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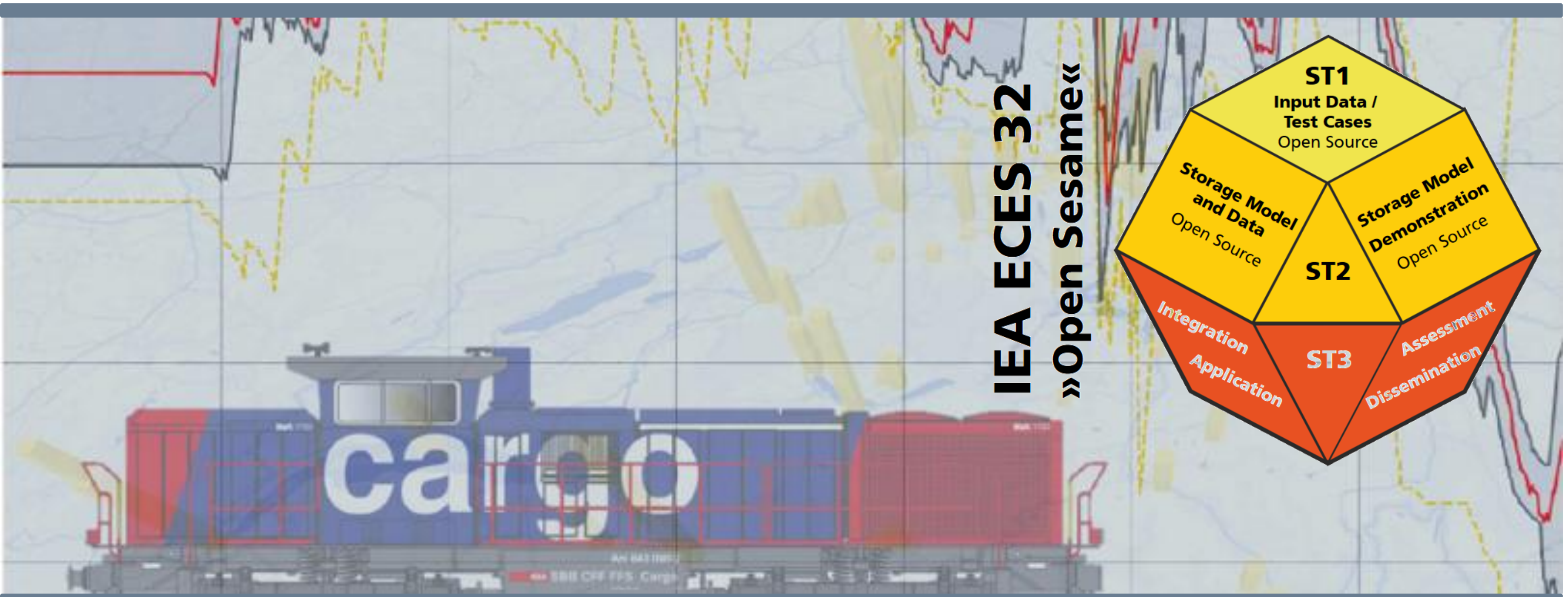


Enabling long-lasting battery systems for the provision of several decarbonization services

IEA Networking Event

2022-05-24; Dr. Priscilla Caliandro, Prof. Dr. Andrea Vezzini, Marco Beyeler, Steffen Wienands

▸ BFH Energy Storage Research Centre

ECES Annex 32:

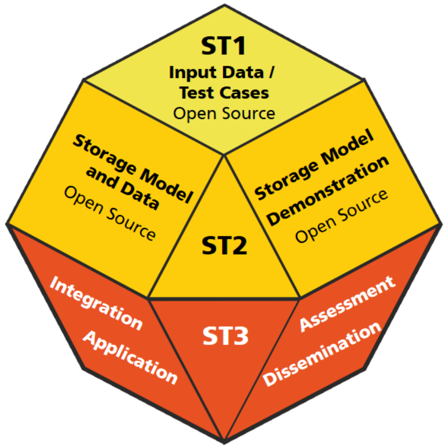
Modelling of Energy Storages for Simulation/Optimization of Energy Systems

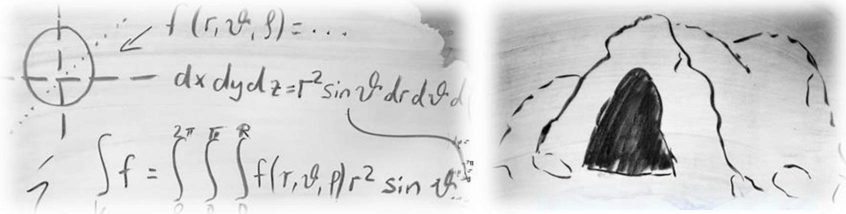
»*Open Sesame*« – *Open Source Energy Storage Models*

Prof. Dr.-Ing. Christian Doetsch, Fraunhofer UMSICHT | Ruhr University Bochum

Fraunhofer UMSICHT

IEA ECES 32
»Open Sesame«





energy storage

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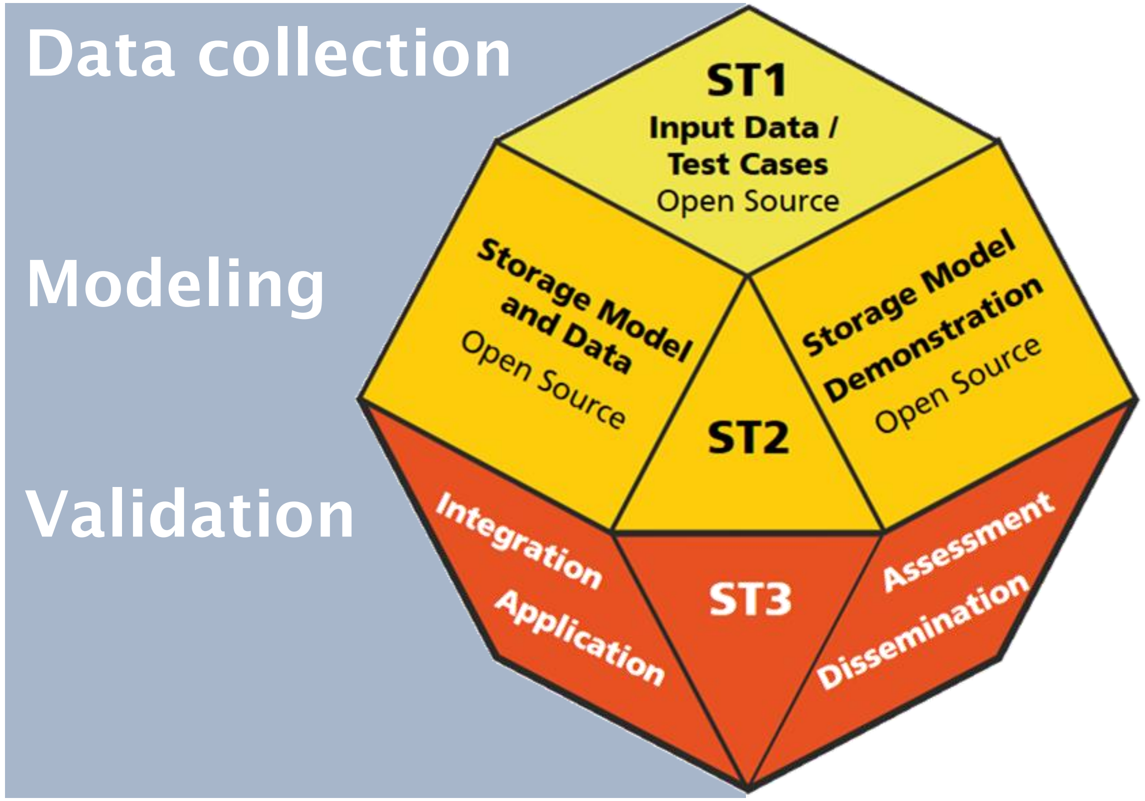
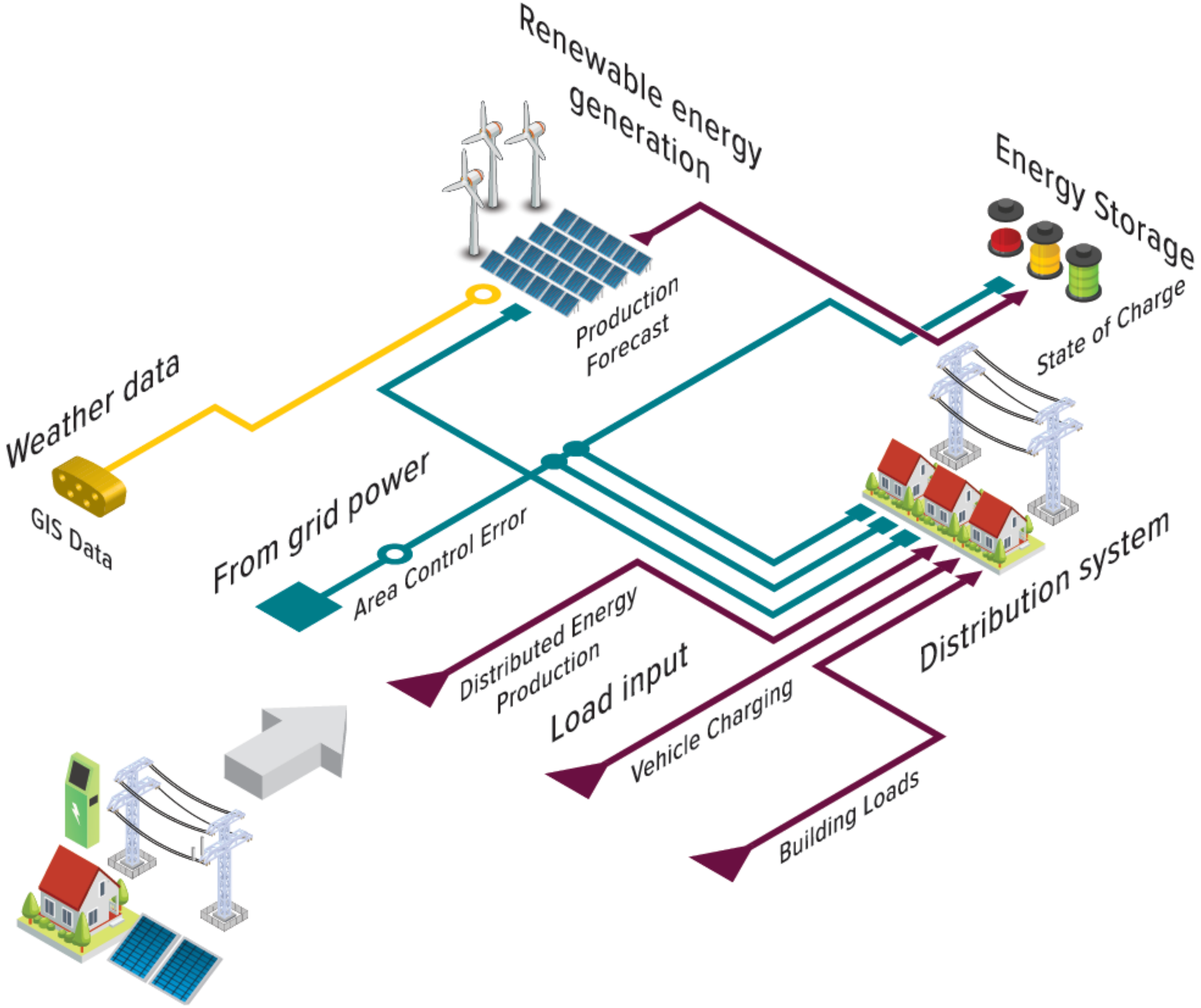
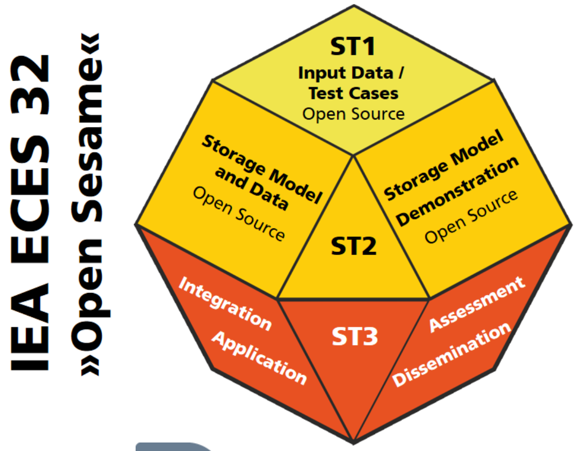
Activities – the big picture





Existing collaboration



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ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM

TIMES
The Integrated MARKAL EFOM System

PAUL SCHERRER INSTITUT
PSI

Generic open-source ecosystem for energy storage models and data sets, which allows for finding answers to current storage questions (technical, economical, regulatory)

ES configurations, which meet the end-use energy service demands at least cost while also adhering to various constraints (emission reduction, % of renewable electricity, etc.)

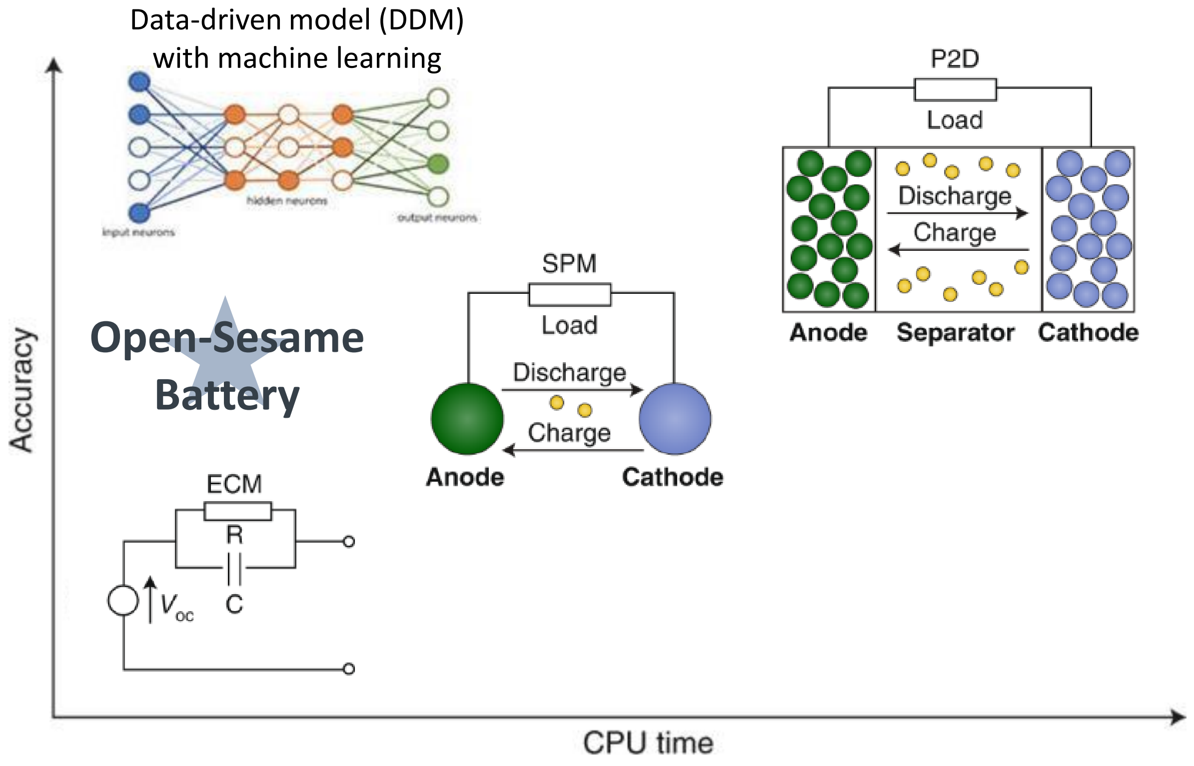
Model options for Battery SOX estimation

ECM

- Benefits
  - simple parameter identification
  - robustness against high current changes
  - Low computing power
- Drawbacks
  - Lack of representation of electrochemical state

PBM

- Benefits
  - All states are physically meaningful
  - Predictive capabilities of non parameterized operating conditions
- Challenges
  - High computational load - partial differential equations
  - High parameterization effort due to large number of parameters



Accuracy vs. CPU time for equivalent circuit model (ECM), single-particle model (SPM), pseudo 2D model (P2D) and Data-driven model (DDM) with machine learning

Ng, MF., Zhao, J., Yan, Q. et al. Predicting the state of charge and health of batteries using data-driven machine learning. Nat Mach Intell 2, 161–170 (2020). https://doi.org/10.1038/s42256-020-0156-7

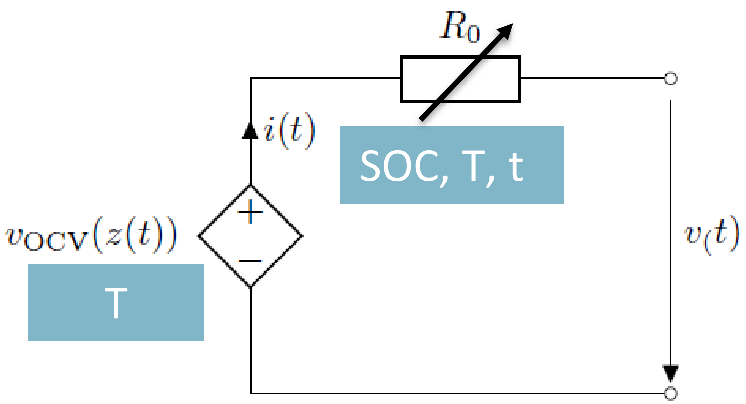
Open-Sesame-Battery model

Battery dynamic model

The battery performances are mapped over different operating conditions

$$v(t) = v_{OCV}(SOC) - i(t)R(t, SOC, T)$$

$$SOC_n = SOC_{n-1} - i(t) * t/Q_0$$

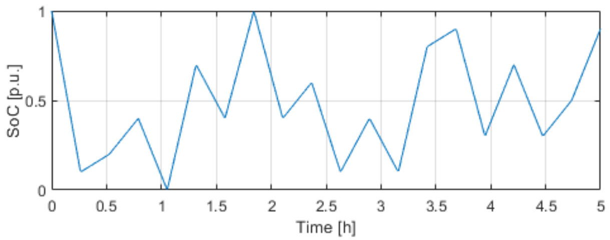


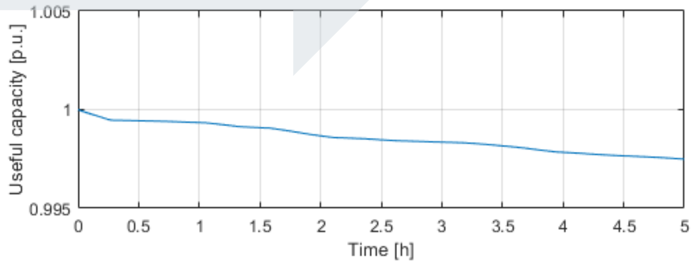
Battery degradation model

Calendaric and Cycling capacity fading is modeled in terms of severity factors matrix

$$f_{degradation} = f_{calendaric} + f_{cycling}$$

SOC profile → Degradation model → Aging profile





SOC profile	Temperature SOC	Calendaric degradation
Cycle analysis	Average SOC Average Temperature DOD Crate	Cycling degradation

\+ Capacity/Power fading

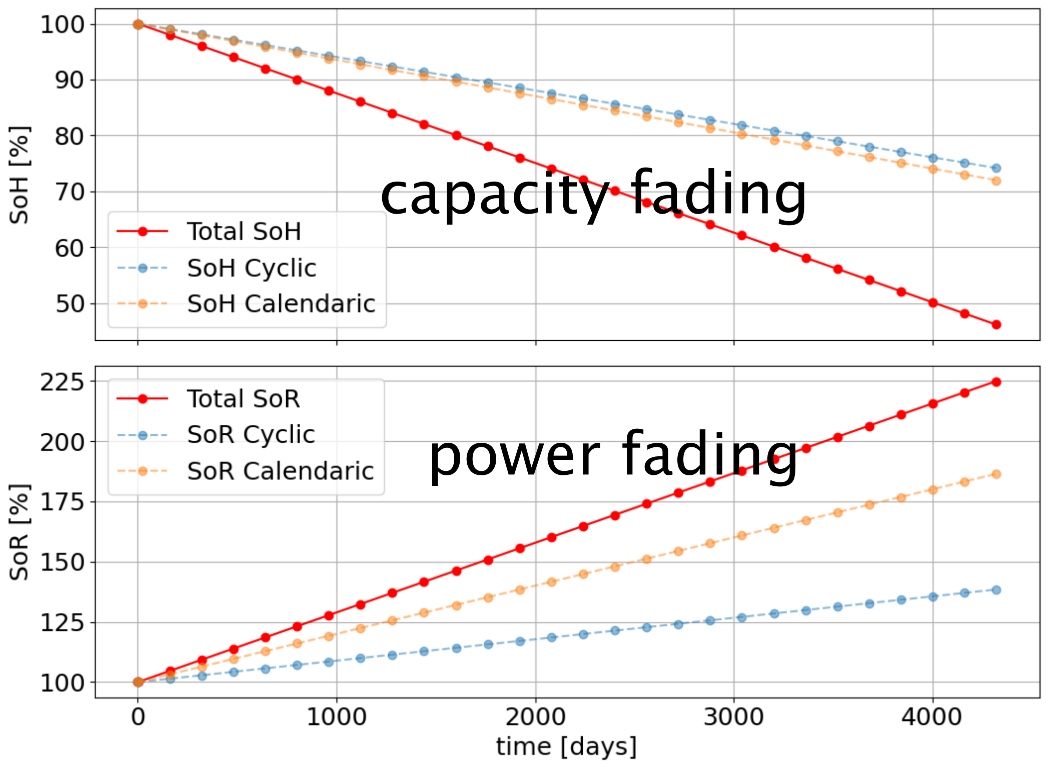
Simulation Environment

Open-Sesame-Battery

https://gitlab.ti.bfh.ch/oss/esrec/open-sesame

- Semi-empirical aging model of different cell types
  - Lithium Titanate Oxide (LTO)
  - Nickel-manganese oxide (NMC)
  - Lithium iron phosphate (LFP)
- Simulation of cell degradation (SoH) and battery performance (SoR)
- Cost functions to calculate storage costs

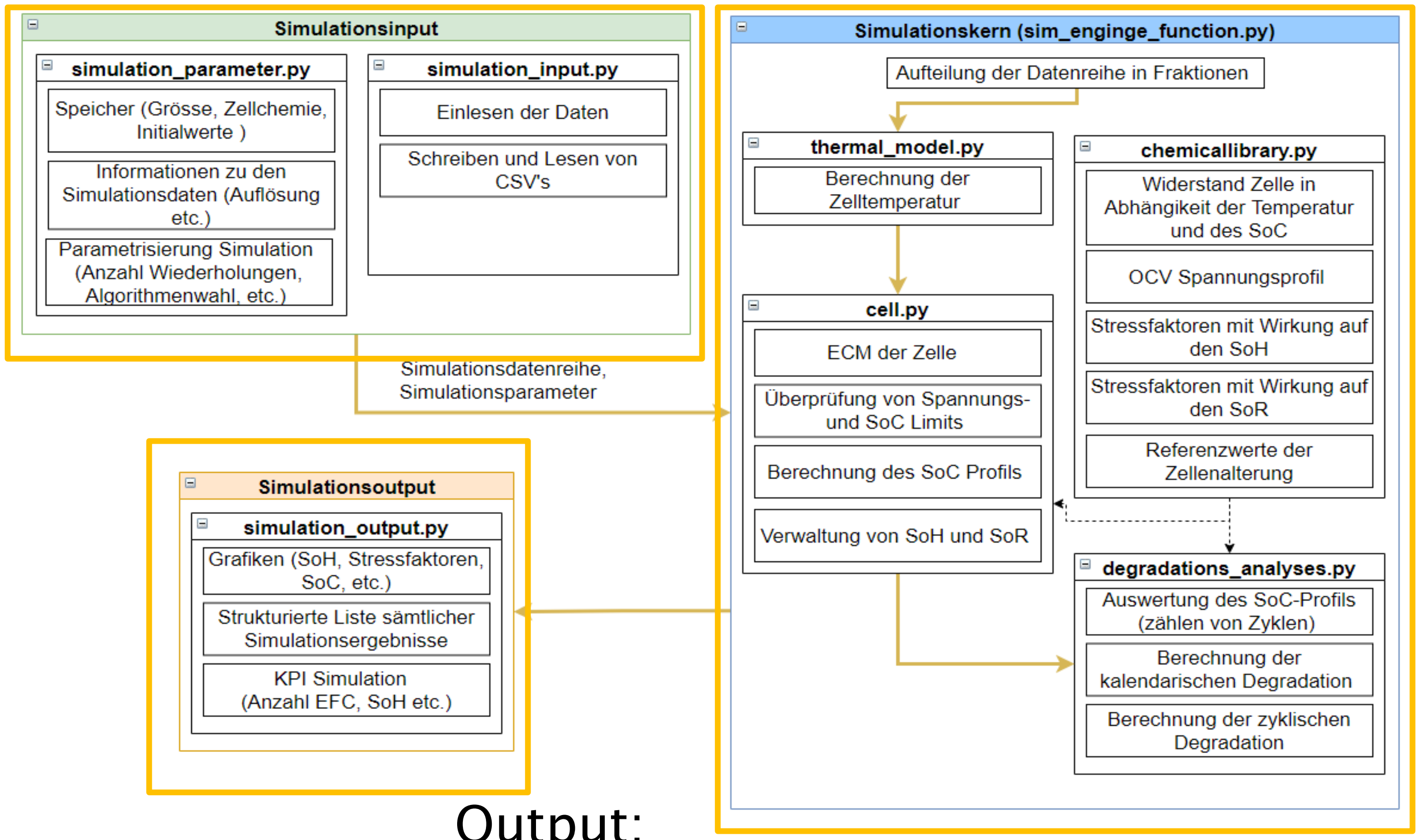
- Object-oriented structure in Python
- Variable simulation length and resolution



Simulation setup

Input:

- Load and temperature profile
- Description of the storage
- Parameterization of the simulation
- Functions for the preparation of the user input



Simulation Core:

- Chemical library
- Performance Analysis
- Load profile -> SoC profile
- Degradation analysis
- Thermal battery model

Output:

- Structure results
- Create graphics
- KPI's summarized

BIENE - Integration & management of batteries on rail vehicles

SBB CFF FFS

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Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Federal Office of Transport FOT

700 diesel-powered rail vehicles
(maintenance work, construction site operations, shunting, fire-fighting and rescue operations).

SBB current **diesel consumption** for rail traction →**11 million l/y**

SBB goal is to **reduce** fossil **diesel consumption** by **50 %** by **2030** and by **92%** by **2040**.

BIENE - Integration & management of batteries on rail vehicles

SBB CFF FFS

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Federal Office of Transport FOT

Conversion/Replacement of SBB diesel locomotive fleet to **battery drive systems** that are also **connected to the grid → total of 140MWh**

Battery cargo fleet can be used to **satisfy main application** but also auxiliary services **to increase flexibility** while optimizing battery lifetime and return of investment.

Identification of Battery Energy profile for Am843

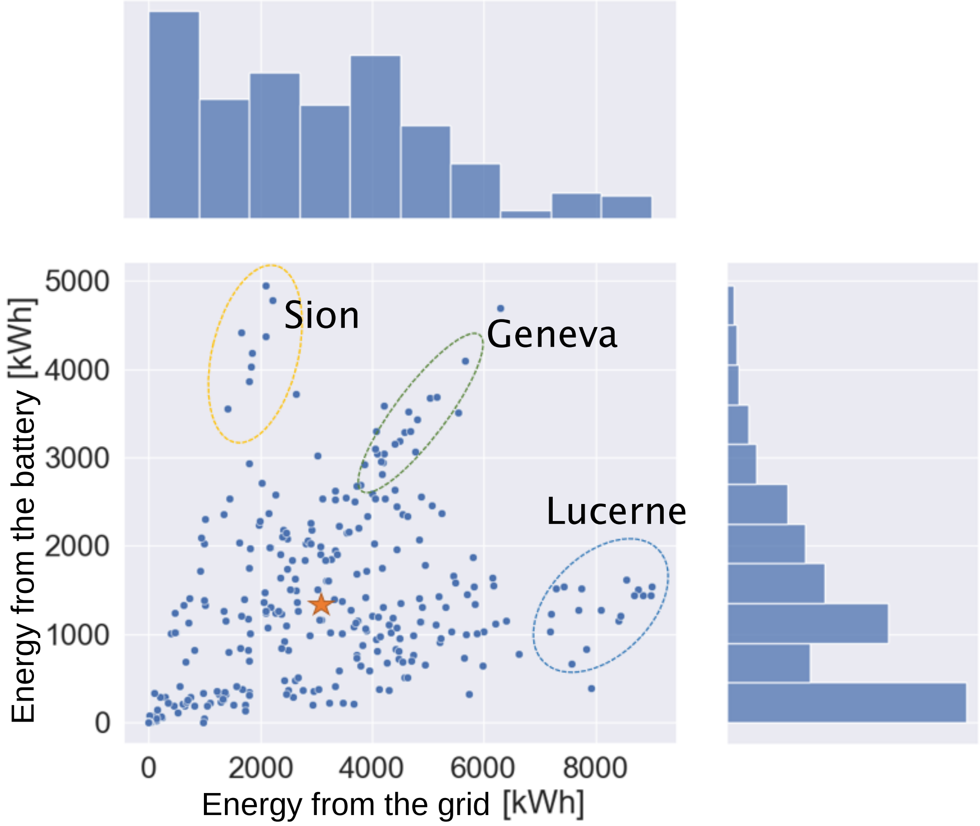
Baseline:

- Diesel locomotive for shunting operations and freight train locomotive
- 45 vehicles in service with Cargo
- Conversion to alternative drive under consideration
- Hybrid locomotive (catenary + battery storage)
- Data loggers installed on vehicles

Procedure:

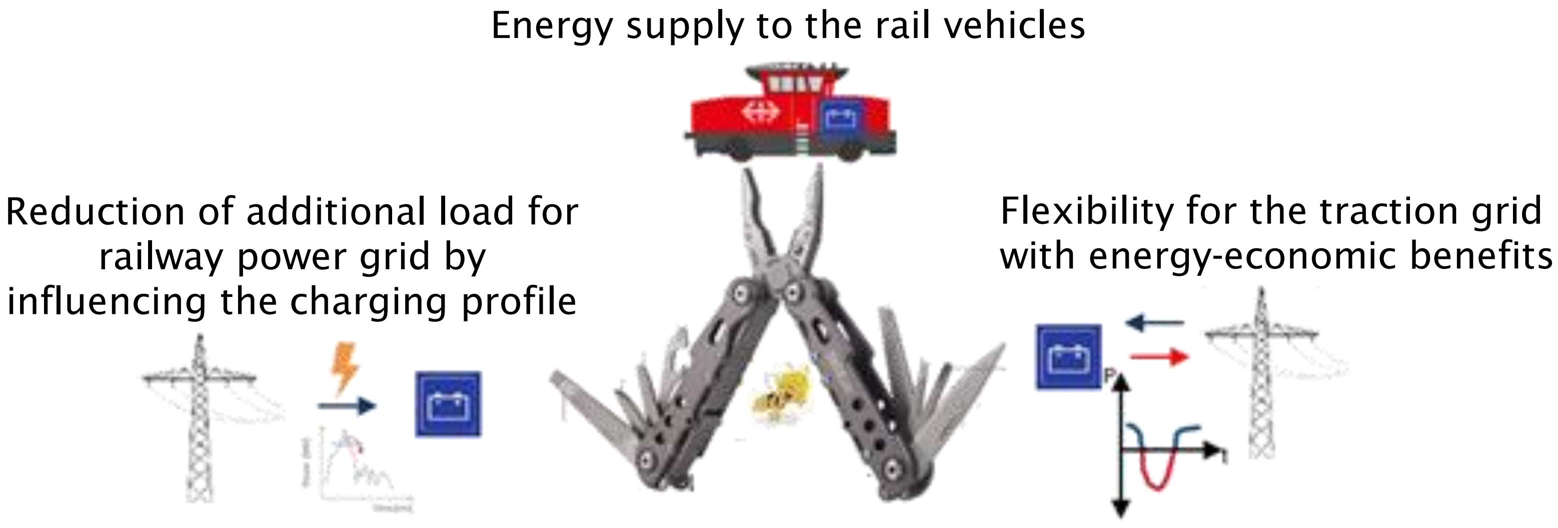
- GPS data for determining the route electrification
- Creation of load profiles based on current vehicle usage
- Simulation of battery use
  - Constant charging power

Weekly profiles:



Several challenges for the battery system

1. How to best charge the battery to serve the application & extend the life time?
2. Is it possible to define optimal operating strategies?
3. Which other auxiliary services can be offered?
4. How the cost of battery degradation should be splitted?

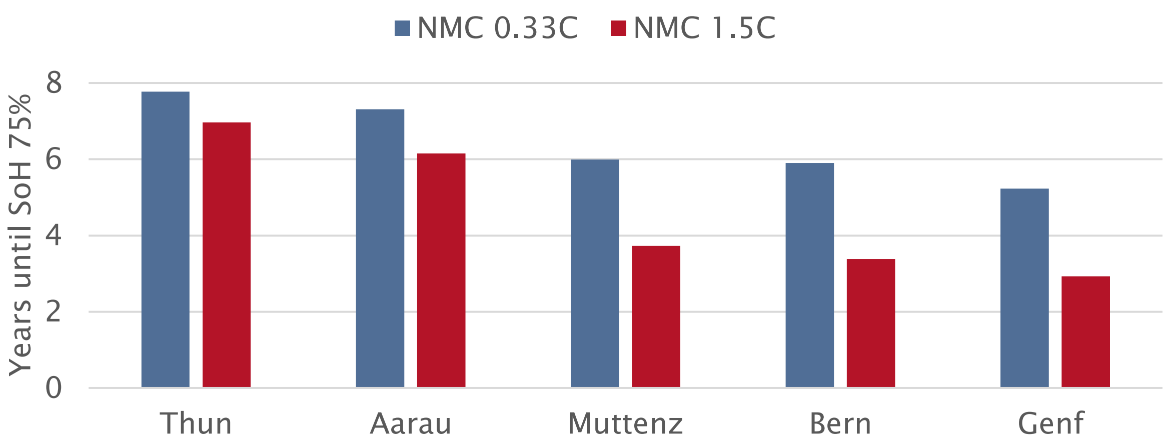


SBB CFF FFS **Battery Management Platform**

Influence of charging strategy on battery aging:

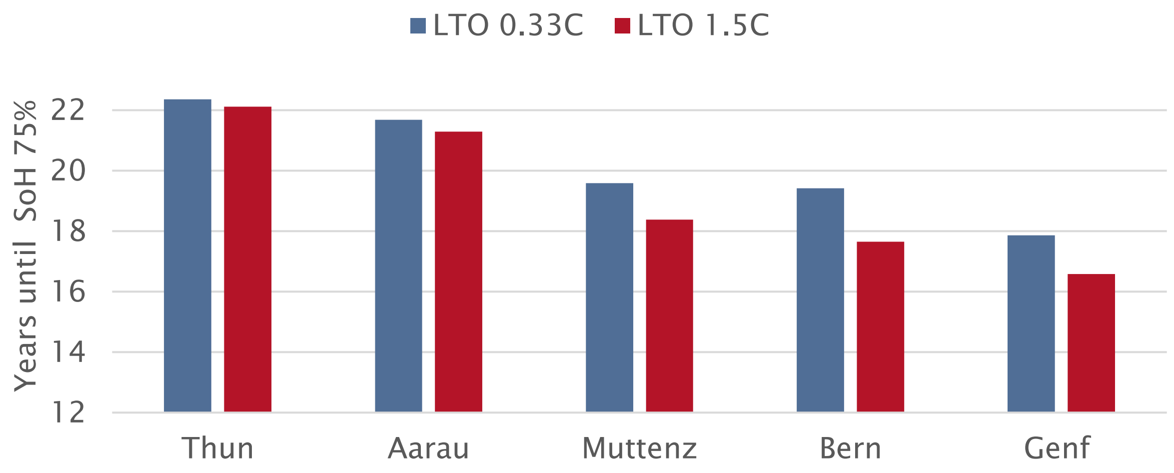
Procedure :

- Choice of 5 different weekly operating profiles
- Simulation of two different charging strategies (0.33C and 1.5C)
- Comparison of the aging over the lifetime



Results:

- High charging power significantly impacts battery aging
- LTO more resistant to high charging power
- Calendar aging dominant
- Battery-saving charging is possible from an operational point of view



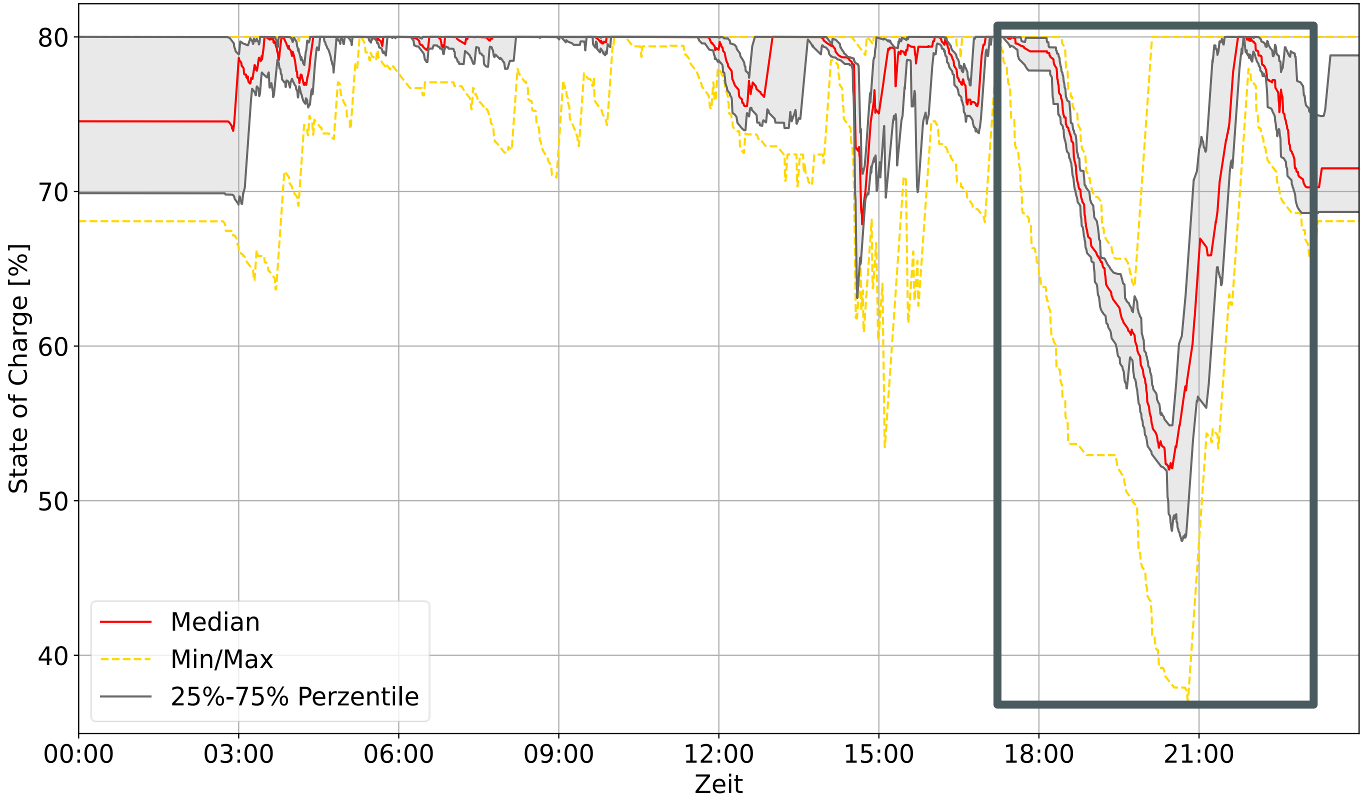
Predictability of vehicle deployment

Hypothese:

- Recursive deployment pattern at the respective locations

The example of Basel:

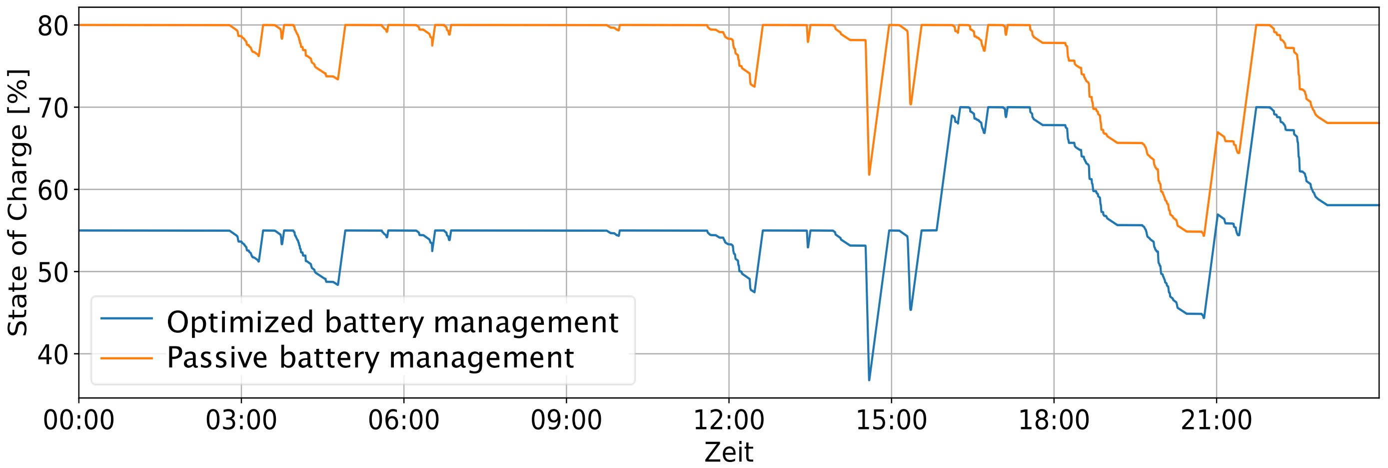
- Simulation of battery use over 4 weeks
- Comparison of the SoC profile
- Similar storage usage on weekdays Mon-Thu
- Intensive storage usage in the evening hours



Suggesting aging aware operating strategy

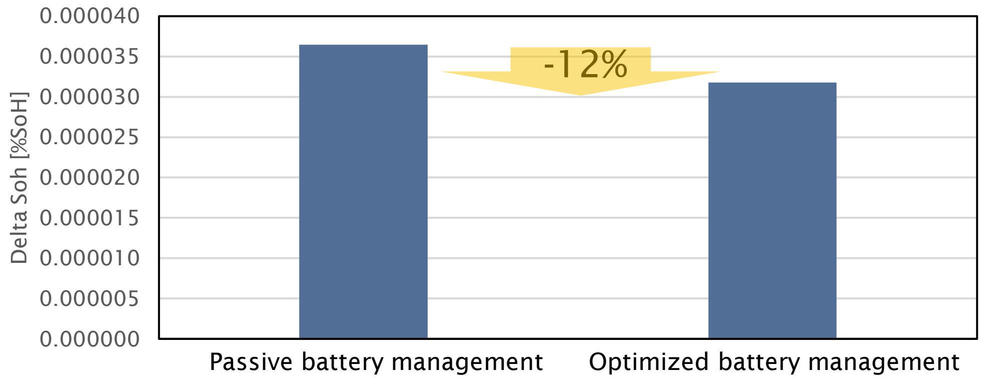
Management Proposal:

- Lowering of the SoC until the evening shift
- Shortly before evening shift the battery is charged from 55% to 70% SoC (0.5C)



Benefit:

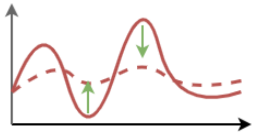
- lower SoC leads to 12% reduction of calendar aging



Conclusion:

- If vehicle usage is known, the battery can be managed in an aging-optimized manner

Smoothing the load profile:



Initial situation:

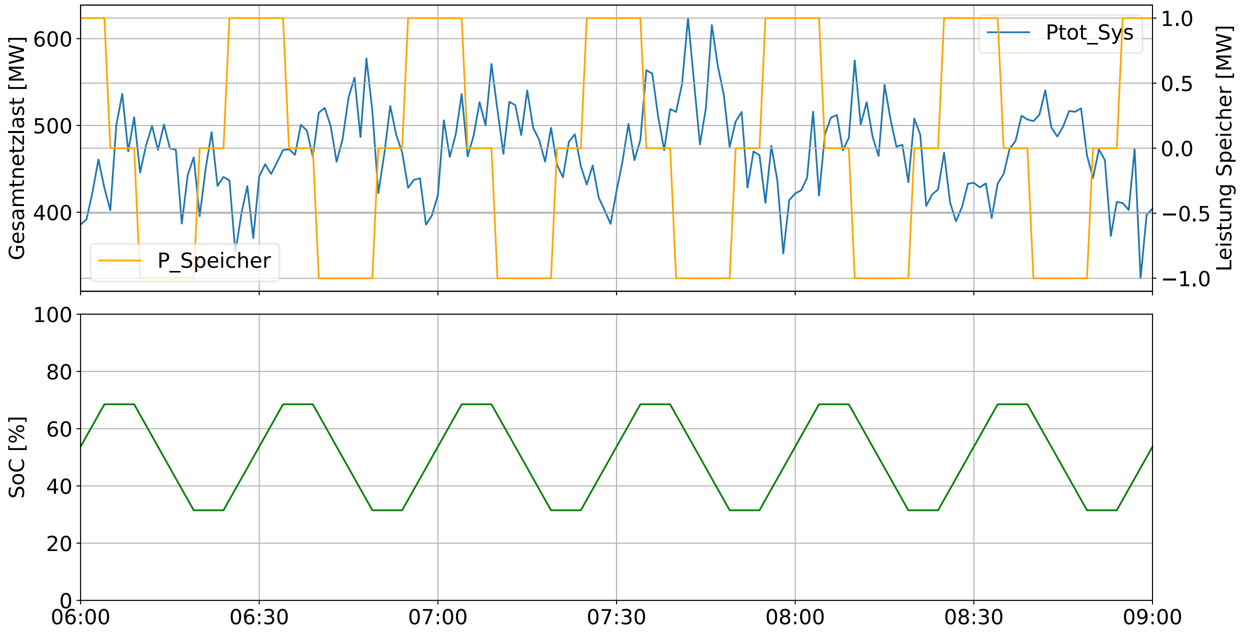
- Load dynamics require high power reserves
- Smoothing with the help of battery storage conceivable in the future
  - Bidirectional operation
  - Availability of vehicles

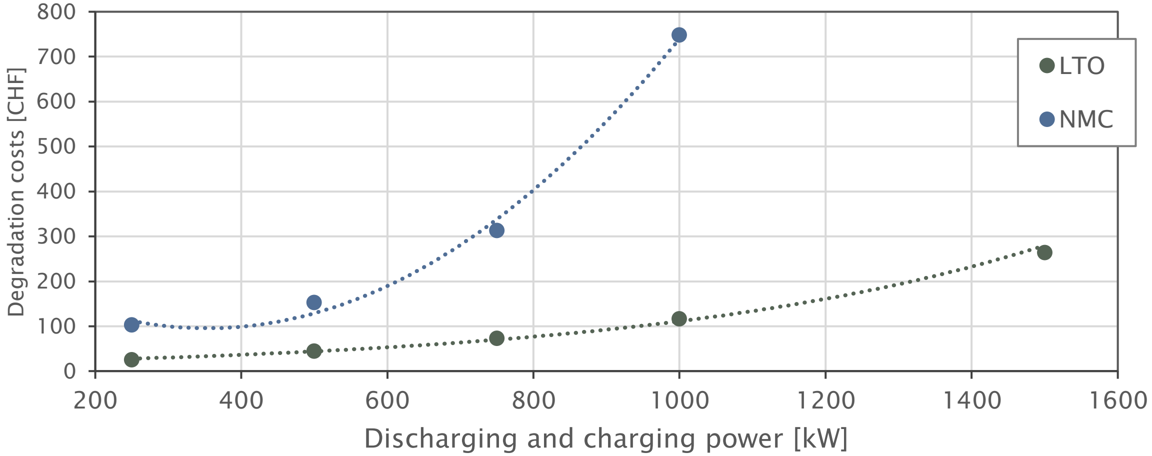
Procedure:

- Simulation of storage use to smooth the load profile during HVZ (06:00-09:00).
  - Vehicle reserved only for secondary use during this time
  - Constant charging / discharging power

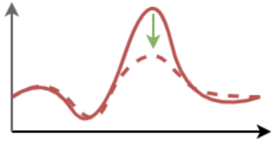
Results:

- Large number of vehicles necessary
- Distribution over several vehicles is profitable



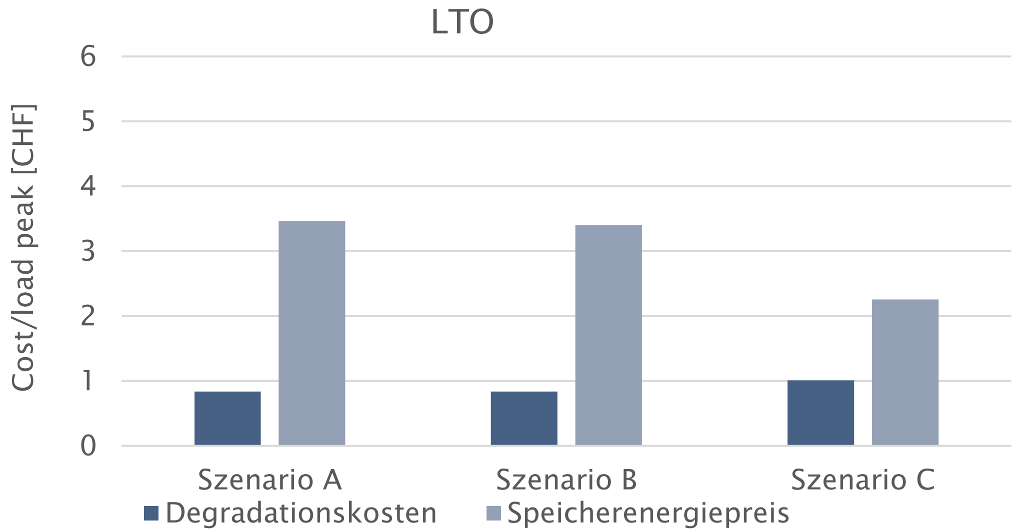


Peak shaving:



Baseline:

- High dynamics in SBB energy network lead to load peaks
- SBB already operates a load management system
- Locomotive energy storage could reduce load peaks in the future



Procedure:

- Definition of three different scenarios
- Simulation of peak load reduction
- Degradation analysis and application of the cost function

Storage deployment scenario:	Number of peak load applications:	Storage use during peak loads:
A	Once a week	Unloading with 1.5MW for 30 seconds
B	Once a day	Unloading with 1.5MW for 30 seconds
C	Twice per hour	Unloading with 1.5 MW (LTO) or 0.75MW (NMC) for 30 seconds

Conclusion

- Creation of an open-source battery model from experimental data for different chemistry that can be calibrated on different battery system
- The open-source model give as output capacity&power fading of battery systems
- The model has been applied to evaluate the conversion of SBB cargo fleet
- The degradation of the battery system is crucial to maximize the total cost of ownership over the lifetime
- For the SBB case the predictable use of the storage systems enables ageing-optimized management.

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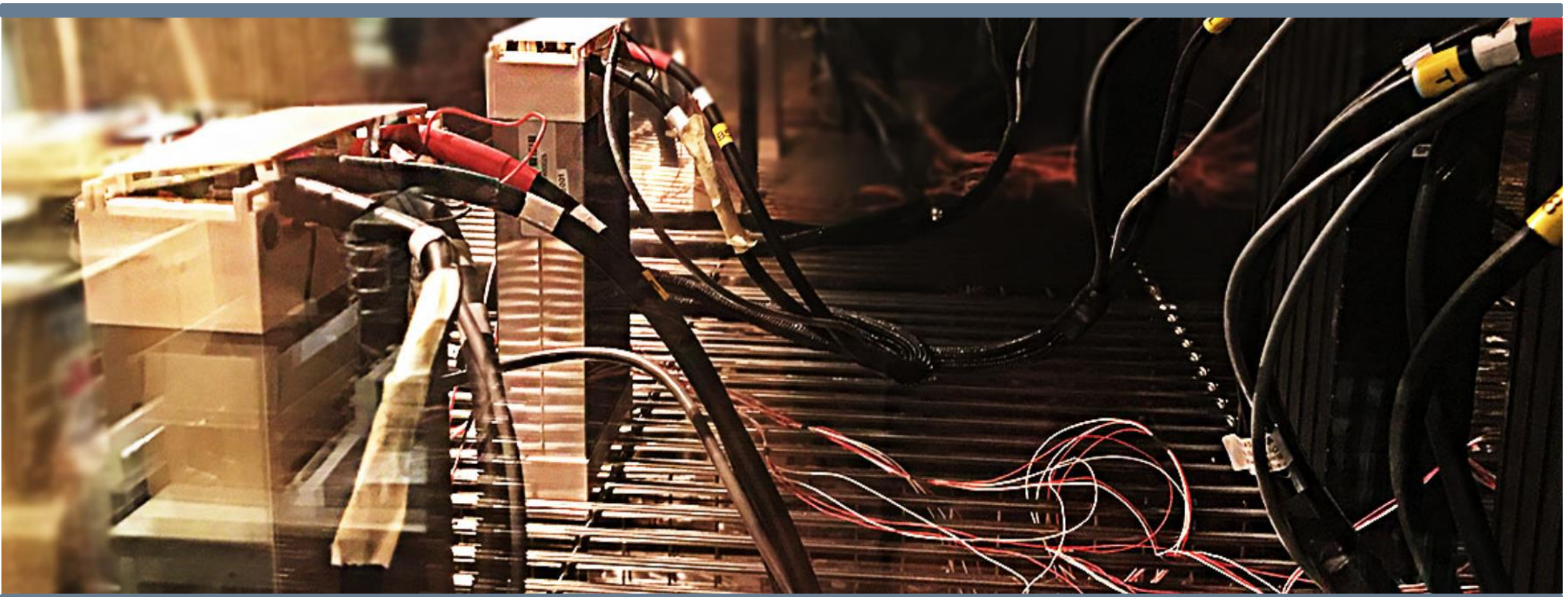

Thank you for your attention

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