Multi-Use für Batteriespeicher

Eine technisch-ökonomische Analyse für den deutschen Energiemarkt

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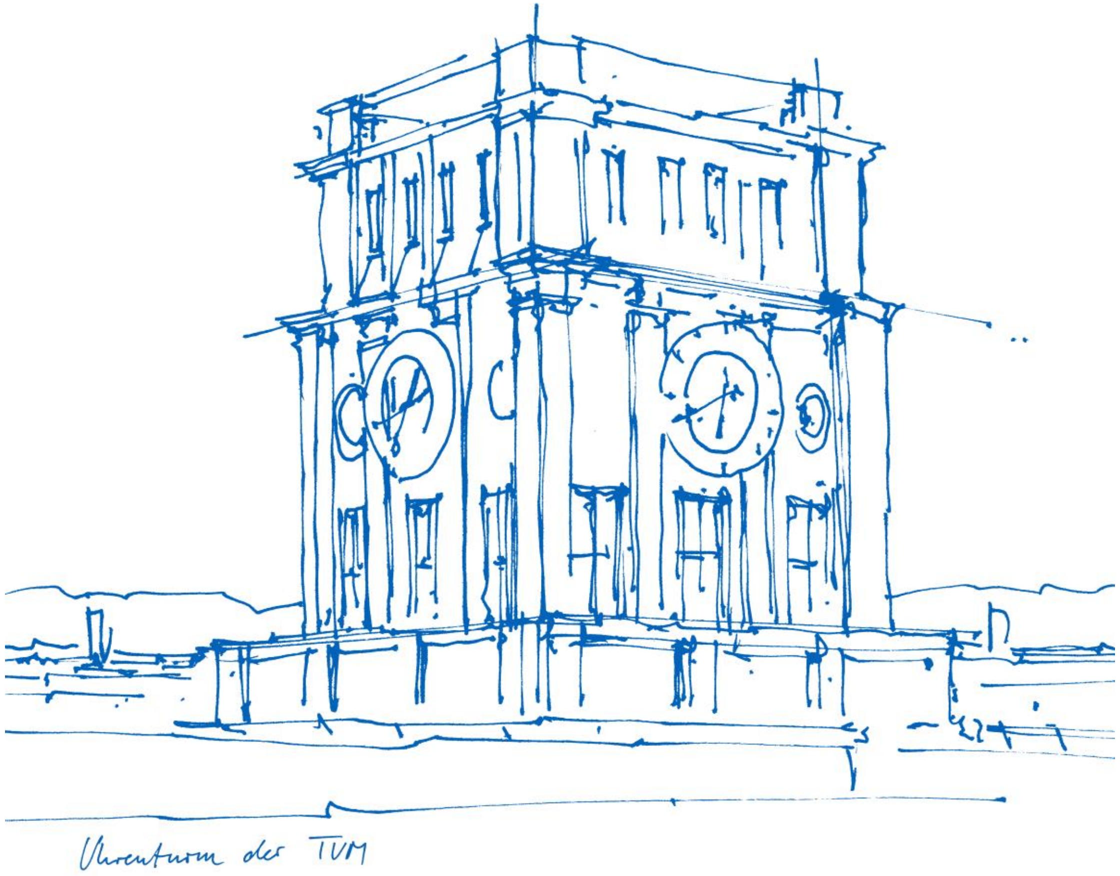
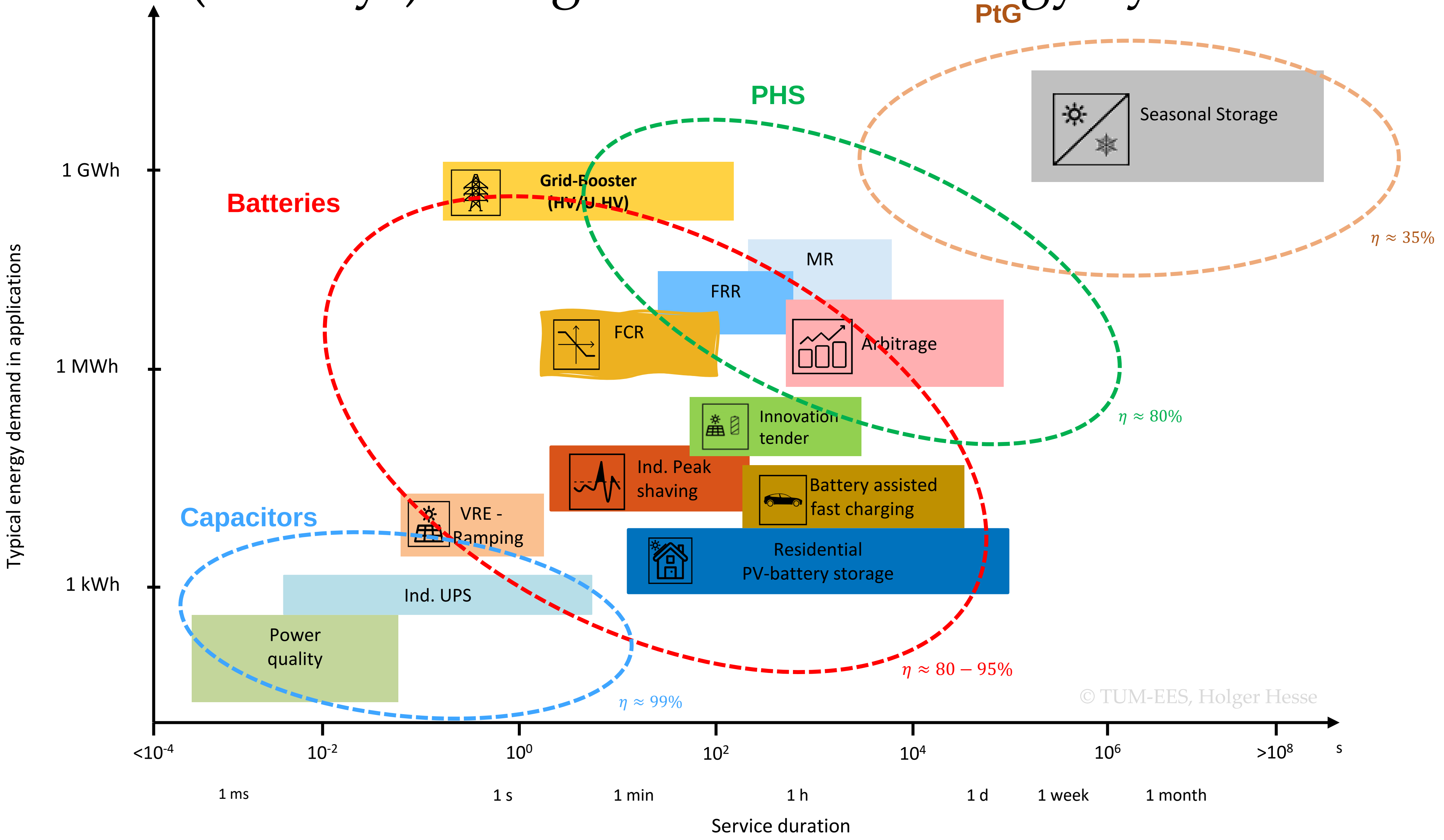
5. Herbstworkshop Energiespeichersysteme

Technische Universität Dresden (online), 7.12.2021

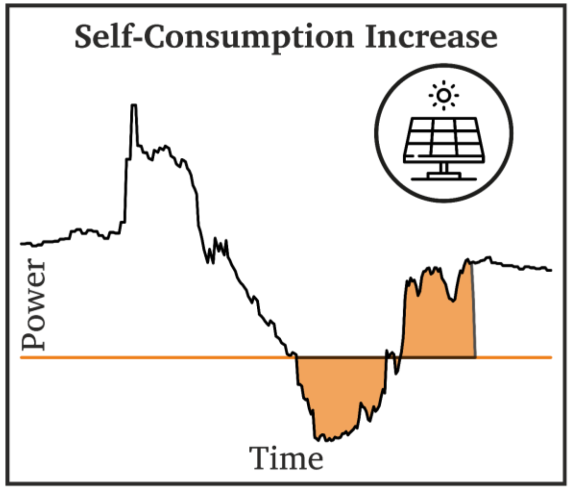


Role of (Battery-)Storage for Electric Energy Systems



- Widespread field of applications
- Choice of storage according requirements
- Assessment criteria dispatch duration, capacity demand, efficiency, aging, ramping capability, …
- **Broad coverage through batteries**
- ***What is economically feasible?***

Behind-the-Meter Anwendungsfälle



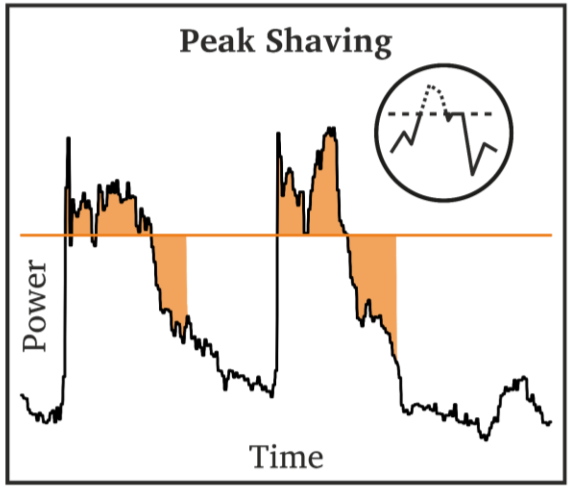
Self-Consumption increase (SCI)

ΔE

- Buildings with onsite PV generation
- Tariff structure 2021 Germany:
  - Residential: E_{Buy} ~32 $ct\ /\ kWh$; E_{Sell} ~7 $ct/\ kWh$
  - Commercial: E_{buy} $16 - 23\ ct\ /\ kWh$; E_{sell} ~5 $ct/\ kWh$

→ Attractive mainly for residential customers

"Economic optimization of component sizing for residential battery storage systems", HC Hesse, et al. Energies 10 (7), 835 (2017)



Peak Shaving for Industry (PSI)

- Industry / commercial buildings with load peaks
- Tariff structure 2021 Germany:

  Wholesale energy: E_{buy} ~16 $ct\ /\ kWh$

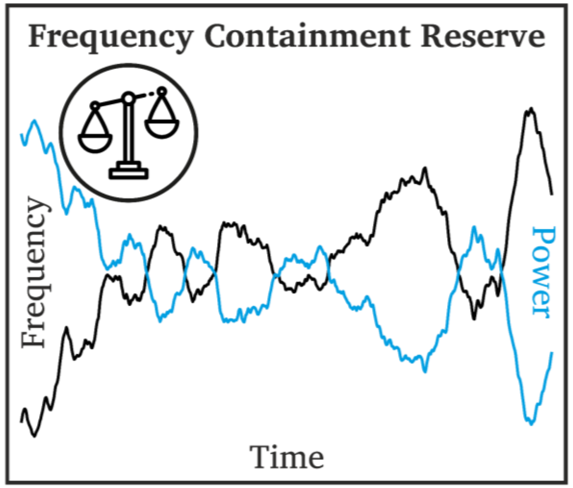
  Peak power tariff: P_{max} ~ 100 € / kW

ΔP

→ Attractive mainly for industry with non deferrable and distinguished load peaks

"Optimal Component Sizing for Peak Shaving in Battery Energy Storage System for Industrial Applications," R. Martins, et al. Energies 10 (8) 2048 (2018)

Front-of-the-Meter Anwendungsfälle



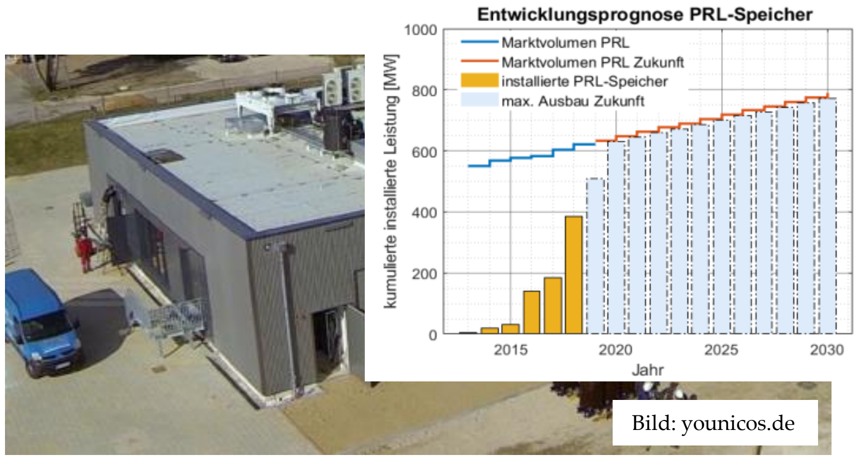
Frequency Containment Reserve (FCR)

Maintain frequency of UCTE grid: 50 Hz

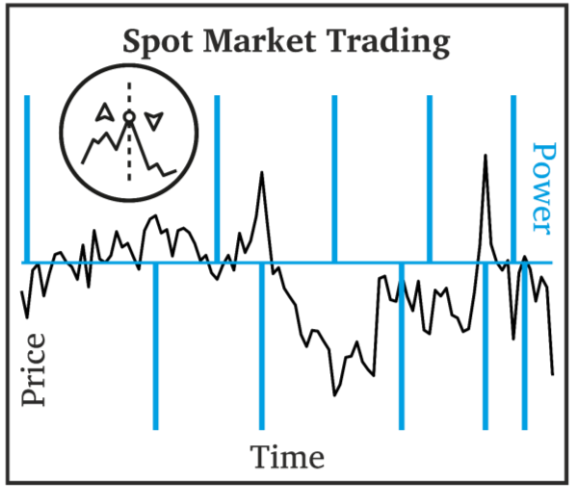
- Power delivery at under-frequency
- Power withdrawal at over frequency
- Reimbursement for power provision via market clearing auction

Δf

→ Limited market size, saturation expected



M. Müller et al. "Fundamentals of using Battery Energy Storage Systems for providing Primary Control Reserve" Batteries, 2, 29 (2016)

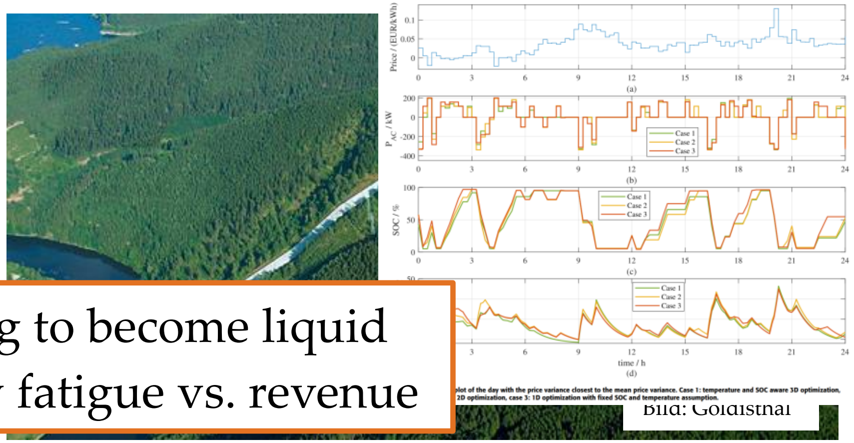


Spot Market Trading (SMT)

Trade energy on wholesale energy markets

- Day ahead markets (>24h ahead, 1 h)
- Intraday trading (same day, 15+ min)

Δ€

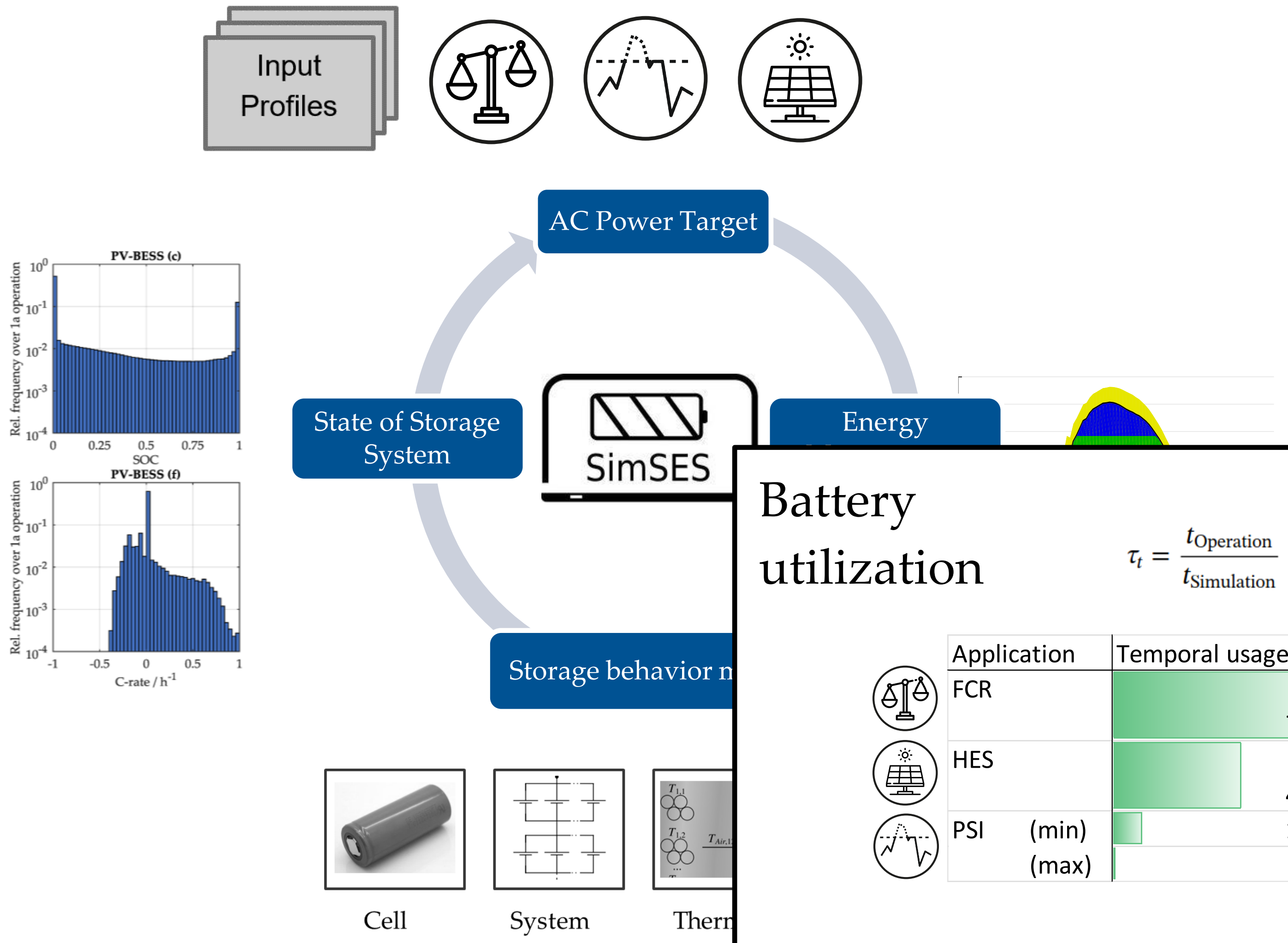


→ BESS relevant intraday market only starting to become liquid
→ Heavy cycling through arbitrage → battery fatigue vs. revenue

Kumtepeli, V., Hesse, H. C. Energy Arbitrage Optimization With Battery Storage:… *IEEE Access*, **2020** *8*, 204325-204341

Detailanalyse von Anwendungsfällen

- Presentation of "Standard Battery Application Profiles"
- Method to derive battery usage from input profile data
- Assessment of BESS usage in SCI, PSI and FCR applications
- Open Access availability of all data and battery simulation tool



Battery utilization

$$\tau_t = \frac{t_{Operation}}{t_{Simulation}} \qquad \tau_Q = \frac{Q_{Throughput}}{Q_{Throughput,theoretical\ max}}$$

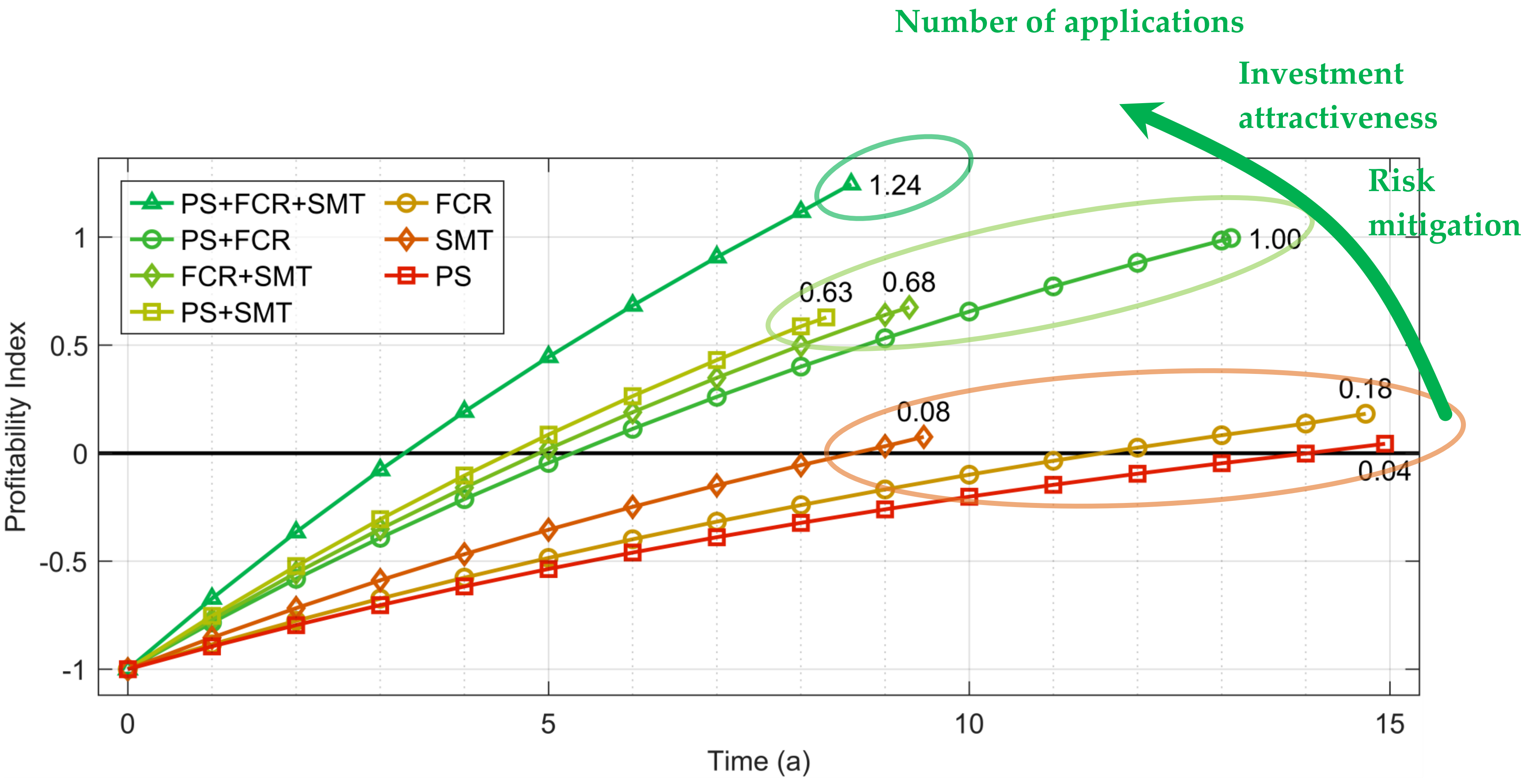
Application		Temporal usage	Charge based usage
FCR		76.53%	0.79%
HES		49.76%	0.52%
PSI	(min)	11.30%	0.13%
	(max)	0.60%	0.10%

"SimSES: A holistic simulation framework for modeling and analyzing stationary energy storage systems" M. Möller et al. Journal of Energy Storage (2021)

"Standard Battery Energy Storage System Profiles: Analysis of various Applications …" D. Kucevic, B. Tepe et al. Journal of Energy Storage (2020)

Multi-use increases the utilization of the energy storage

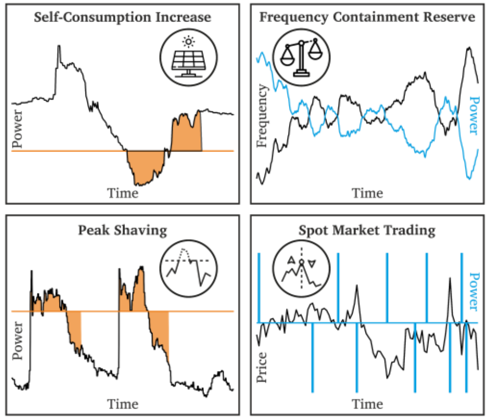
- Only moderate profitability for single-use cases over the battery lifetime
- Multiple-sourcing allows risk diversification and multi-use focuses on lucrative markets
- Multi-use increases the technical and economic potential of the battery storage system

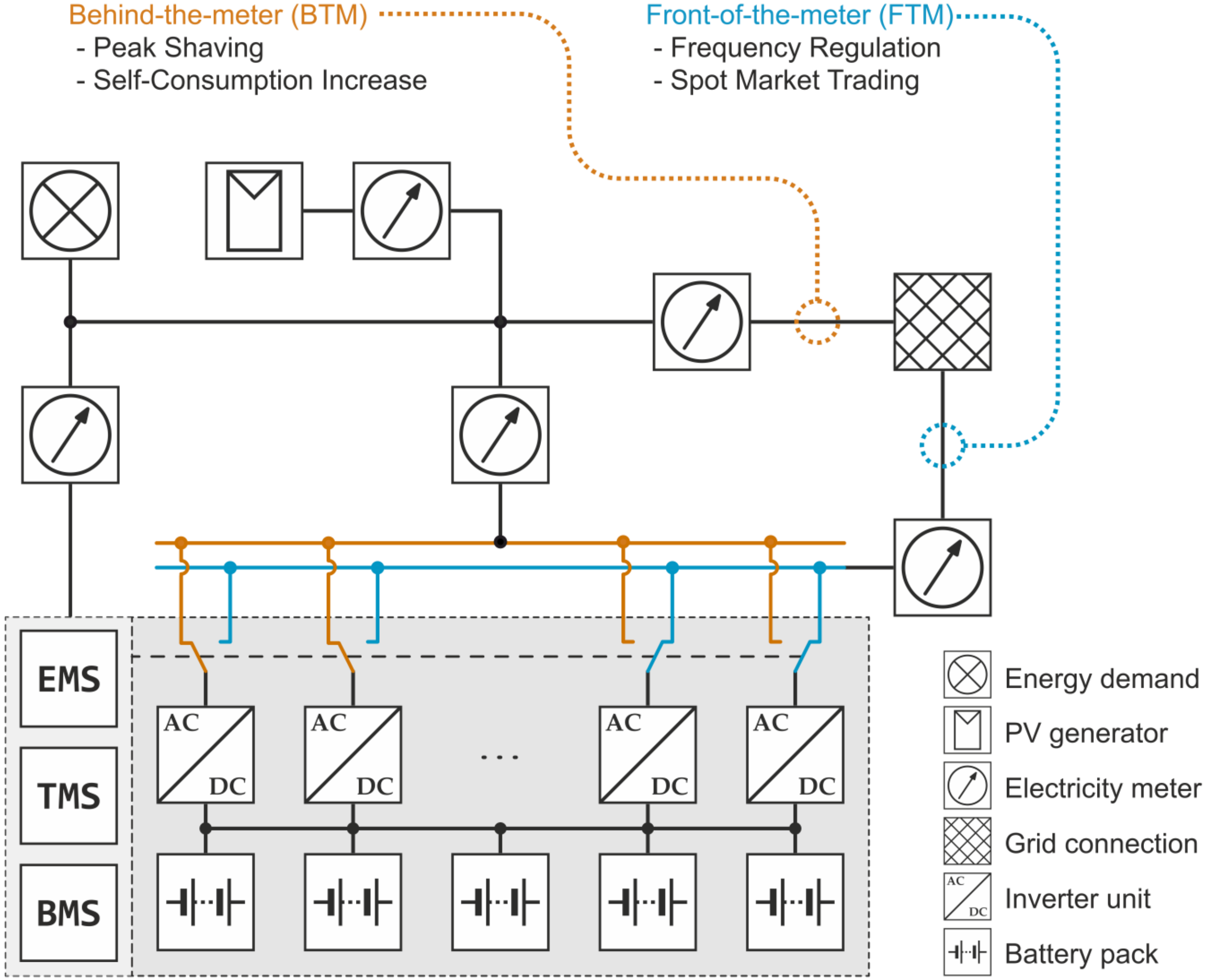


Englberger, S.; Jossen, A.; Hesse, H.: *Unlocking the potential of battery storage with the dynamic stacking of multiple applications*, in: Cell Reports Physical Science 1 (11), 2020

Technical Multi-Use Concept

- Applications are BTM or FTM
- Physical storage system is divided into virtual storage partitions
- Allocation of storage capacities
  - Energy from the battery cells
  - Power from the power electronics





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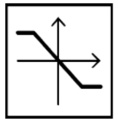
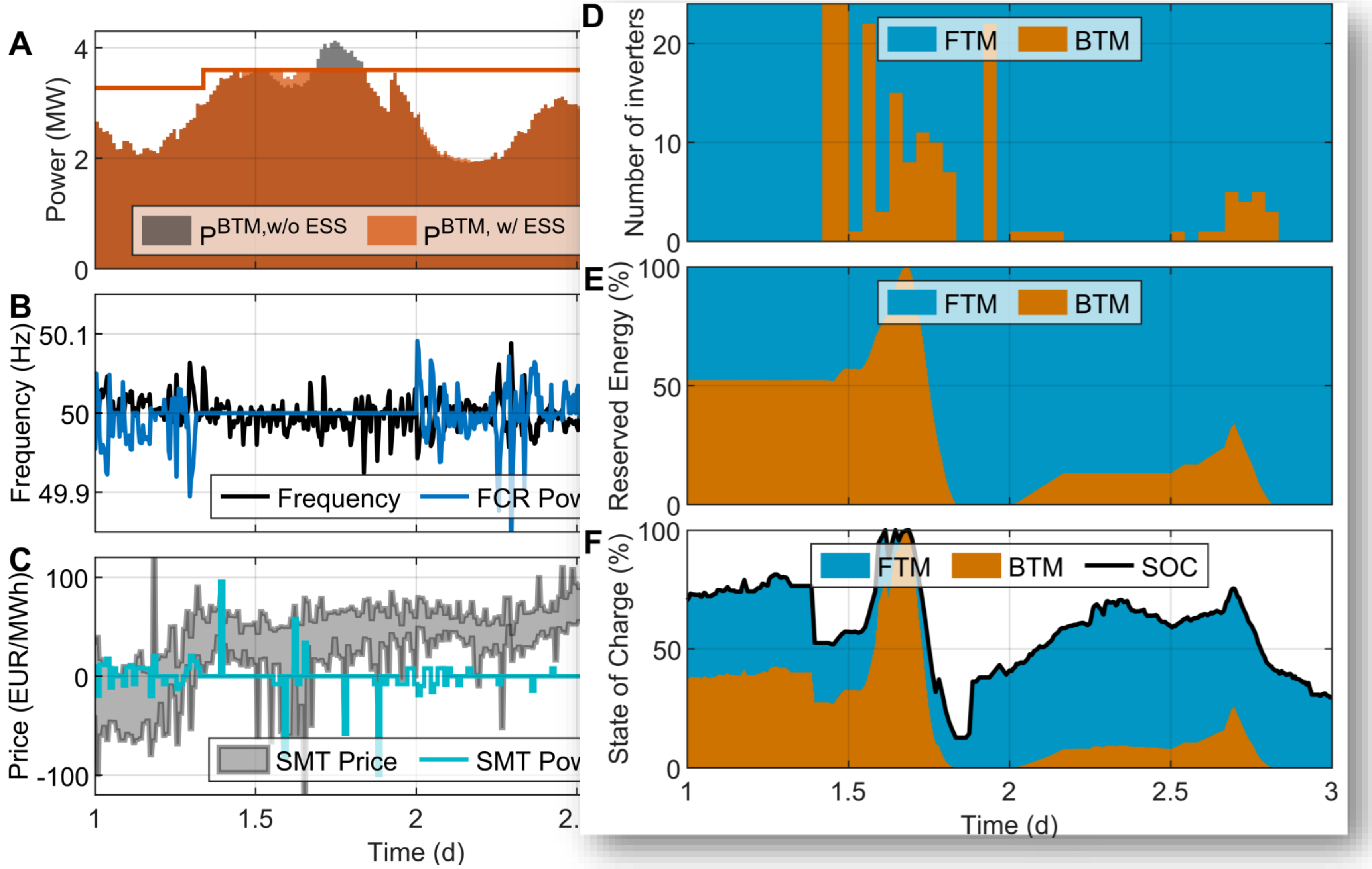
Optimized stacking of applications

- Simultaneous operation in multiple applications

- Switching of physical inverters according to BTM / FTM application power needs



- Allocation of energy content and SOC according to BTM / FTM application energy needs



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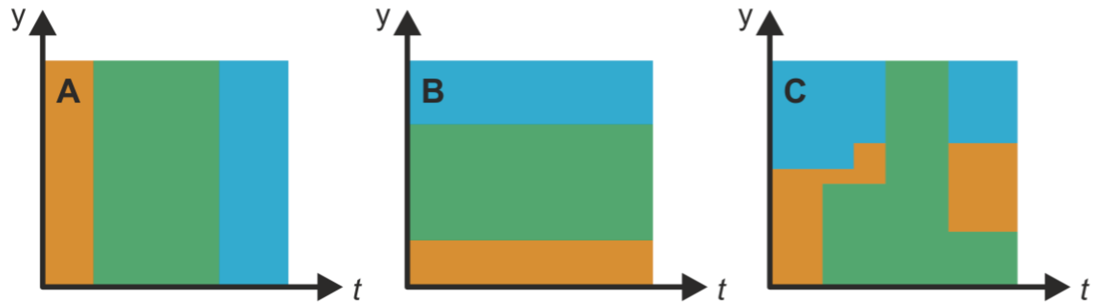
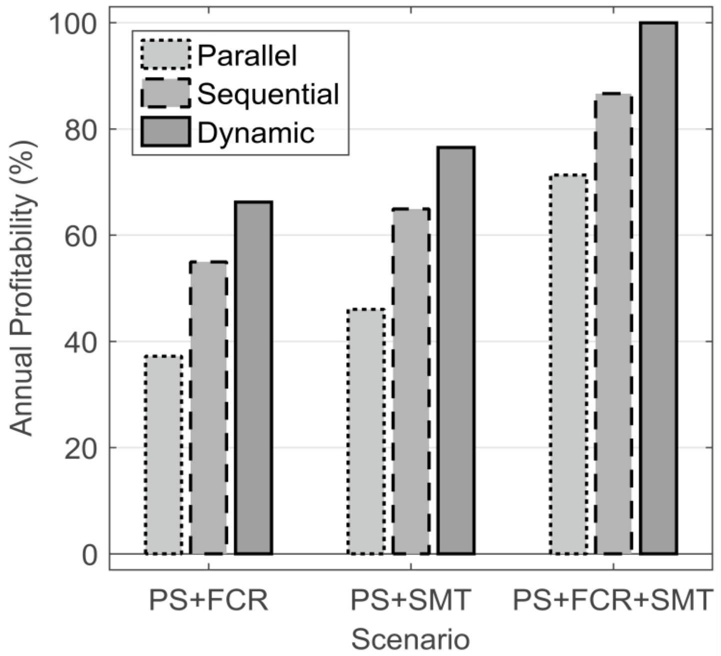
Types of multi-use and their characteristics

- **Sequential Multi-Use (A)**
  - + Temporal flexibility
  - – Exclusive allocation of storage capacities
- **Parallel Multi-Use (B)**
  - + Capacities are distributed across applications
  - – Not flexible in terms of time
- **Dynamic Multi-Use (C)**
  - + Combines the advantages of sequential and parallel multi-use





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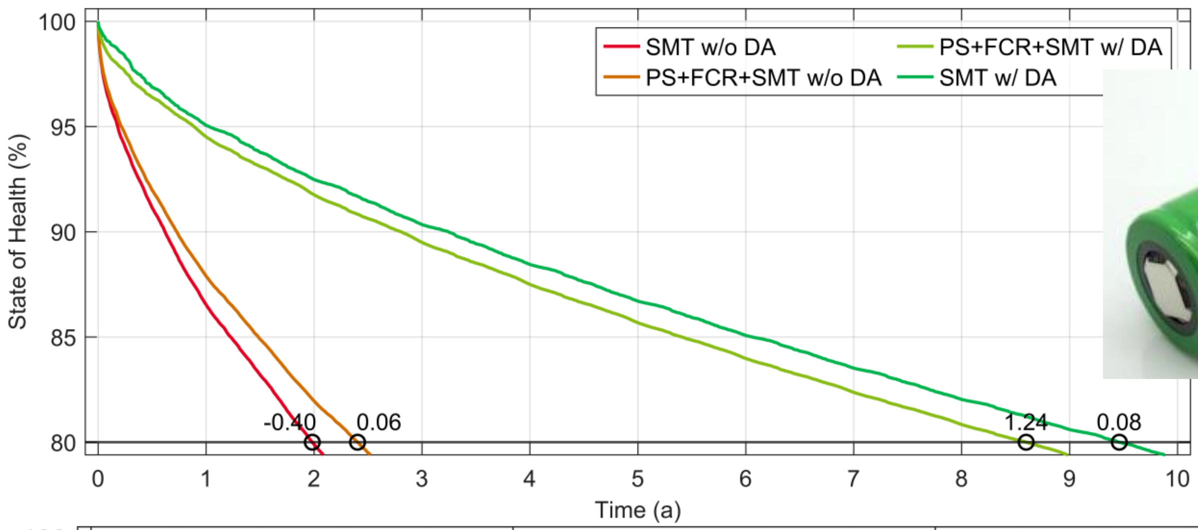
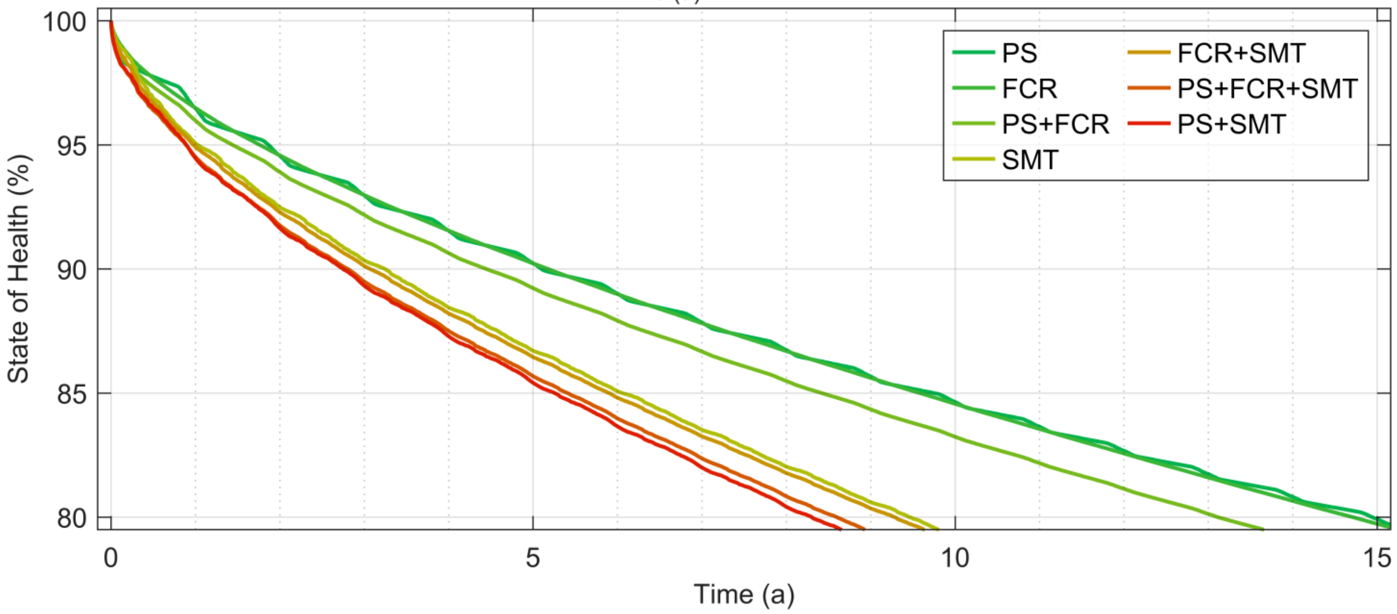
Opportunity costs from battery cell degradation

- Degradation model
  - Calendar and cycle degradation of NMC cell

- Active consideration of the costs of storage utilization leads to a significantly higher lifetime expectancy

- Techno-economic optimum counterbalances profit maximization and energy throughput related cost





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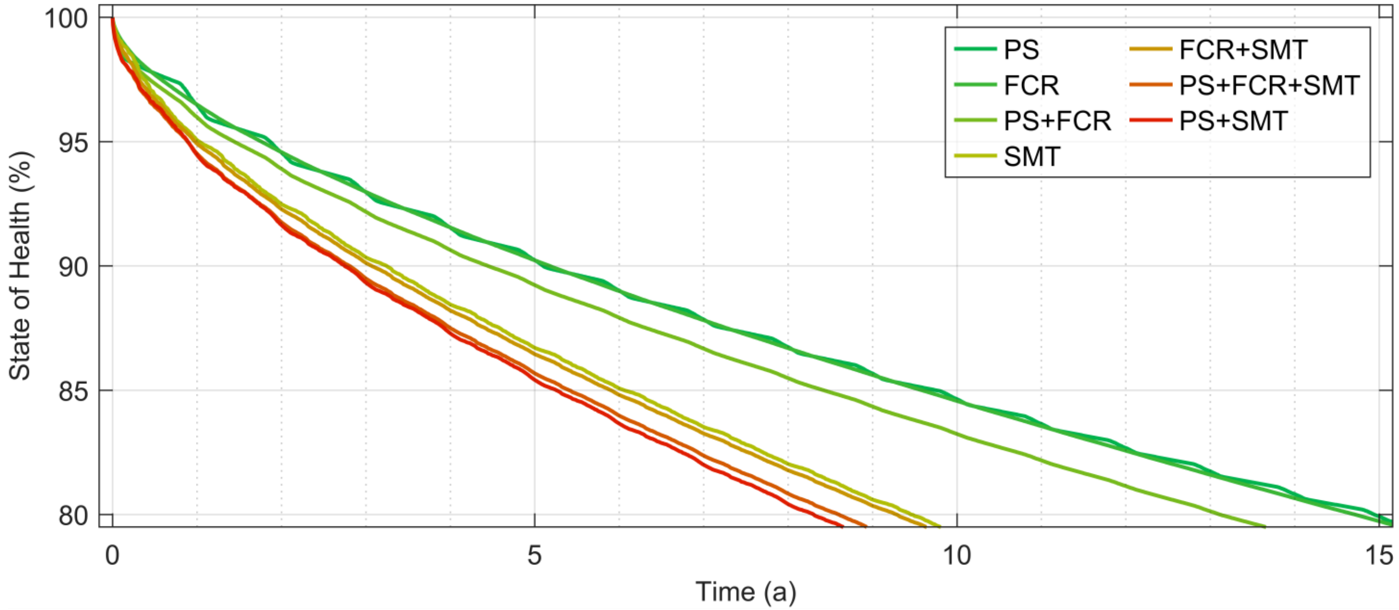
Code	Revenue	EFC	SOH
Self-Consumption Increase	0	0.0	98.3%
Peak Shaving	57,027	46.1	96.5%
Frequency Containment Reserve	62,327	128.6	96.5%
Spot Market Trading	155,040	419.9	92.5%
Multi-Use	**235,681**	**434.8**	**93.2%**

EFC = Equivalent Full Cycles, SOH = State of Health (remaining capacity)



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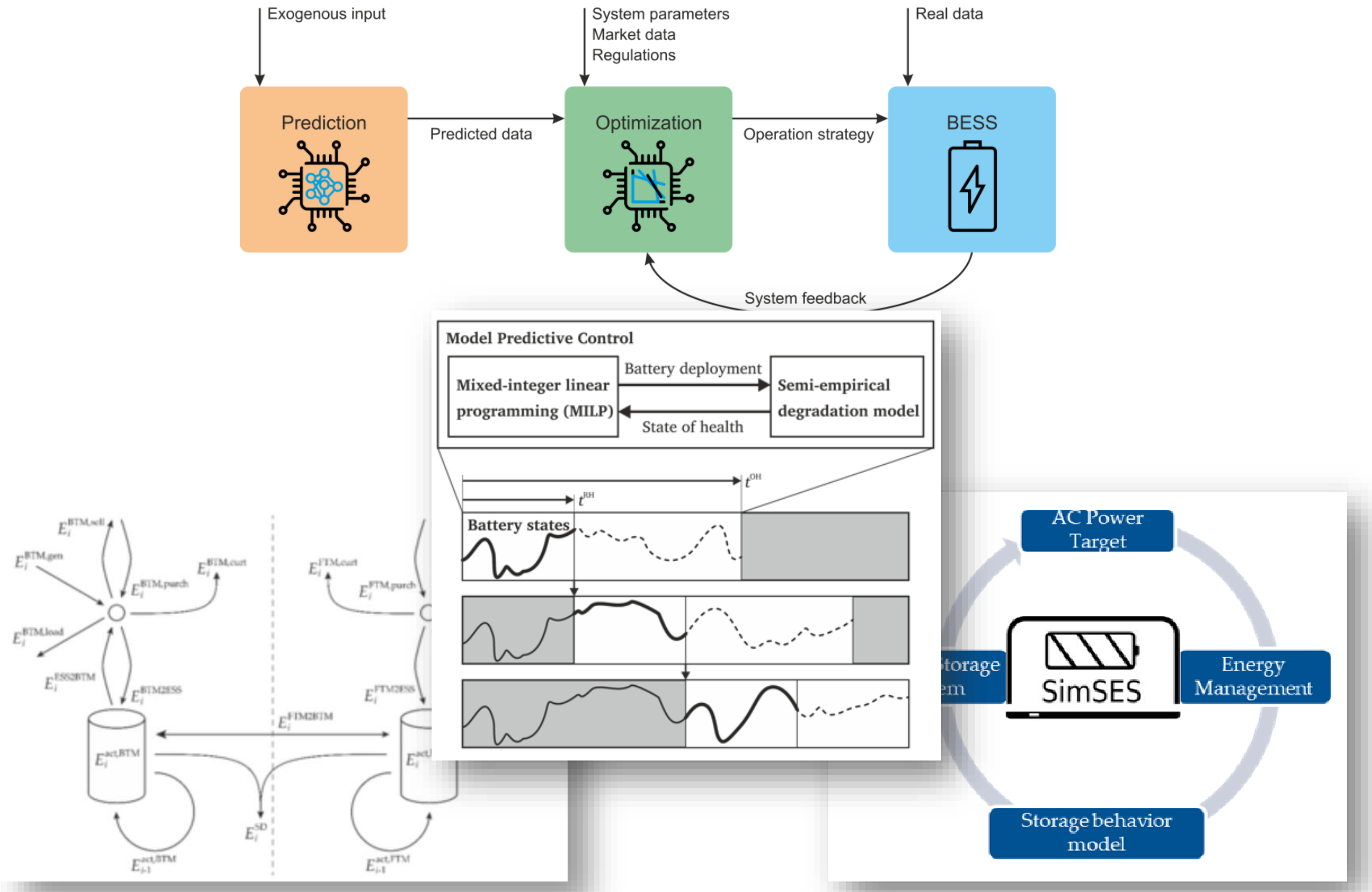
Model predictive control against prediction errors

- Multi-Use optimization formulated as mixed integer linear problem
- Linkage to SimSES Simulation tool to mimic BESS behavior
- Model Predictive control loop minimize fuzziness of prediction errors and allows modelling non-linear BESS behavior
- Code available open source (MATLAB)



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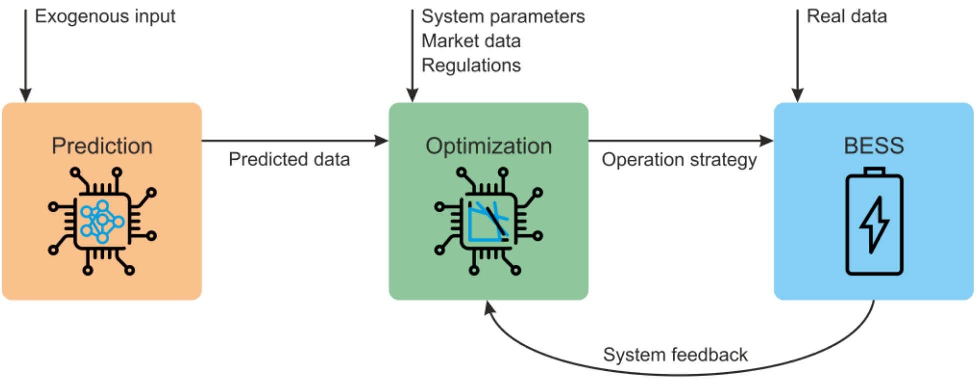
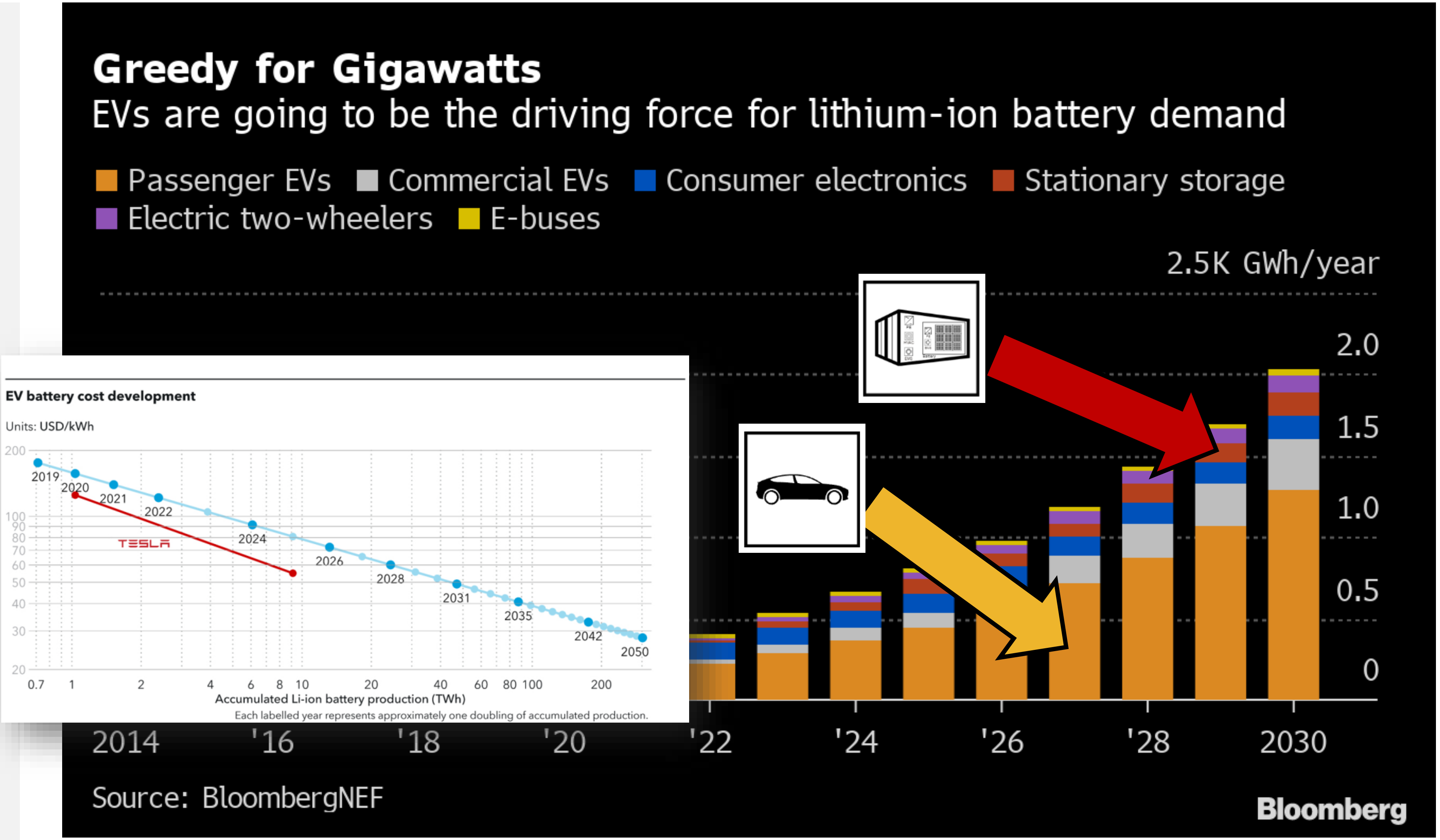


Open-source Code:
https://gitlab.lrz.de/open-ees-ses/mu_opt

Englberger, S.; Jossen, A.; Hesse, H.: *Unlocking the potential of battery storage with the dynamic stacking of multiple applications*, in: Cell Reports Physical Science 1 (11), 2020

EV Multi-Use

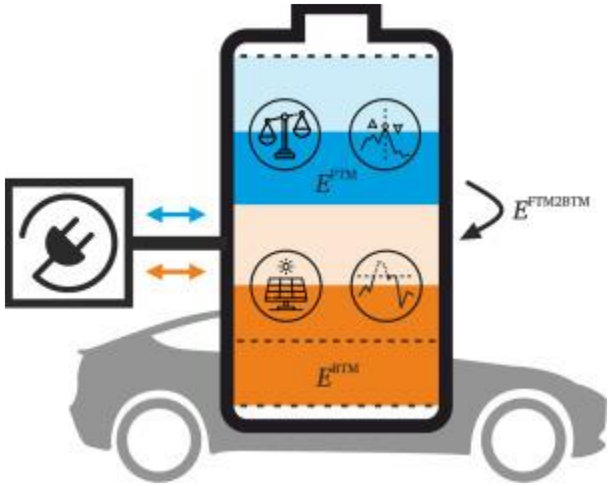
- Projected 2030 LIB market share:
  ~ 60% EV batteries
  ~ 5% BESS batteries
- BESS System Cost 2020: ~400 $/kWh (*)
- Battery Pack Cost 2020: ~200 $/kWh (*)
- LIB (EV) experinecs rate ~19% p.a. (**)

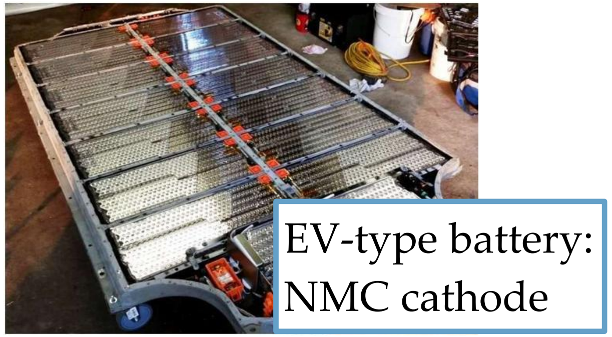


* EU EC-JRC Report (2018) **DNV-GL Tesla Battery Day (2020)

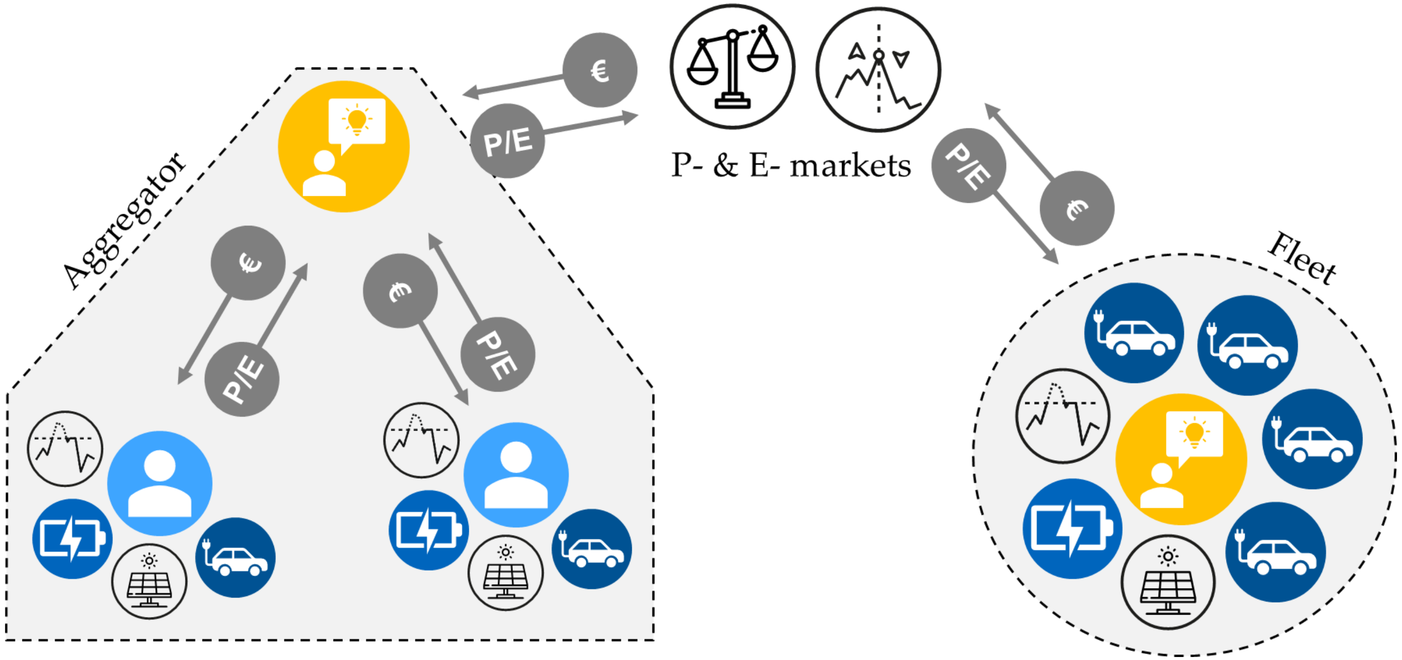
EV Multi-Use

- EVs top priority application is mobility provision
- Passenger vehicles are parked 96% of the time
- Fleet / aggregator Scenario: variation of 1 – 150 vehicles
- Combine Multi-Use and Multi-EV storage management





Tesla Model S battery pack



S. Englberger et al., "Electric vehicle multi-use: Optimizing multiple value streams using mobile storage systems in a vehicle-to-grid context," Applied Energy 304, 2021.

Multi-use with electric vehicles

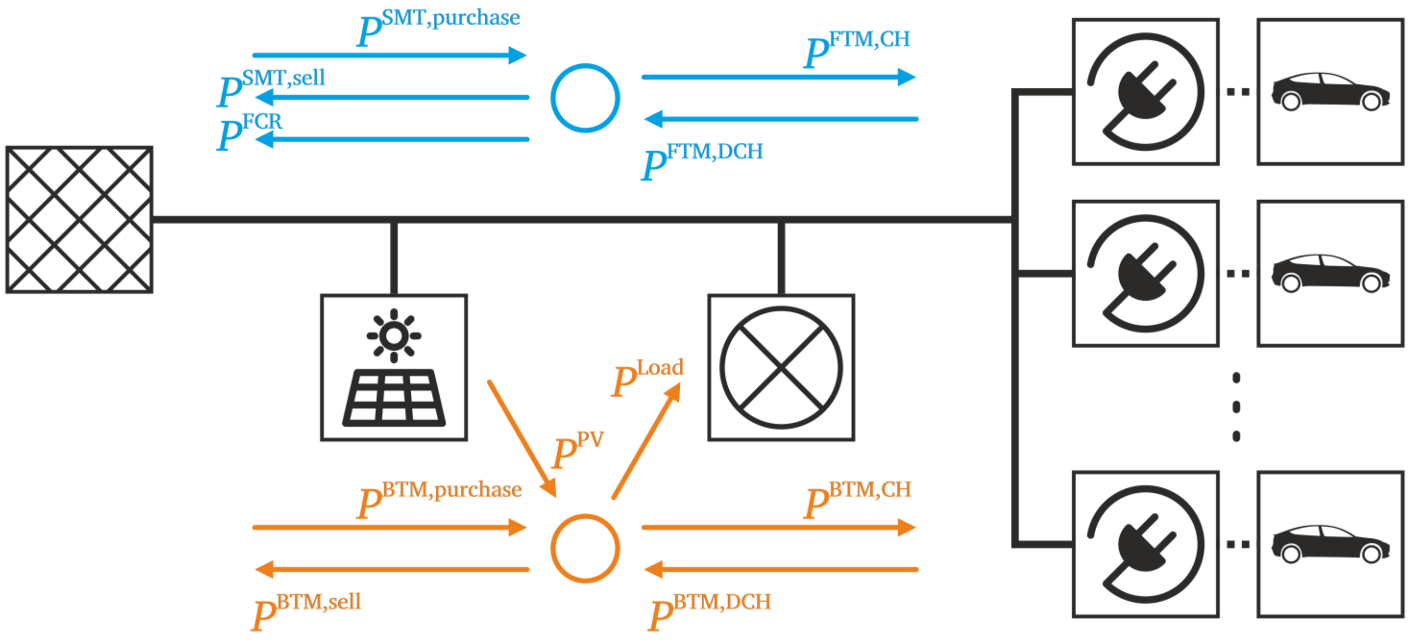
- No fixed point of common coupling (two nodes)
- No permanent connection to the grid ($x^{plugged}$)
- No allocatable power electronics (SW metering)
- Case analysis:
  - Uni-/Bididirectional V2G
  - BTM⇔FTM energy shift

Mobility provision:

$$E^{\text{nominal}} \cdot SOC^{\text{preference}} \cdot x_t^{\text{plugged}} \leq E_t^{\text{BTM,actual}} + E_t^{\text{buffer}}$$

FTM⇔ BTM energy shift

$$E_t^{\text{drive}} = E_t^{\text{drive,BTM}} + E_t^{\text{FTM2BTM}}$$



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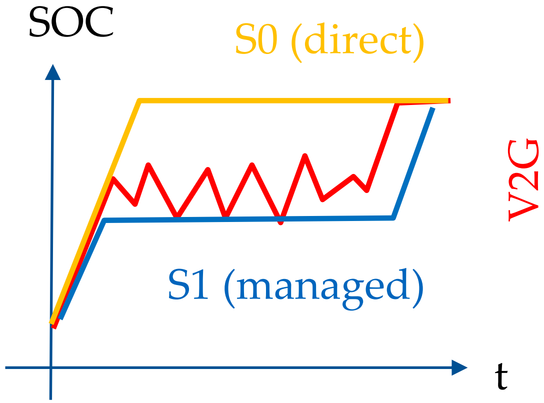
Multi-use with electric vehicles

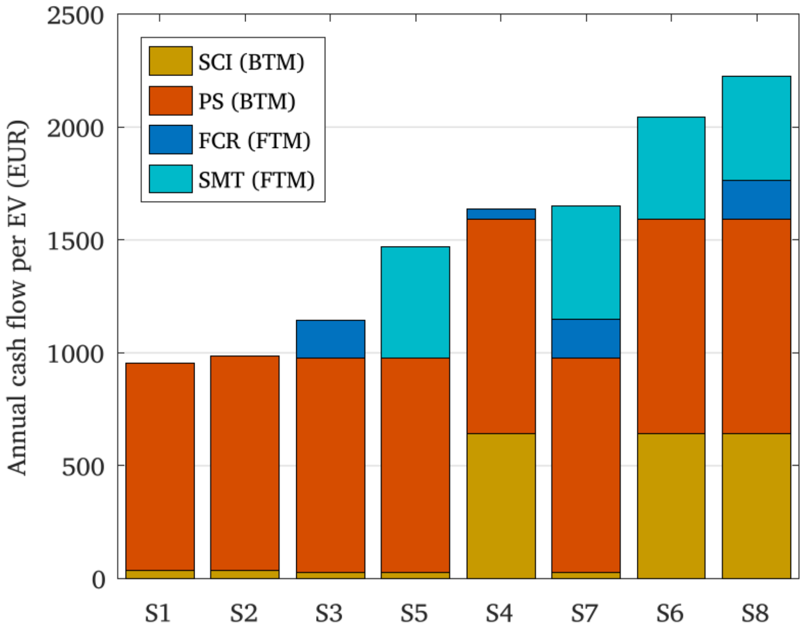
Multiple case Analysis: S0-S8

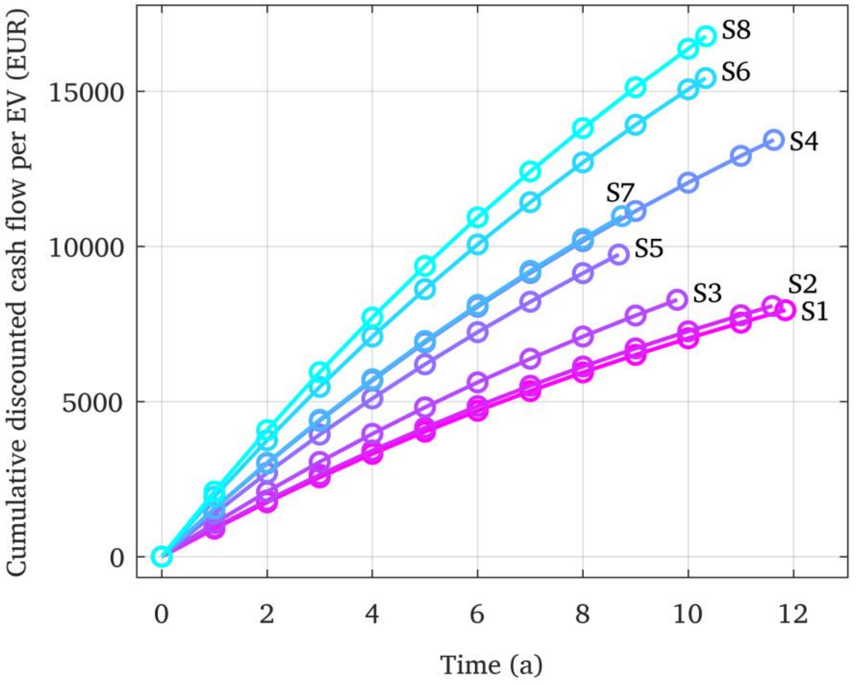
Revenue of 2000+ €/p.a. per EV (S8)

Degradation:
~8 yr lifetime for S0
~12 yr lifetime for S1
~10 yr lifetime for S8

Scenario	Applications	Optimized charging	V2G	FTM2BTM	EFC/a	EOL (a)
S0	–	no	no	no	47.4	7.9
S1	SCI, PS	yes	no	no	47.4	11.8
S2	SCI, PS	yes	yes	no	47.5	11.6
S3	SCI, PS, FCR	yes	yes	no	54.7	9.8
S4	SCI, PS, FCR	yes	yes	yes	47.8	11.6
S5	SCI, PS, SMT	yes	yes	no	72.3	8.7
S6	SCI, PS, SMT	yes	yes	yes	61.1	10.3
S7	SCI, PS, FCR, SMT	yes	yes	no	71.6	8.7
S8	SCI, PS, FCR, SMT	yes	yes	yes	60.7	10.3







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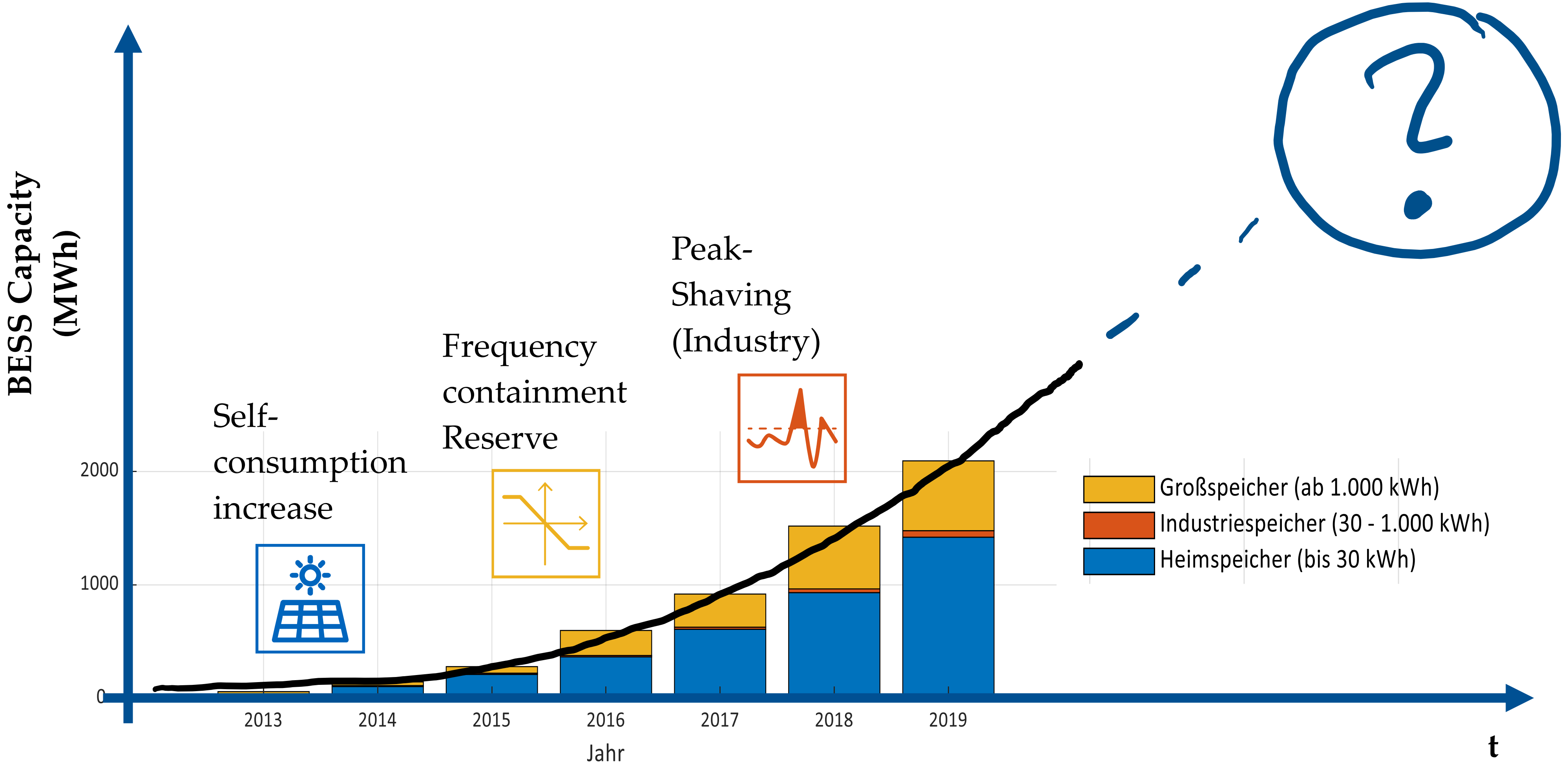
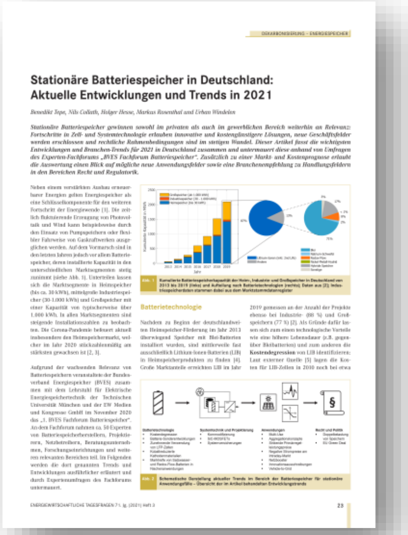
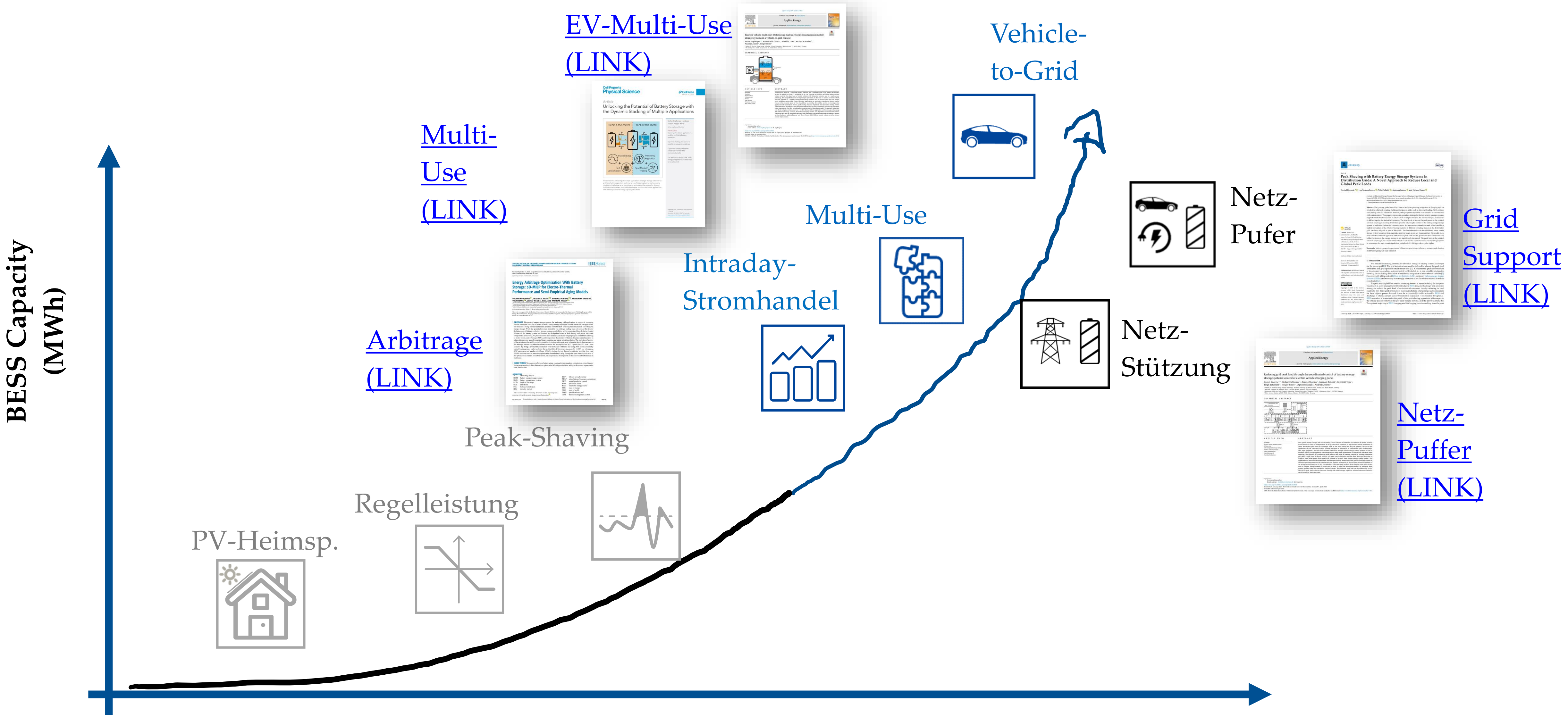
Batterie-Speicherzubau in Deutschland - Status




Stationäre Batteriespeicher in Deutschland: Aktuelle Entwicklungen und Trends in 2021

[“Energiewirtschaftliche Tagesfragen 71 (2021): Stationäre Batteriespeicher in Deutschland: Aktuelle Entwicklungen und Trends in 2021 (BVES)”]

Batterie-Speicherzubau in Deutschland - Ausblick



Vielen Dank!

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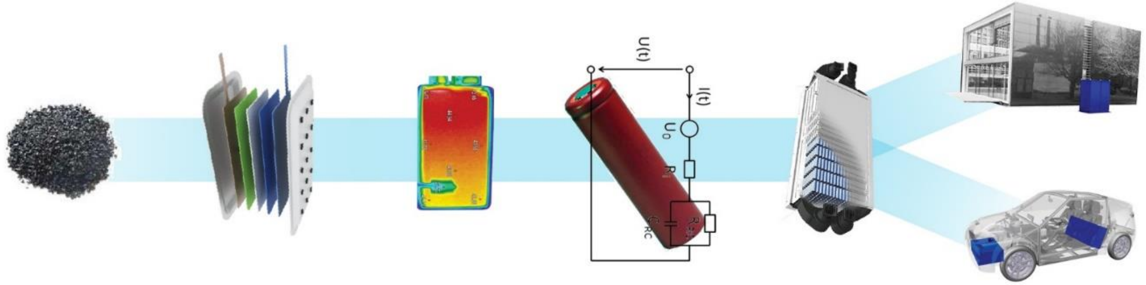

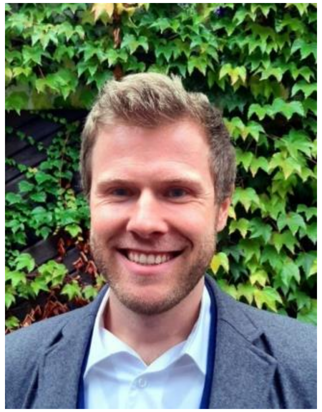

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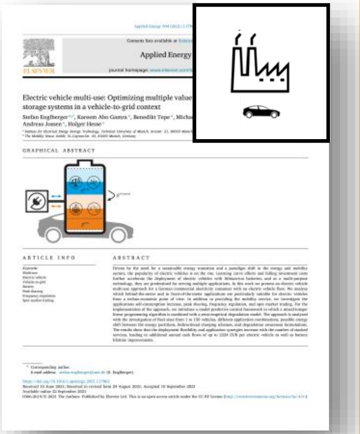
Zukünftige Anwendungsfälle Batteriespeicher

Home Storage System (HSS)

“5 - 30 kWh”

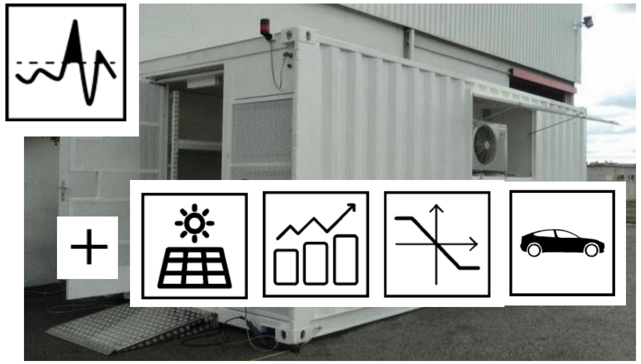
Source: sonnen.de



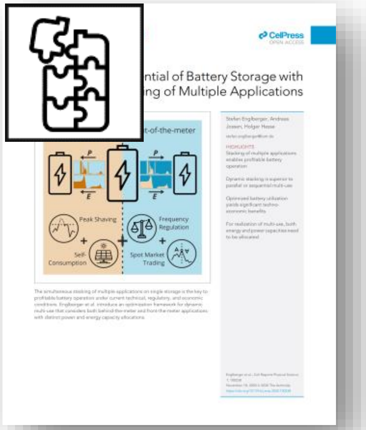
[V2H (LINK)] [EV-Multi-Use (LINK)]

Industry Scale Storage (ISS)

“30 kWh – 1 MWh”



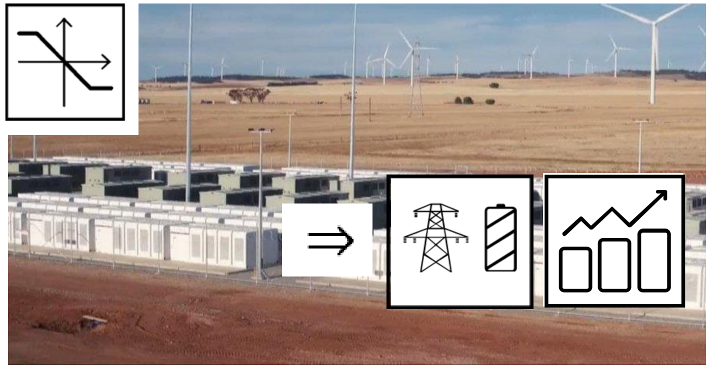
Source: NEC.de



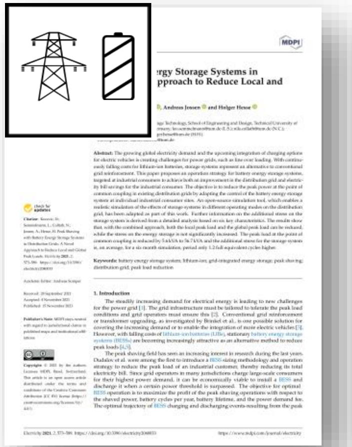
[Multi-Use (LINK)] [Netz-Puffer (LINK)]

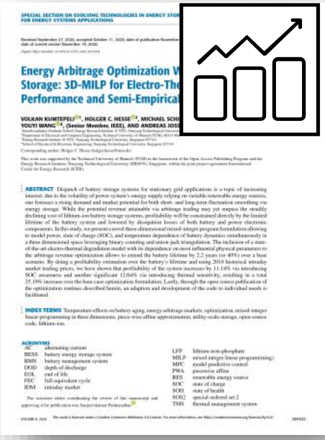
Utility Scale Storage (USS)

“1 MWh+”



Source: tesla.com





[Grid Support (LINK)] [Arbitrage (LINK)]