ NPV = -I_{\text{batt, total}} + \sum_{t=1}^{25} \frac{\Delta C_t}{(1 + i)^t} = 0 \]

\[ I_{\text{batt, total}} = \sum_{t=1}^{25} \frac{\Delta C_t}{(1 + i)^t} \]

Cash flow:

\[ C_t = q_t \text{ self consumption} * c_{\text{electricity purchase}} + q_t \text{ feed in} * p_{\text{feed in}} - c_t \text{ O&M} \]

\[ \Delta C_t = \text{Cash flow with battery} - \text{Cash flow without battery} \]

Assumption: Battery prices decrease to 70% in 12 years, rebuy of a battery is also considered.

- Interest rate: 1%

- Price increase: 2% p.a.

- \( c_{\text{electricity purchase}} = 16.5 \frac{c}{kWh} \)

- \( p_{\text{feed in}} = 8 \frac{c}{kWh} \)
Results

**Lithium battery:** 1% interest rate

Battery investment costs [€/kWh]:

Max. investment costs: $445 \frac{€}{kWh}$ (15 kWP, 1 kWh)

Min. investment costs: $3.4 \frac{€}{kWh}$ (1 kWP, 14 kWh)
Results

Rate of self-consumption [%]: 2

Rate of self-sufficiency [%]: 2

Small PV systems: Self consumption is already high without battery, minor benefit in terms of self sufficiency

Battery capacity above 7 kWh: A further increase of battery capacity would not achieve much more benefit in case of self consumption and coverage of the load profile
Results

**Lead battery:** 1% interest rate

Battery investment costs [€/kWh]:

Max. investment costs: $233 \frac{€}{kWh}$ (15 kWp, 1 kWh)
Min. investment costs: $2.66 \frac{€}{kWh}$ (1 kWp, 14 kWh)
Actual battery prices (German Market 2013) for lithium batteries and necessary price reduction

Lithium battery prices have to decrease to 82% – 95% of actual battery prices to reach an economic benefit for households!
Actual battery prices (German Market 2013) for lead batteries and necessary price reduction

Lead battery prices have to decrease to 81% – 93% of actual battery prices to reach an economic benefit for households!
Battery prices can vary in a high range.

For a measured load profile, the rate of self consumption and the coverage of the load profile can differ from the standardized load profile.

Electricity price increase > 2% p.a. necessary price reduction has to be lower.

Expected rate of return > 1% necessary price reduction has to be higher.
Conclusion

- The necessary price reduction is equal for lithium–batteries and lead batteries, even if the prices are much lower for lead batteries.

- Start-up financing is necessary for a broad diffusion of battery systems in the near future.

- With high diffusion prices should get lower to an affordable level.

- Battery research should be subsidized to increase battery lifetime and to decrease costs for consumers.
Thank you for your attention!

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Methods and Assumptions

- Cycling life expectancy: Lead Battery

![Graph showing cycling life of a battery]

- 10 kWh Battery -> 5 kWh usable
- ~3000 cycles
- ~1700 cycles

Source: Datasheet Hoppecke OPzV solar.power
www.hoppecke.de
Methods and Assumptions

- Cycling life expectancy: Lithium Battery

Source: Datasheet Saft Intensium Flex
www.saftbatteries.com