Heat & Electricity Storage 9th Symposium (21 October 2020)
Energy System Level & Technology Level

Dr. David Parra, University of Geneva (UNIGE)
Christian Bauer, Paul Scherrer Institute (PSI)
Assessment of Energy Storage WP5

- **HSLU**: J. Worlitschek
  - Assessment of heat storage

- **ETHZ**: T. Schmidt
  - Policy assessment

- **UniGE**: D. Parra & M. Patel
  - Economic assessments

- **OST**: M. Friedl
  - Assessment of Power-to-Gas

- **PSI**: Ch. Bauer
  - Environmental assessment

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Swiss Competence Center for Energy Research
Heat & Electricity Storage

[www.sccer-hae.ch](http://www.sccer-hae.ch)
Storage in the energy system

Key research questions

**National level**
What are the optimal investments to decarbonise difficult-to-decarbonise sectors such as heating and transport?
What’s the role of energy storage in a “net-zero” energy system in CH?

**Regional level**
How do flexibility options compare to increase renewable generation?

**Local level**
What are the trade-offs between prosumer benefits and grid impacts?

Source: D. Parra et al. (2017), Sustainable and Renewable Energy Reviews
Local level: Household storage

Photo from www.PVP4Grid.eu

Source: Pena-bello et al. (2019), Sustainable and Renewable Energy Reviews
## Local level: Household storage

<table>
<thead>
<tr>
<th>Application</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Energy application</td>
<td></td>
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<tr>
<td>- Supply side</td>
<td></td>
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<tr>
<td>- PV charging</td>
<td></td>
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<tr>
<td>- Driver: difference between Retail price and feed-in tariff</td>
<td></td>
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<tr>
<td>- We focus on the UK</td>
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<tr>
<td>- Driver: varying-price tariffs</td>
<td></td>
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<tr>
<td>- We use a 2-period time-of-use tariff: Economy 7 [22]</td>
<td></td>
</tr>
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<td>- Power application</td>
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<td></td>
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<tr>
<td>- PV charging</td>
<td></td>
</tr>
<tr>
<td>- Driver: regulation (e.g., Germany) or capacity-based tariffs</td>
<td></td>
</tr>
<tr>
<td>We use a feed-in limit of 50% of PV capacity [23]</td>
<td></td>
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<td>- PV or grid charging</td>
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<tr>
<td>- Driver: capacity-based tariffs</td>
<td></td>
</tr>
<tr>
<td>- We use a value of 8 £/kW$_{peak}$·month [16]</td>
<td></td>
</tr>
</tbody>
</table>

Local level: Household storage

The combination of applications (benefit stacking) is key for storage’s economic viability

Source: Pena-bello et al. (2019), Sustainable and Renewable Energy Reviews
Local level: Household storage

Heat pump and thermal storage

Source: Pena-Bello et al., in review
Local level: Household storage

- Batteries are a two-edge sword depending on the presence of capacity tariffs
- Decarbonizing the residential heating sector
  - Peak power increases in poorly insulated houses (3.8 - 17.6 kW)
  - LCOE difference up to 0.2 USD/kWh (type house)

Batteries
- LCOE increase by 0.08 USD/kWh
- Peak power reduction (2.2-2.6 kW)
- Self-consumption (11-30%)
- Self-sufficiency (15-17%)

Space heating storage
- LCOE reduces by USD/kWh
- Peak power reduction (0.5-2.2 kW)
- Self-consumption (2-6%)
- Self-sufficiency (3-5%)

Source: Pena-Bello et al., in review
Local level: community storage

1. Better balancing than bulk systems
2. More cost-effective and efficient than household systems
3. Citizen engagement to accelerate the energy transition

### Local level: community storage

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Self-consumption community</th>
<th>Peer-to-peer community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total electricity demand (MWh)</td>
<td>329.2</td>
<td>329.2</td>
</tr>
<tr>
<td>Total solar PV generation (MWh)</td>
<td>453.8</td>
<td>453.8</td>
</tr>
<tr>
<td>Total PV export (MWh)</td>
<td>210.8</td>
<td>197.7</td>
</tr>
<tr>
<td>Total grid import (MWh)</td>
<td>243.2</td>
<td>231.4</td>
</tr>
<tr>
<td>Self-sufficiency (%)</td>
<td>48.0</td>
<td>50.5</td>
</tr>
<tr>
<td>Bill [€ p.a.]</td>
<td>59671</td>
<td>56886</td>
</tr>
</tbody>
</table>

**Autarky paradox**

Source: Pena-Bello et al., in preparation
Regional level: distributed (grid) storage

Solar, heat pumps and electric vehicles

Flexibility

BKW

Source: Gupta et al., in review
The cost for 42.2 GW\textsubscript{p} PV capacity in Switzerland by 2050 is 2264 CHF per household.

Source: Gupta et al., in review
### Regional level: distributed (grid) storage

<table>
<thead>
<tr>
<th>Transformer stations (%)</th>
<th>PV Aggressive 2035</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV capacity (MWp)</td>
<td>Grid reinforcement cost (M CHF)</td>
</tr>
<tr>
<td>1%</td>
<td>1.5</td>
<td>6.9</td>
</tr>
<tr>
<td>5%</td>
<td>13.8</td>
<td>32.2</td>
</tr>
<tr>
<td>10%</td>
<td>40.0</td>
<td>64.3</td>
</tr>
<tr>
<td>15%</td>
<td>70.5</td>
<td>90.9</td>
</tr>
<tr>
<td>20%</td>
<td>113.5</td>
<td>120.1</td>
</tr>
<tr>
<td>30%</td>
<td>203.1</td>
<td>163.8</td>
</tr>
<tr>
<td>40%</td>
<td>294.7</td>
<td>192.7</td>
</tr>
<tr>
<td>50%</td>
<td>403.0</td>
<td>215.6</td>
</tr>
</tbody>
</table>

- Batteries can help to defer distribution grid reinforcement costs
- Distribution system operators could organise tender for market parties to offer storage capacity

Source: Gupta et al., in review
Swiss national level – the role of storage

Model-based assessment of Net-Zero CO₂ emissions scenarios from fuel combustion and industrial processes in Switzerland

![Graph showing CO₂ emissions from various sources in Switzerland from 1990 to 2050. The graph indicates a decrease in emissions, with negative emissions projected for 2050.](image)

Source: Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
Energy storage is “everywhere” on the road to Net-Zero

Source: Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
Stationary batteries help integrating VRES in electricity supply & reducing costs for consumers

Source: Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
Vehicle on-board storage enables smart charging and V2G flexibility

Source: Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
P2X and seasonal storage provide flexibility and enable sector & energy markets coupling

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Capacity (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis</td>
<td>5.0</td>
</tr>
<tr>
<td>SMR/ATR w CCS</td>
<td>2.6</td>
</tr>
<tr>
<td>Wood gasification w CCS</td>
<td>3.1</td>
</tr>
<tr>
<td>Hydrogen produced (H₂)</td>
<td>10.7</td>
</tr>
<tr>
<td>Hydrogen consumed (H₂)</td>
<td>10.7</td>
</tr>
<tr>
<td>H₂ Storage Losses</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>District heating</td>
<td>1.0</td>
</tr>
<tr>
<td>Industry</td>
<td>2.0</td>
</tr>
<tr>
<td>Residential/Commercial</td>
<td>0.9</td>
</tr>
<tr>
<td>Freight transport</td>
<td>2.6</td>
</tr>
<tr>
<td>Passenger transport</td>
<td>3.0</td>
</tr>
<tr>
<td>Fuel synthesis</td>
<td>1.1</td>
</tr>
<tr>
<td>Injected to gas grid</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Source:** Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
Swiss national level

Thermal storage acts as an additional flexibility measure for integration of VRES

Source: Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
Swiss national level

Value of storage in achieving the Net-Zero emission goal in CH

Relative to net-zero scenario with storage

- Solar & Wind TWh/yr. decrease, 2050
  - No batteries: 5.0
  - No batteries + No thermal: 5.4

- Import dependency increase, percentage points, 2050
  - No batteries: 2%
  - No batteries + No thermal: 3%

- Electricity cost increase Rp/kWh, 2050
  - No batteries: 21
  - No batteries + No thermal: 24

- Climate Policy cost increase in BCHF, 2020-2050
  - No batteries: 12
  - No batteries + No thermal: 13

Source: Panos, E. and Kober, T. (2020) ERA-Net ACT project ELEGANCY, D5.3.6
Assessment @ Technology level
Thermal energy storage

Economic & environmental assessment

Daily-weekly Thermal Energy Storages

- Surface water tank
- Underground pipes
- Borehole storage
- Ice storage

Solar PV  +  Solar Collector  +  Auxiliary Heating

Thermal Energy Storages

Li-ion battery (NMC)

Multi-family House (MFH)

1 MJ of Heat

1 MJ of Heat

Single-family House (SFH)

cost optimized system

Alternative Heat Supplies

- Boilers
- Heat pumps
- Gas
- Air-water
- Borehole
- Wood

Source: Berger, M., Zhang, X., et al. (to be submitted)
Thermal energy storage

Evaluated alternatives for heat supply

**PV w/wo battery + HP**
- PV only
- PV Battery
- (auxiliary heating)

**PV + Thermal Energy Storage + HP**
- PV, Borehole
- PV, Ice storage
- PV, Surface water tank
- PV, Underground water tank
- (auxiliary heating)

**Solar Collector + Thermal Energy Storage + HP**
- Solar thermal, Borehole
- Solar thermal, Ice Storage
- Solar thermal, Surface water tank
- Solar thermal, Underground water tank
- (auxiliary heating)

Source: Berger, M., Zhang, X., et al. (to be submitted)
Thermal energy storage

Cost-optimal design: system simulation

Loop A: parameter sweep of PV or ST collectors versus the storage size
Loop B: adjustment of the controller regime
Loop C: adjustment of other systems

Source: Berger, M., Zhang, X., et al. (to be submitted)
Thermal energy storage

Performance of SFH60* with heat pump and solar photovoltaics as relative TCO, self-sufficiency and own-consumption versus CAPEX and number of PV modules

a) Near-surface (underground) water tank
b) Surface water tank
c) Borehole thermal energy storage

*60 kWh/m²/year space heating demand (modern single-family house)
Thermal energy storage

Results: Life-cycle GHG emissions (CH)

Source: Berger, M., Zhang, X., et al. (to be submitted)
Thermal energy storage

Results:
Life-cycle GHG emissions (CH)

Conclusions:
• PV (+battery) + HP as preferred option in CH
• Results highly dependent on:
  a) System design
  b) Electricity from grid

Source: Berger, M., Zhang, X., et al. (to be submitted)
Assessment of hybrid systems

Source: Gupta et al. (2020), Journal of Energy Storage
Assessment of hybrid systems

- Model to determine the required energy storage size (in terms of energy and power capacity) for different hybrid systems under different supply modes.

- Objective function: to create a firm (constant) RE output level ($\lambda$) on a daily basis.

- Storage operation depends on the RE generation profile, round-trip efficiency of storage and type of supply mode.

- Based on following assumptions:
  i. 24h modelling framework
  ii. Perfect day ahead forecast of electricity demand and RE generation

Source: Gupta et al. (2020), Journal of Energy Storage
Assessment of hybrid systems

Source: Gupta et al. (2020), Journal of Energy Storage
Assessment of hybrid systems

(a) LCOHS of PV hybrid systems at the utility scale

(b) LCOHS of wind hybrid systems at the utility scale

Source: Gupta et al. (2020), Journal of Energy Storage
Assessment of hybrid systems

Bulk scale
Hybrid systems-Conclusions

1. Optimal choice for a hybrid system depends on scale rather than supply mode.

2. PHS is optimal storage technology for the PV systems at the bulk scale (0.13 to 0.18 EUR/kWh), Li-ion battery is more cost-effective for utility (0.17 to 0.36 EUR/kWh) and residential scales (0.39 to 0.77 EUR/kWh).

3. PHS is optimal storage technology for wind energy systems at bulk scale (0.15 to 0.18 EUR/kWh), I-CAES is more cost-effective for the utility scale (0.17 to 0.71 EUR/kWh).

4. PV and wind hybrid systems are not cost competitive with conventional supply generators.

5. Sensitivity analysis – 60% reduction in PV CAPEX alone decreases the LCOHS of PV and PHS hybrid systems by 29% and 34% for baseload and generation respectively.

Source: Gupta et al. (2020), Journal of Energy Storage
Hybrid systems

Levelized Cost of Hybrid System Calculator

The levelized cost of hybrid system (LCOHS) calculator provides an estimation of the levelized costs of hybrid systems comprising of renewable energy (RE) technologies supported by energy storage (ES). The calculator enables the user to examine a range of ES technologies which can support RE technologies to supply firm electricity (also referred to as a constant electricity output) for a given hours in a day, depending on the supply mode strategy and the scale of deployment for any centers in Switzerland. The calculator provides a graphical interface where the user can change the input assumptions (e.g. costs, capacity, operational parameters of RE and ES technologies). The user can use the slider to control or enter input values manually for various renewable energy as well as energy storage technology parameters. The calculator will return the value of LCOHS expressed in euros per kilowatt-hour (EUR/kWh), which is automatically calculated after entering the input parameters. In order understand the terms used and the calculator behind the calculator, the detailed documentation page can be accessed either from the top right or the bottom of this page. The Technologies Specifications tab on the upper right corner of the page, showcases typical techno-economic specifications for PV only as well as the various energy storage technologies considering their current state of art in Switzerland and can be used as a reference by the users. This calculator aims to serve as a guide for policymakers, researchers, investors and project implementers for facilitating better investment decisions and policies for future RE hybrid systems and promote the transition to a sustainable energy future.

Accessible at:
http://lcohs.unige.ch:5000/main


Further reading

- A Pena-Bello, E Barbour, MC Gonzalez, S Yilmaz, MK Patel, D Parra. How Does the Electricity Demand Profile Impact the Attractiveness of PV-Coupled Battery Systems Combining Applications?. Energies 13 (15), 4038
- Arthur Rinaldi, Martin Christoph Soini, Martin K Patel, David Parra. Optimised allocation of PV and storage capacity among different consumer types and urban settings: A prospective analysis for Switzerland. Journal of Cleaner Production, 120762
Further information

Energy Efficiency @ UniGe: https://www.unige.ch/efficience/en/
david.parra@unige.ch; @david_parramen

Technology Assessment @ PSI: https://www.psi.ch/en/ta
christian.bauer@psi.ch

Energy Economics @ PSI: https://www.psi.ch/de/eem
evangelos.panos@psi.ch

Thermal energy storage @ HSLU: https://www.hslu.ch/en/lucerne-school-of-engineering-architecture/research/competence-centers/thermal-energy-storage/
joerg.worlitschek@hslu.ch
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[Image of HS-Storage logo]