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Emerging Performance Issues of Photovoltaic Battery Systems

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HTW Berlin - University of Applied Sciences, Germany

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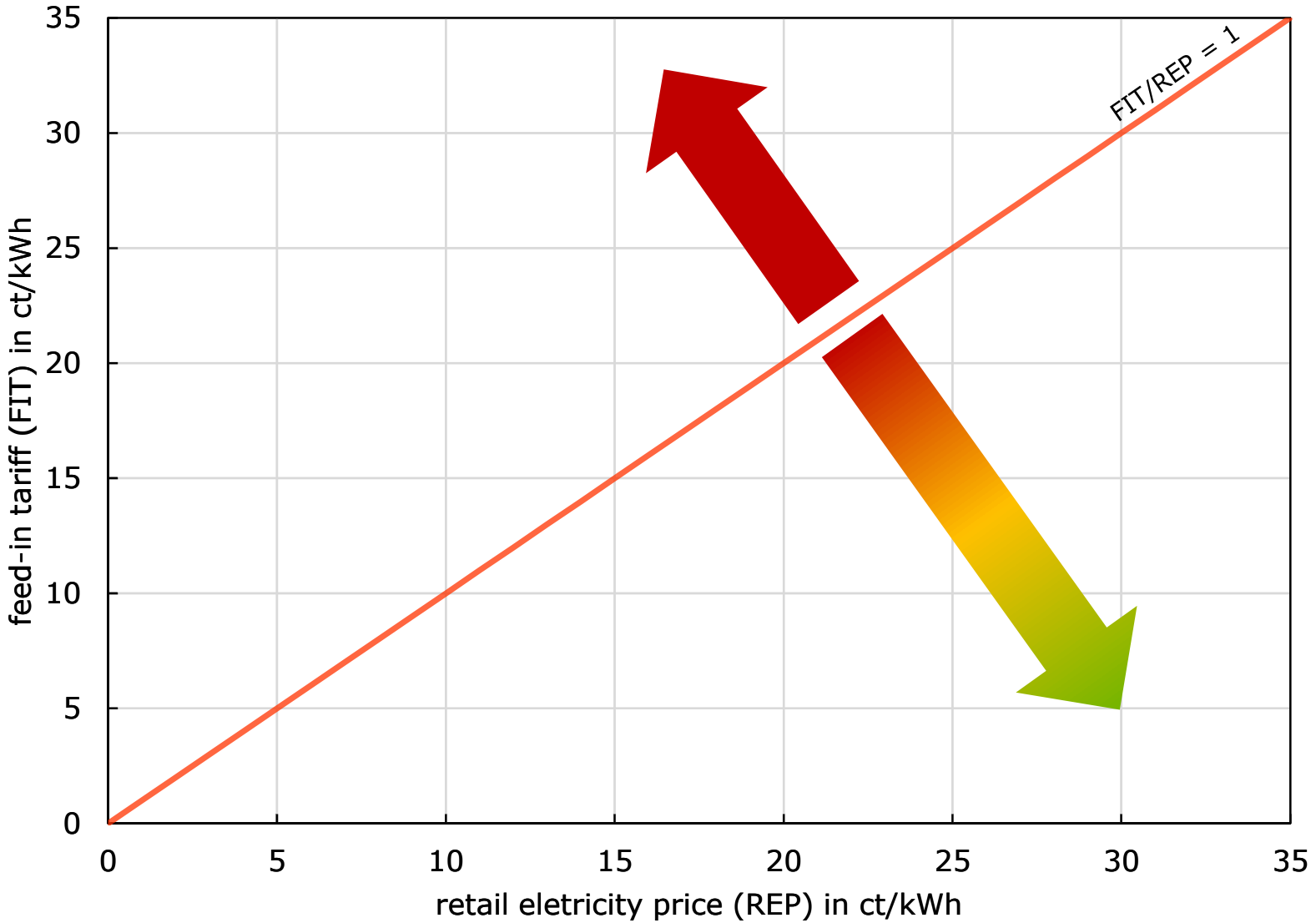
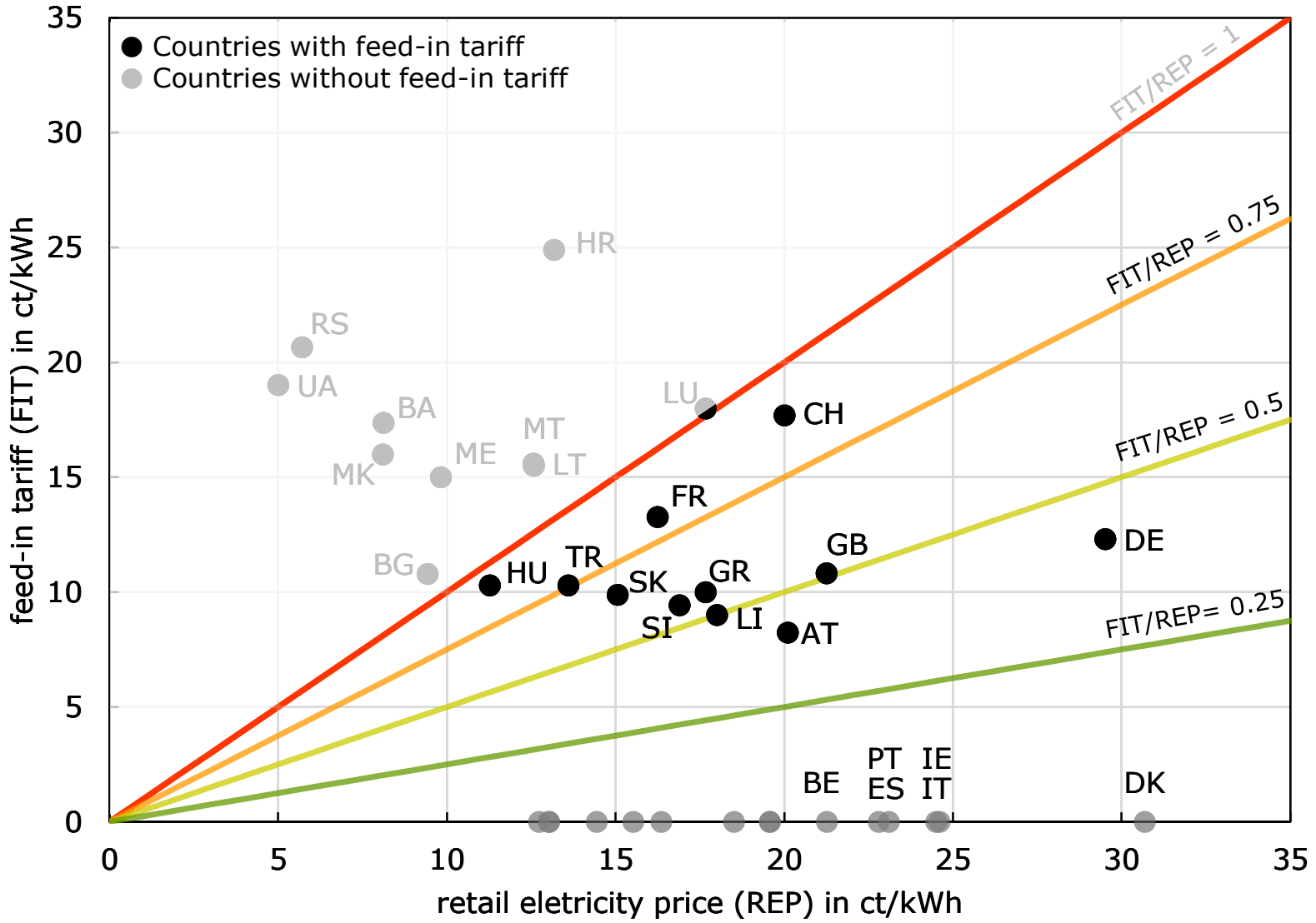
Self-consumption markets in the EU



 Sources: Eurostat, RES Legal, SolarPower Europe

Self-consumption markets in the EU



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Overview on products available on the market

DC-coupled systems with batteries

AC-coupled systems with batteries

AC/DC-coupled systems with batteries

Generator-coupled systems with batteries

AC-coupled inverters

DC-coupled inverters

Batteries

 Source: manufacturer

Overview on products available on the market

DC-coupled systems with batteries


AC/DC-coupled systems with batteries

fully integrated systems

AC-coupled systems with batteries


Generator-coupled systems with batteries

without PV inverter

AC-coupled inverters



without PV inverter and battery

DC-coupled inverters


without battery

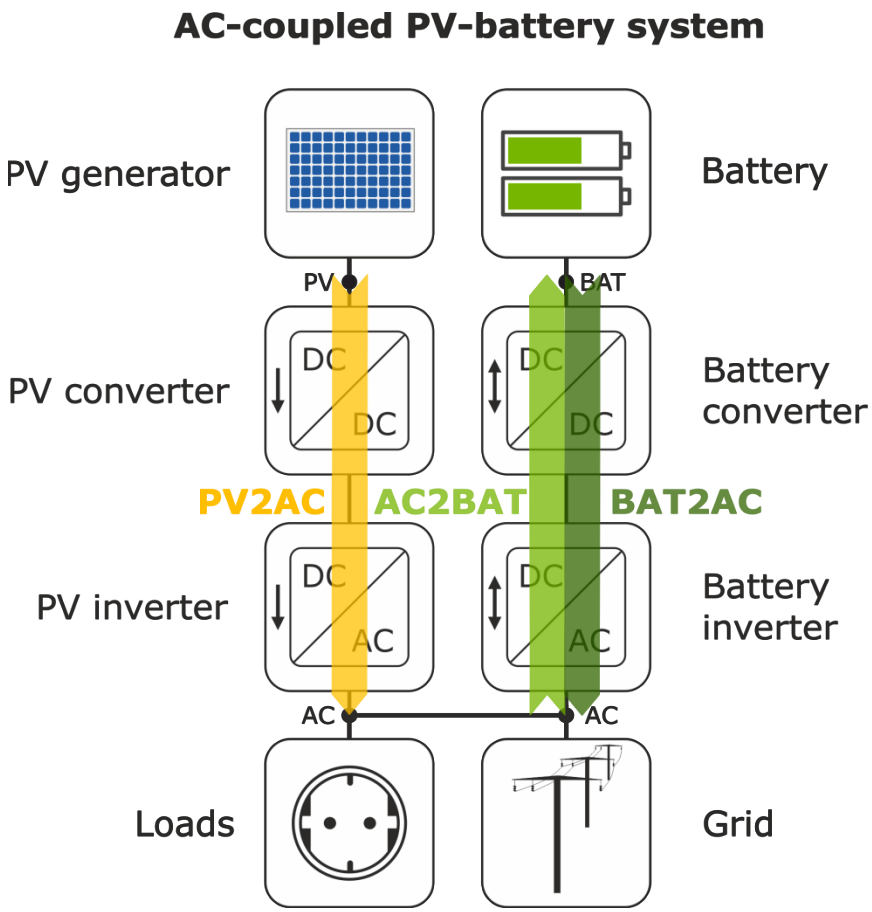
Batteries

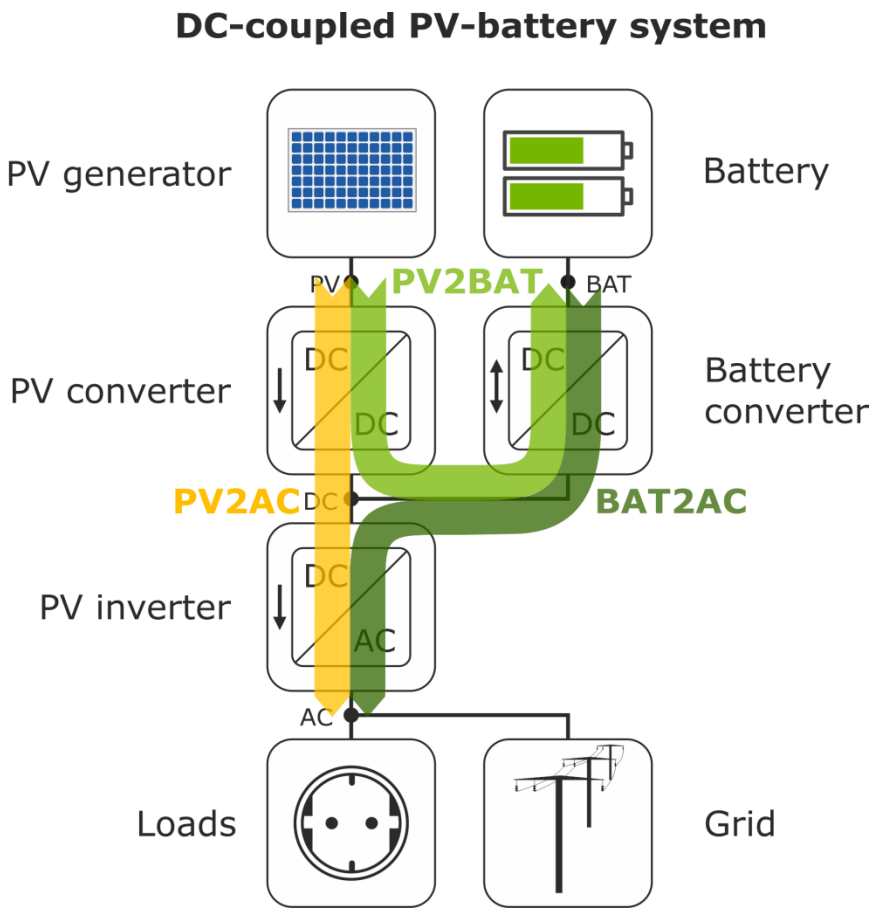




 Source: manufacturer

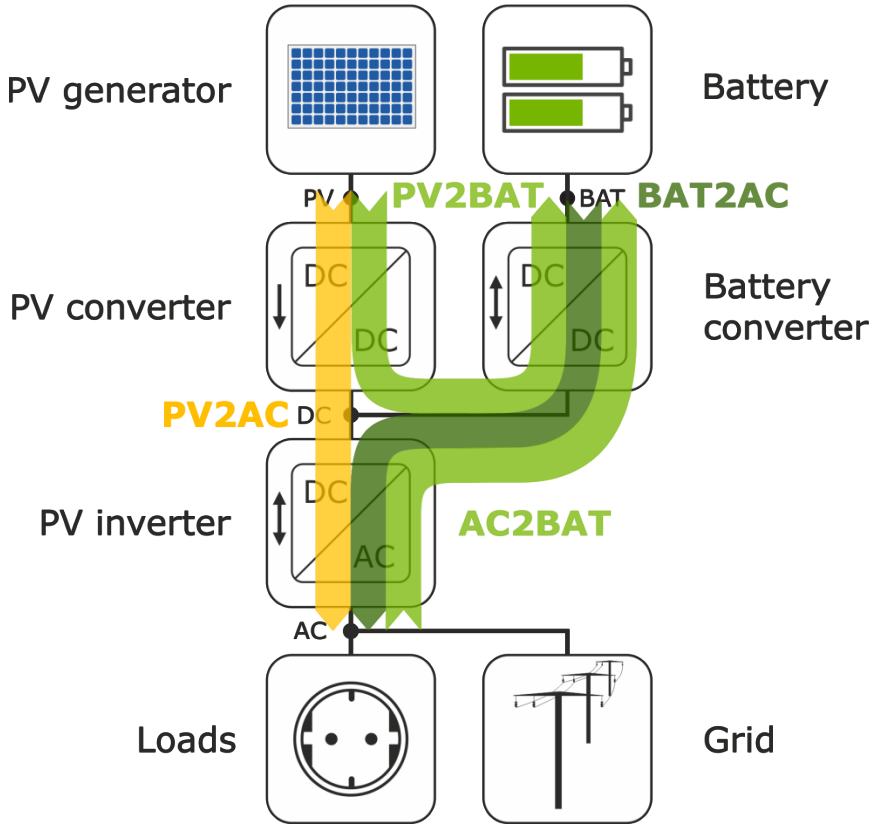
System topologies of PV-battery systems



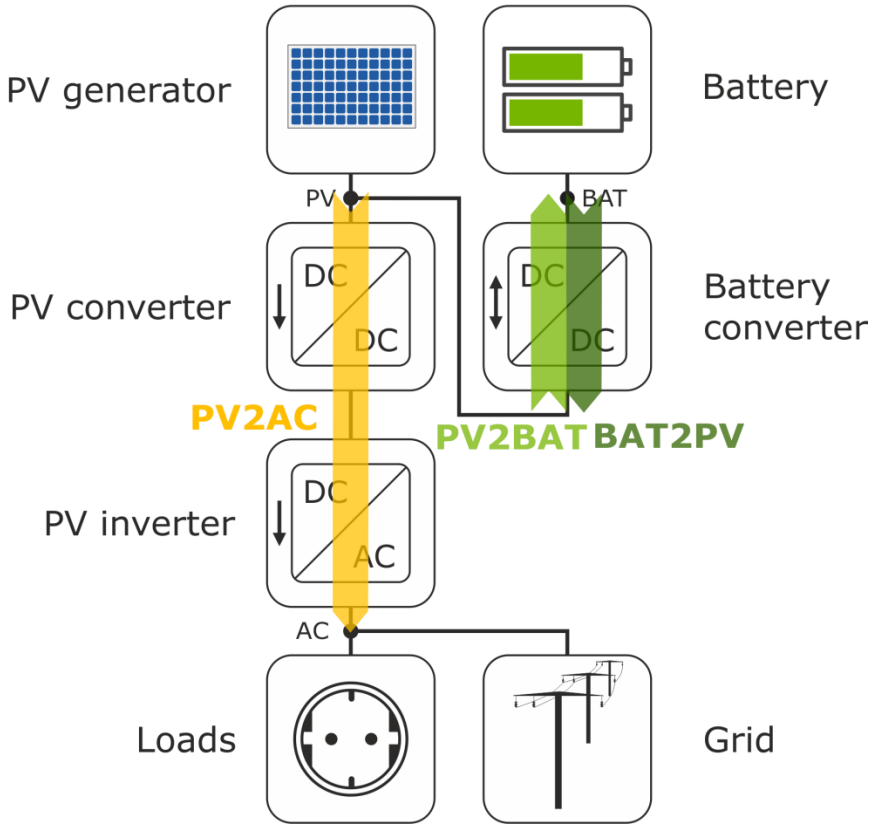


System topologies of PV-battery systems

AC/DC-coupled PV-battery system



Generator-coupled PV-battery system



Classification of system-related loss mechanisms

Conversion losses

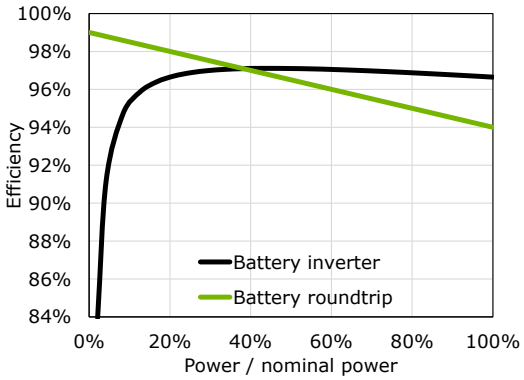
- Efficiency of the power electronics
- Battery round trip efficiency

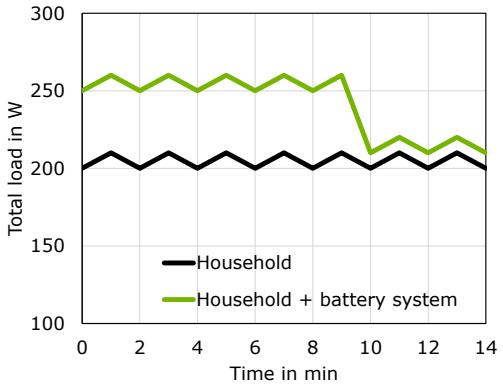
Standby losses

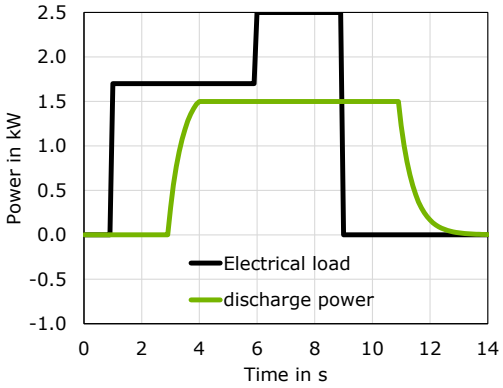
- Battery Management System (BMS)
- Power electronics
- Auxiliaries (EMS, meter)

Control losses

- Transient response
- Measuring accuracy







Typical range

0-99%

5-100 W

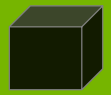
1-60 s

Efficiency of different system components

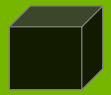
Standby consumption of whole systems

Overall response time

Possible performance evaluation procedures

Field tests	Black-box tests	White-box tests	Simulation tests
			
Characteristics			
• Long-term field tests by monitoring the real operational behavior over a period of at least one year	• Short-term application tests in a laboratory environment with reference profiles or at defined operating points	• Detailed characterization tests under laboratory conditions with the aim of characterizing the efficiency of each component or path of energy flow	• Model-based simulation tests parametrized with measurements from white-box tests and based on measured load and PV output profiles
Results			
• Average operating efficiency and load distributions of distinct paths of energy flow	• Use case-specific performance indicator obtained from measurements	• Measurements of efficiency curves, standby consumption, response behavior, etc.	• Use case-specific performance indicator obtained from simulations
Research activities in Germany and Austria			
ISEA Institut für Stromrichtertechnik und Elektrische Antriebe RWTH AACHEN SPEICHER MONITORING AS/C Austria Solar Innovation Center	Fraunhofer IWES AIT Austrian Institute of Technology TOMORROW TODAY KIT Karlsruher Institut für Technologie SMA E3/DC Energy Storage	Fraunhofer IWES AIT Austrian Institute of Technology TOMORROW TODAY ISEA Institut für Stromrichtertechnik und Elektrische Antriebe RWTH AACHEN ISFH	htw Hochschule für Technik und Wirtschaft Berlin University of Applied Sciences ISFH

Possible performance evaluation procedures

Field tests	Black-box tests	White-box tests	Simulation tests
			
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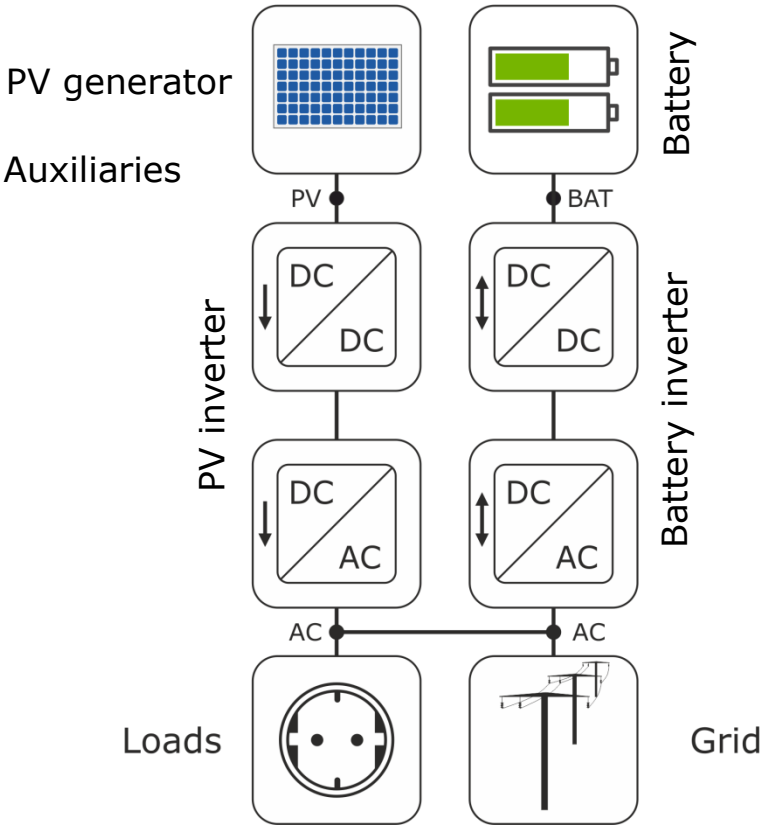
Results			
• Average operating efficiency and load distributions of distinct paths of energy flow	• Use case-specific performance indicator obtained from measurements	• Measurements of efficiency curves, standby consumption, response behavior, etc.	• Use case-specific performance indicator obtained from simulations
Advantages			
• Real operational and long-term performance can be observed	• Short time period required and good comparability of the test results	• Detailed characterization of the components and overall system	• Fast test procedure and good reproducibility of the test results
Disadvantages			
• Long time period required • Results mostly available for outdated products • Identical test conditions are hard to ensure • Limited comparability of the test results from different systems	• Measurements are already affected by the predefined profiles • Test results are only applicable to the specific use case • General validity of the reference profiles has to be demonstrated	• No single performance indicator for the end-customer can be extracted from the test results • Expensive measurement equipment is required • Poor comparability between the results of different topologies	• Detailed characterization measurements are required • Accuracy of the test results depends on the level of detail of the simulation model • Not all loss mechanisms can be modelled exactly

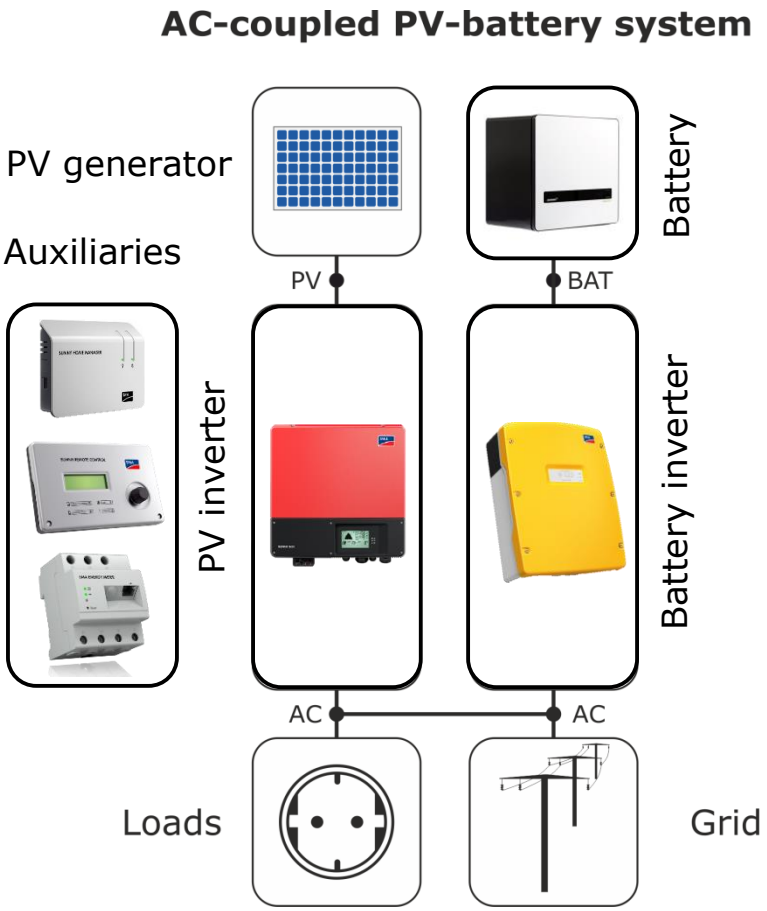
Proposed model-based simulation test

AC-coupled PV-battery system



Exemplary system components

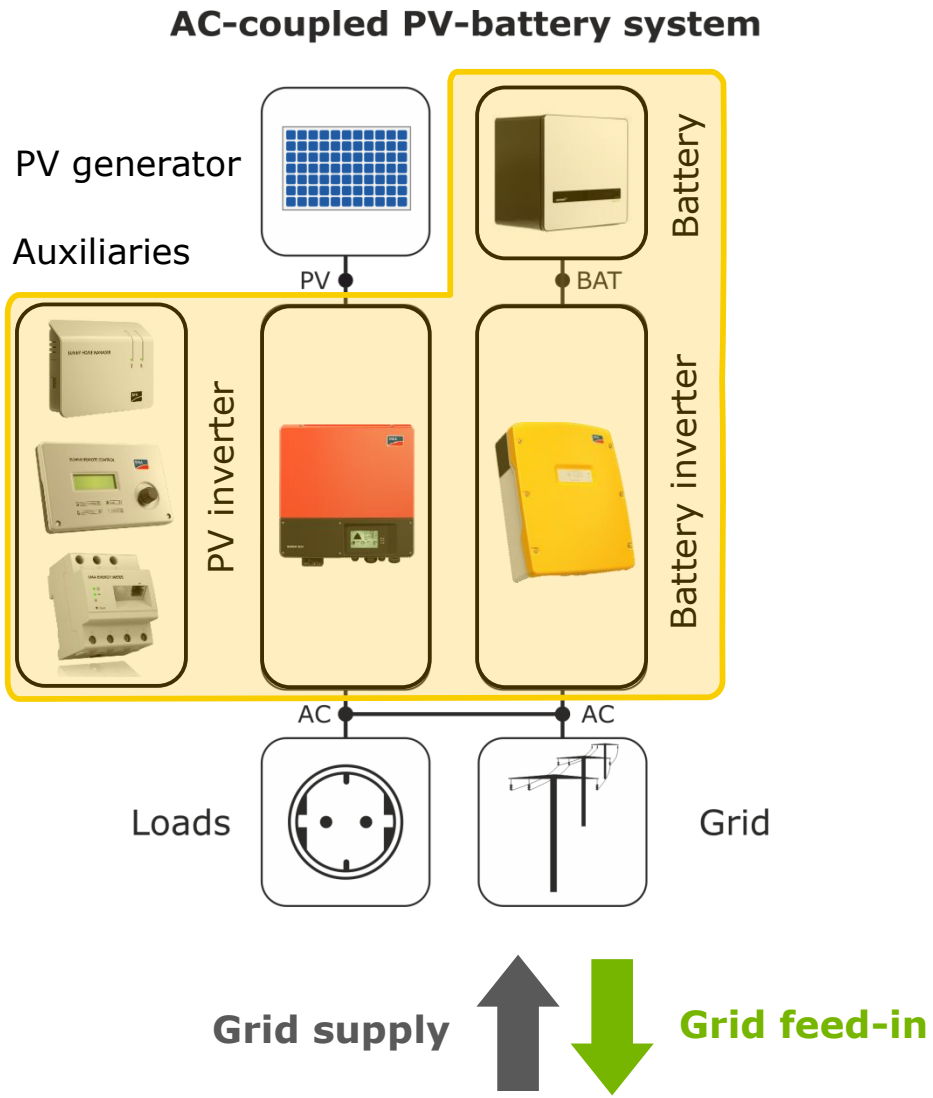
Proposed model-based simulation test



Exemplary system components

- SMA Sunny Boy 5000 TL
- SMA Sunny Island 3.0M
- Akasol neeoQube
- SMA Sunny Home Manager
- SMA Sunny Remote Control
- SMA Energy Meter

Proposed model-based simulation test



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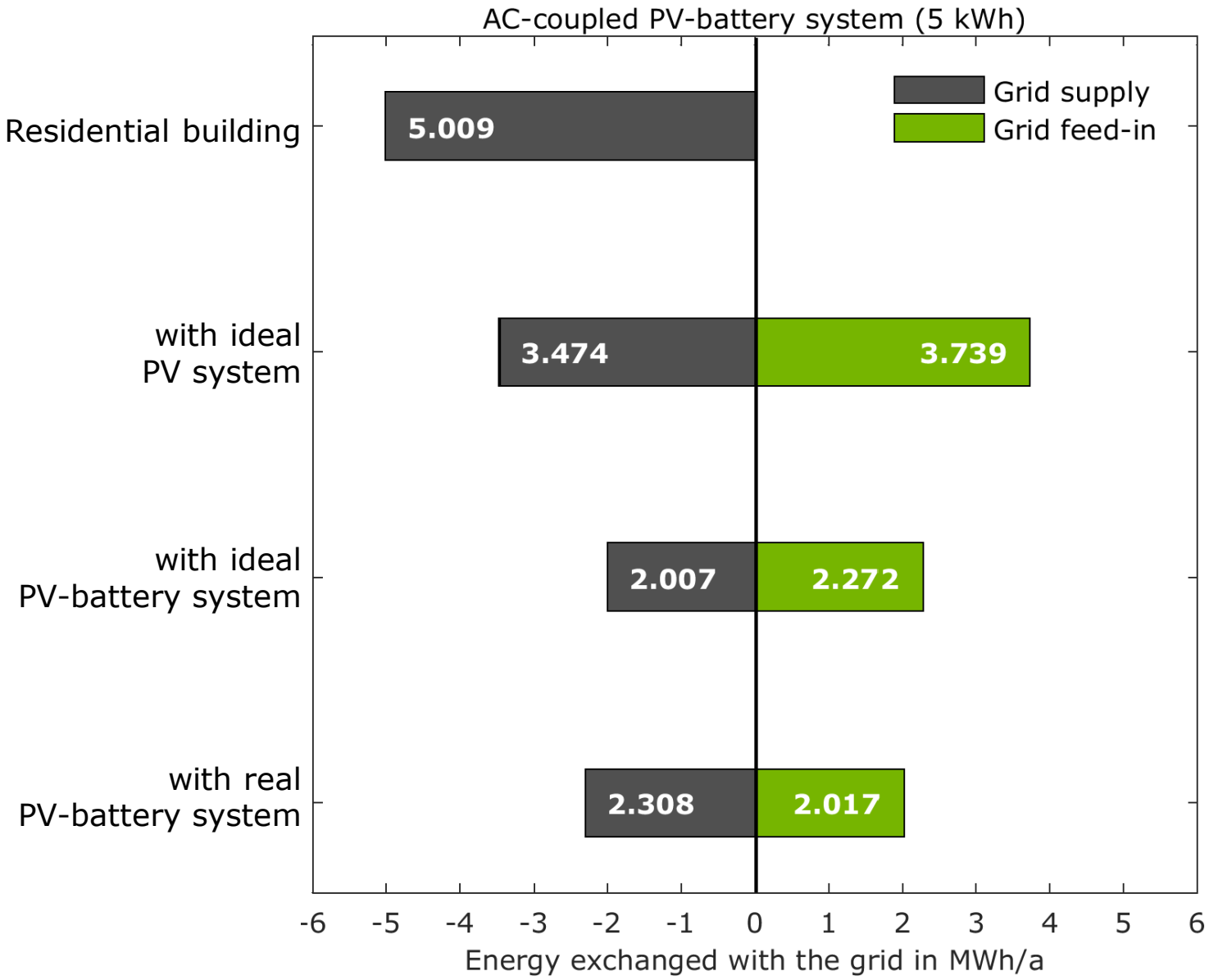
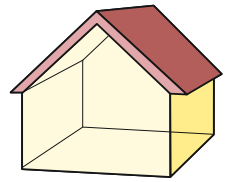
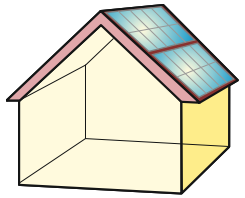
Test procedure

- Input data (1 s): PV generator´s output power (5 kWp) and electrical load (5 MWh/a)
- Time series simulations over one year for the real system in comparison to an ideal, lossless reference system
- Energetic and economic assessment as simulation results

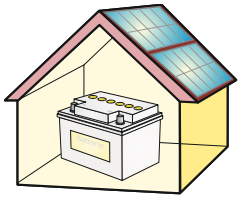
Annual energy balance







$\eta = 100\%$



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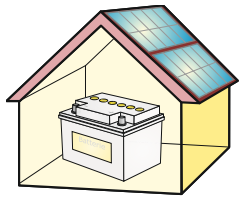
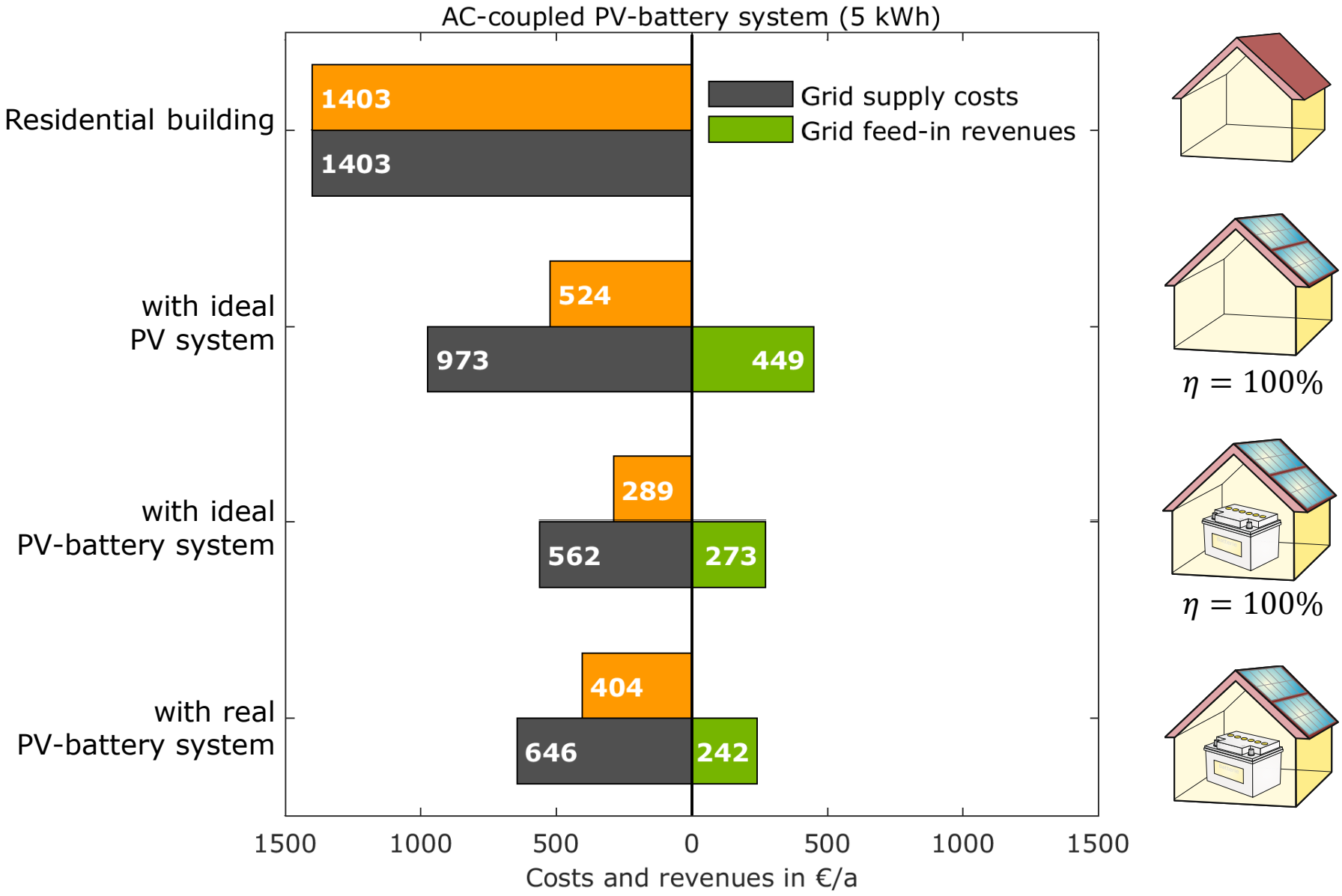


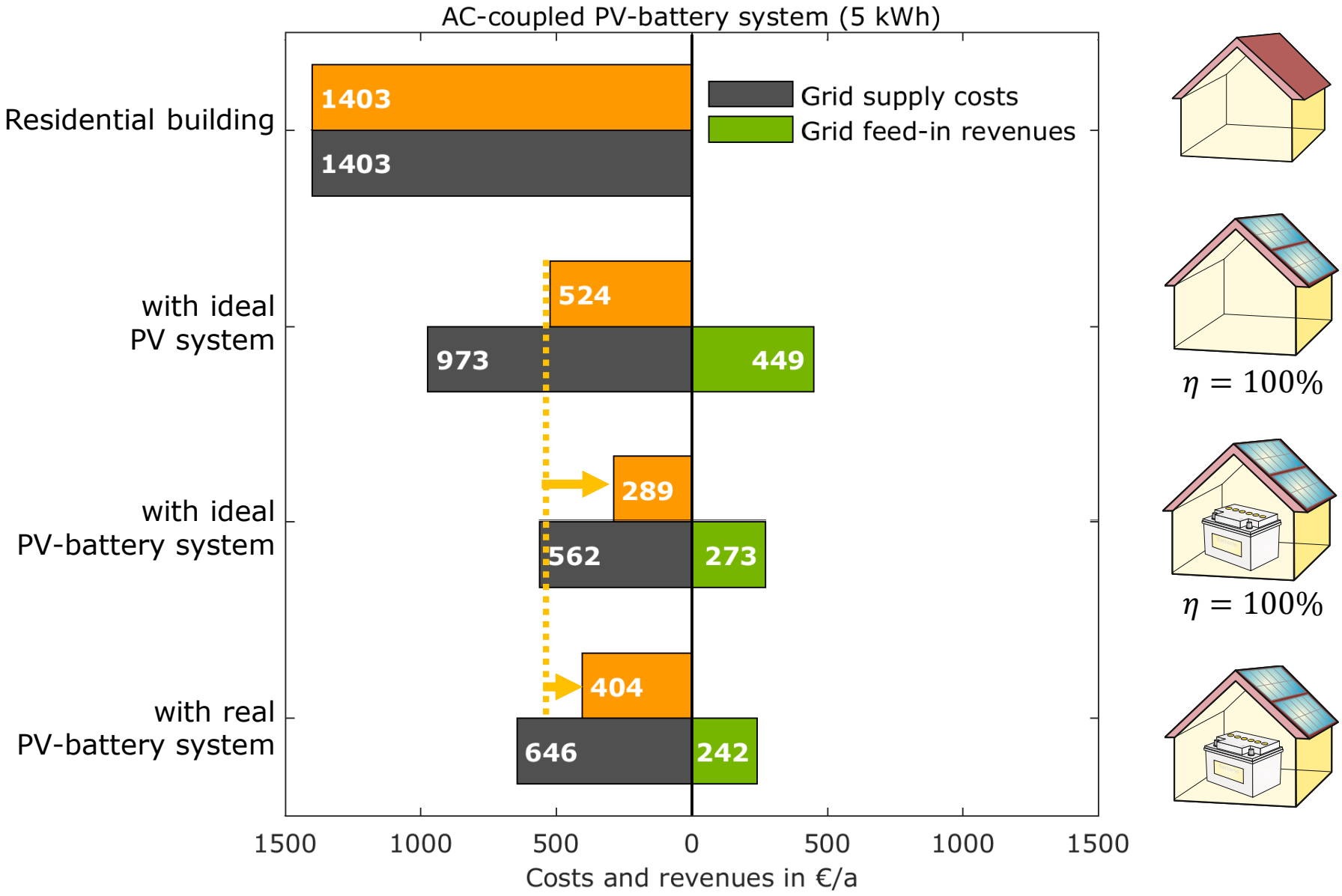
 PV-generator: 5 kWp, load demand: 5 MWh/a, ideal: no conversion, standby and control losses

Annual costs and revenues



 PV-generator: 5 kWp, load demand: 5 MWh/a, feed-in tariff: 12 ct/kWh, retail electricity price: 28 ct/kWh

Annual costs and revenues



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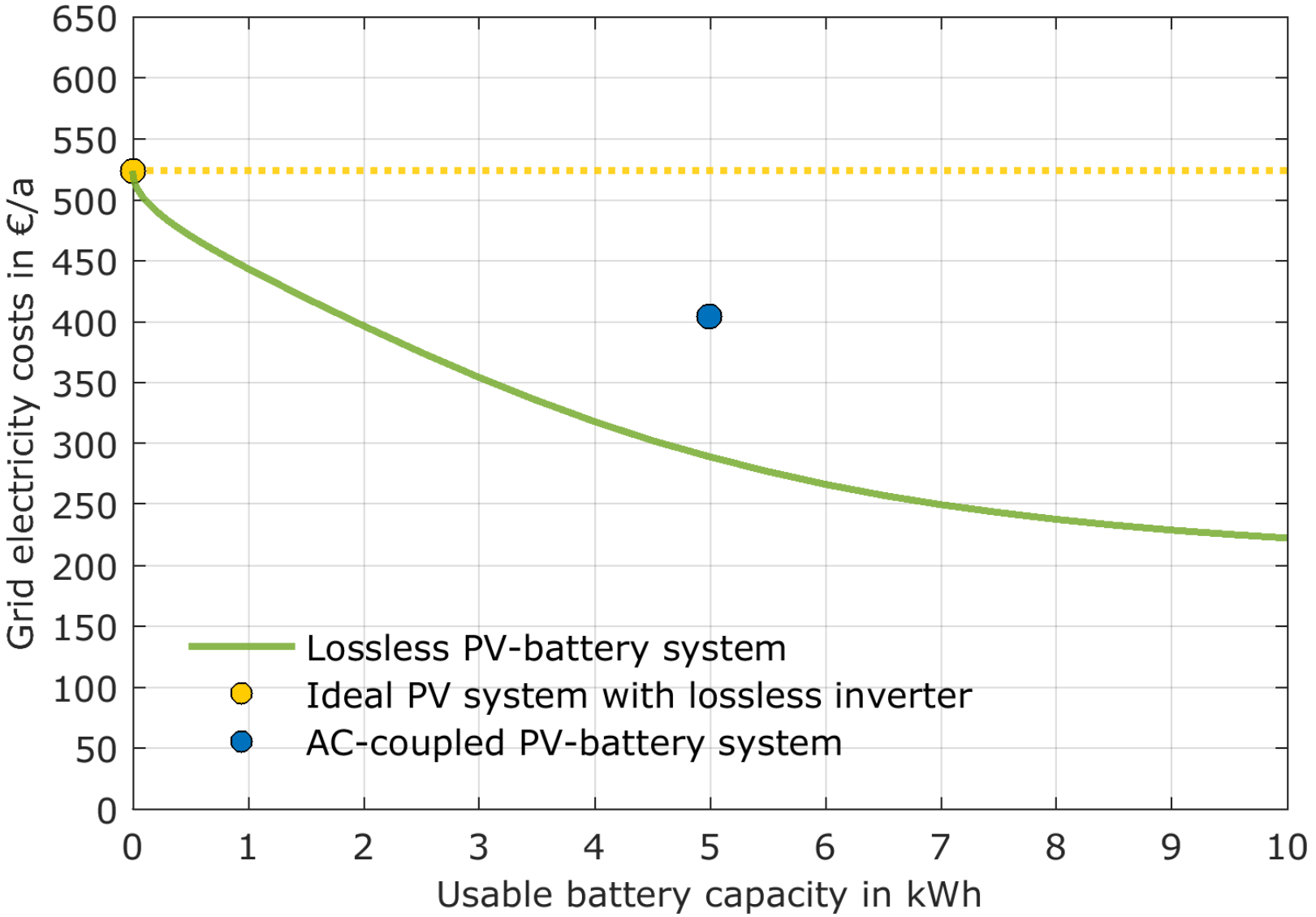
Definition of the Storage Performance Index (SPI)



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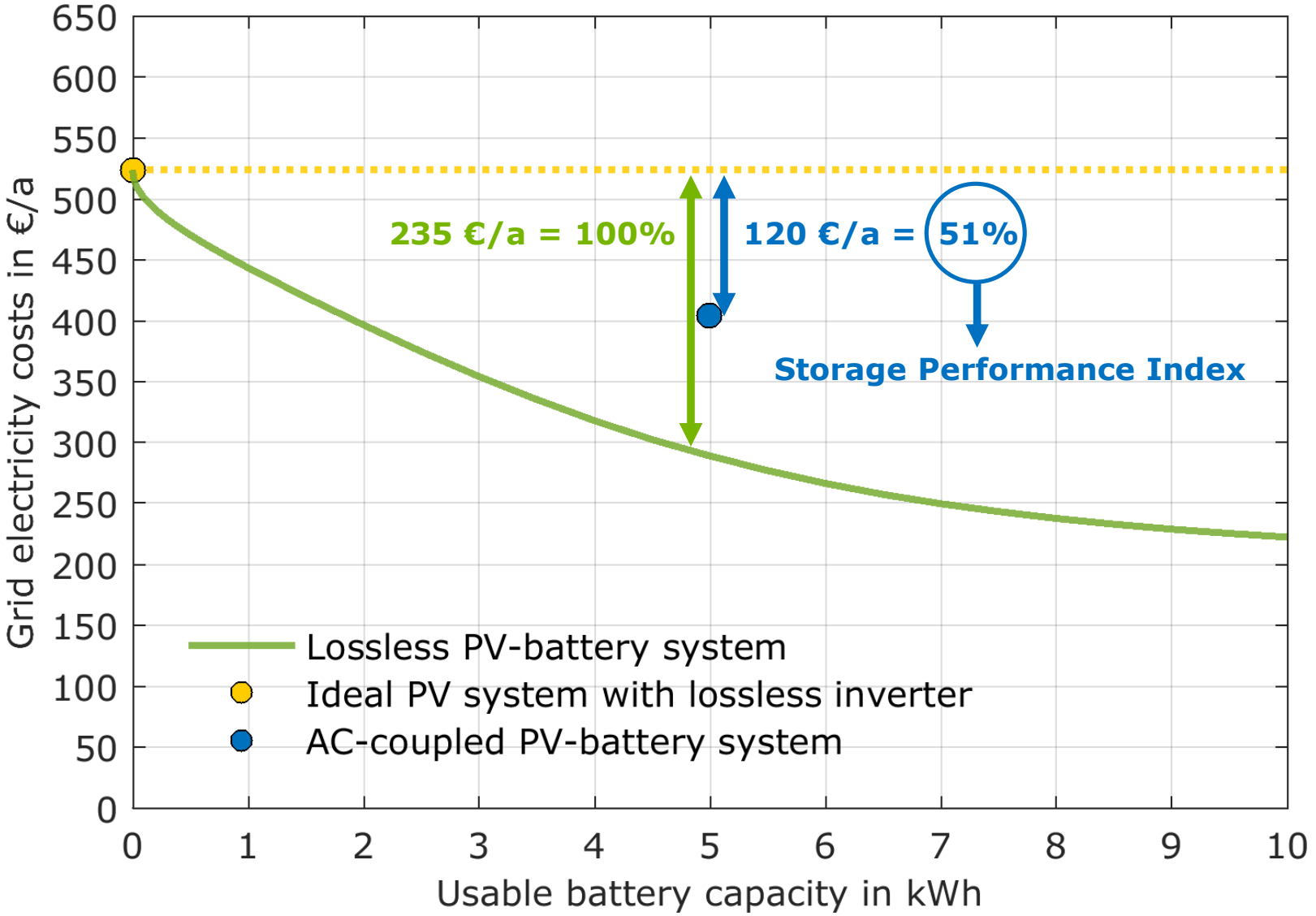

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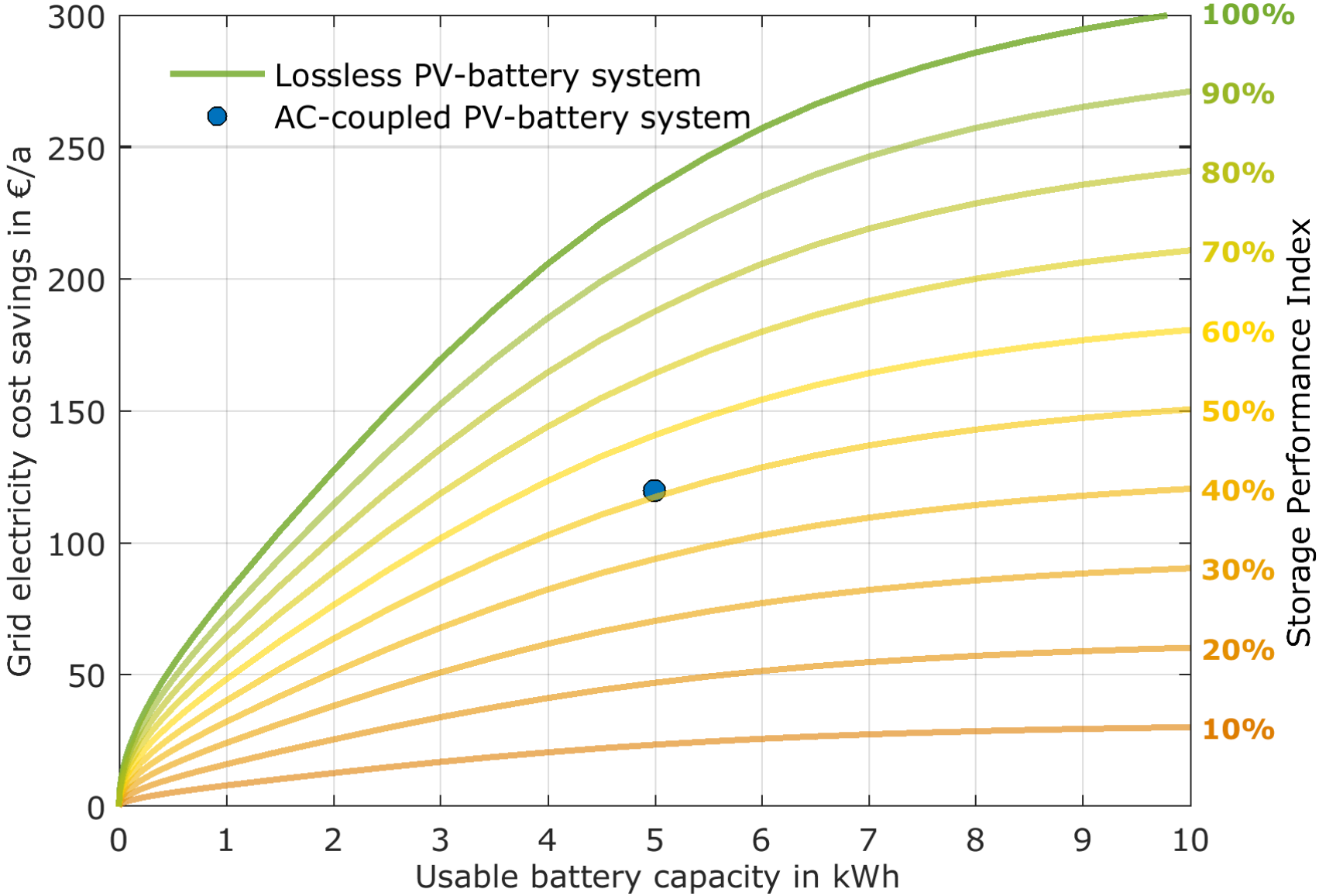
SPI: Realized grid electricity cost savings



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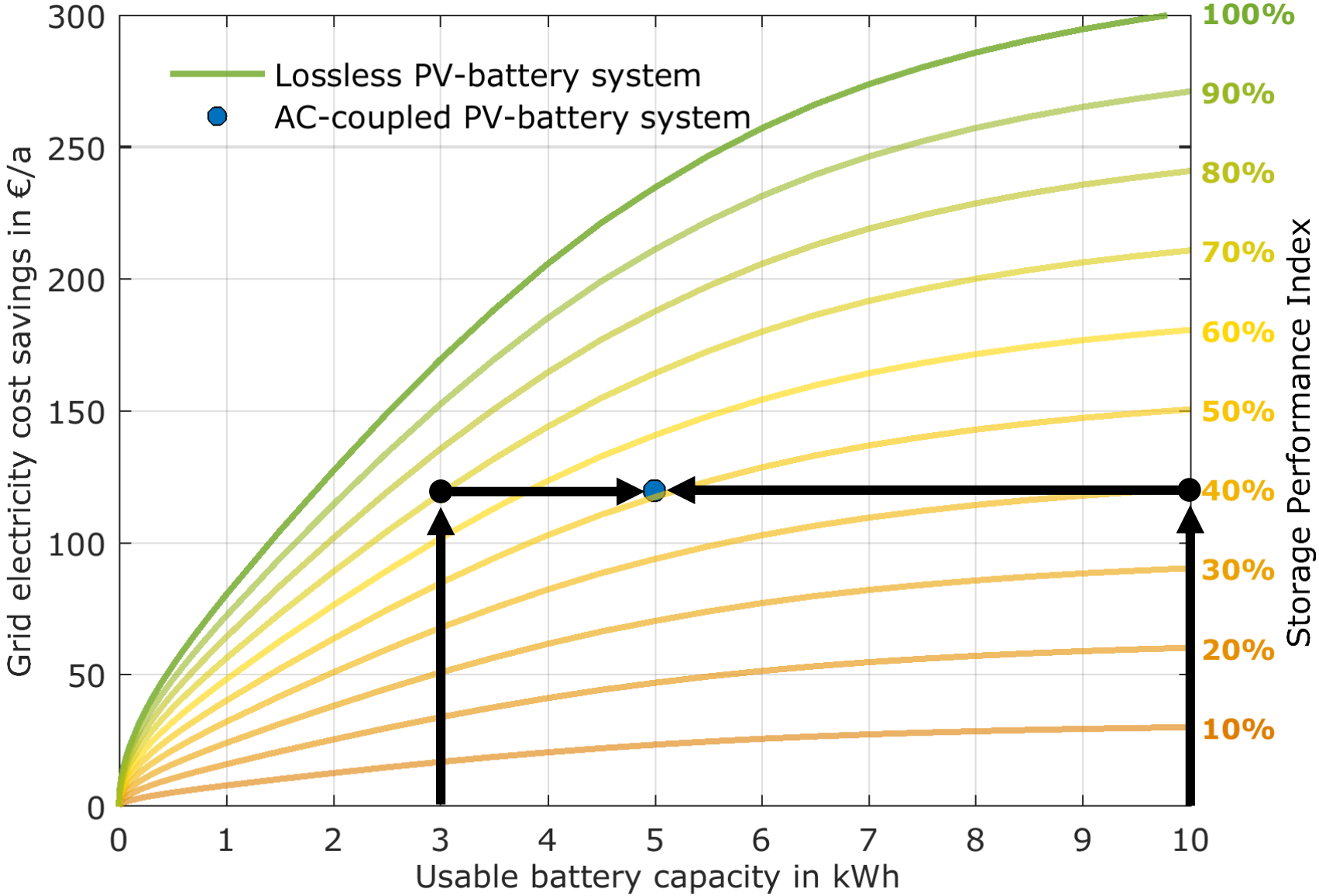

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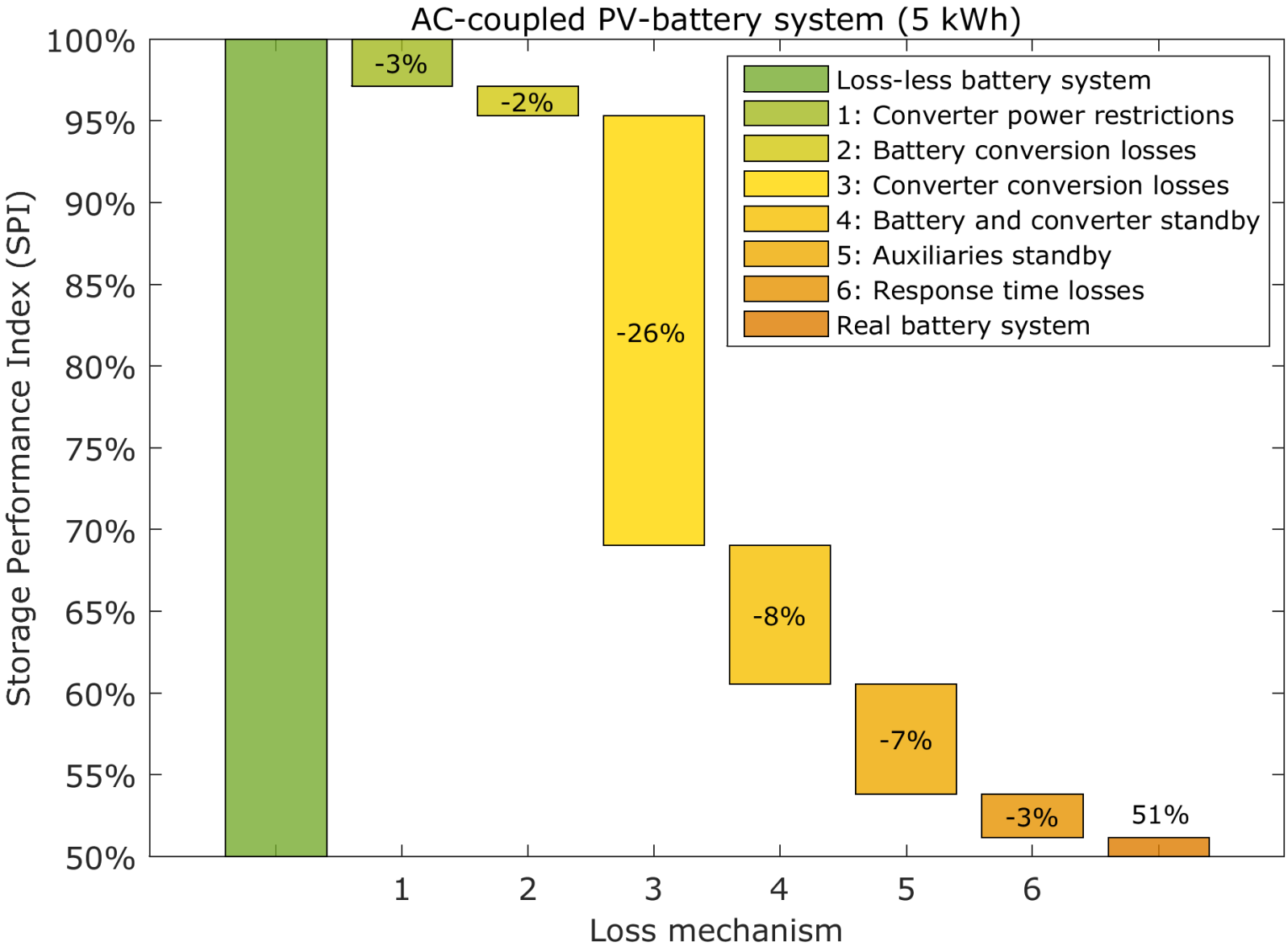
Contribution of different loss mechanisms to the SPI



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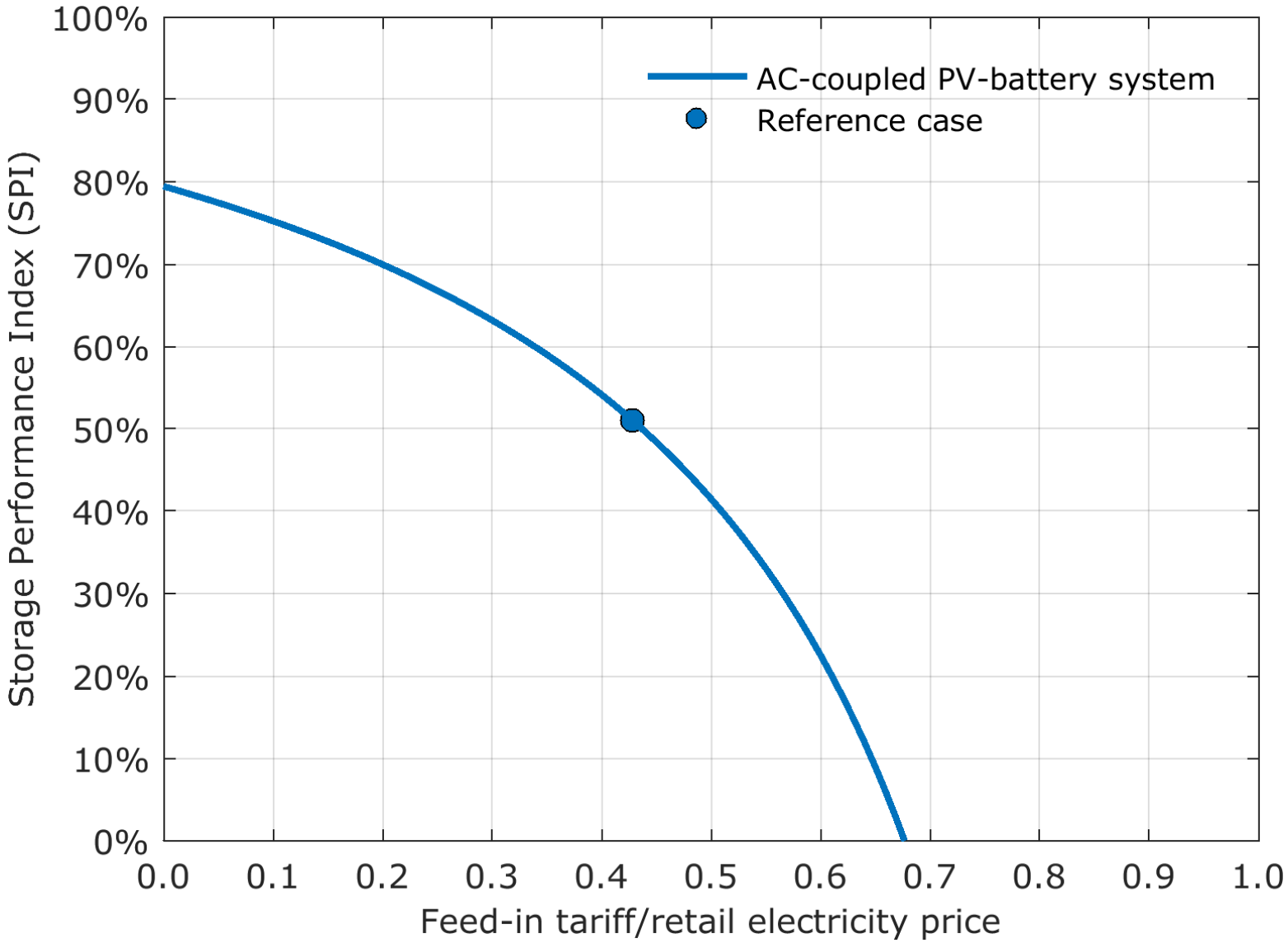
Variation of the Storage Performance Index



 PV-generator: 5 kWp, load demand: 5 MWh/a

Conclusion

- **Performance-related specifications** are rarely stated in the data sheets of PV-battery systems.
- Standardized performance tests are required to improve the **comparability of the performance** between different products, and thereby the transparency from the end customer`s point of view.
- A **variety of performance test procedures** is currently under discussion.
- Adequate system performance tests should assess the **conversion, standby and control-related losses**.
- The performance of PV-battery systems of different sizes and system topologies can be assessed with the proposed **Storage Performance Index (SPI)**.
- The developed simulation test allows the optimization of the **system layout, system sizing and control algorithms** and will be published as open source model in the future.