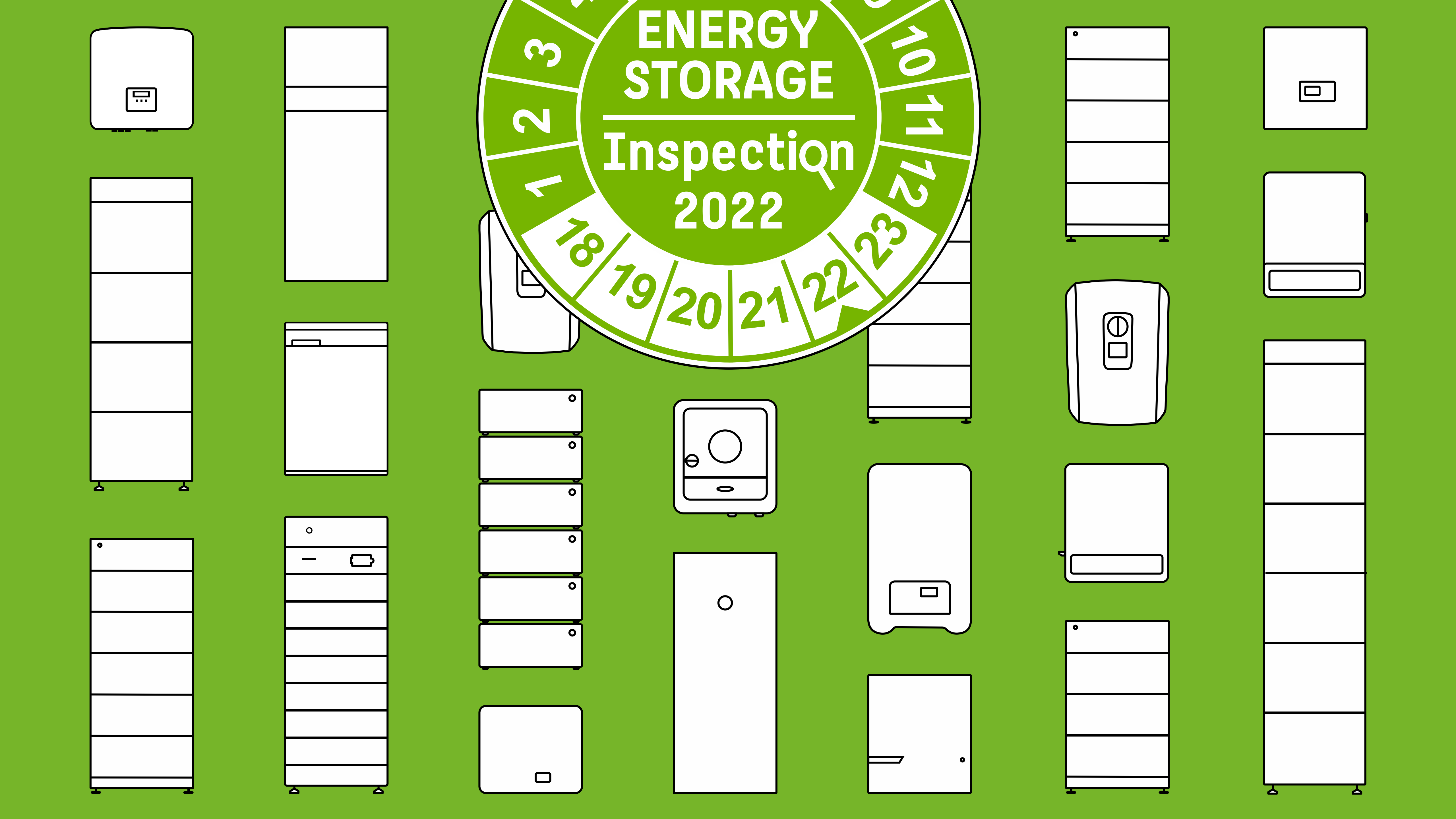

ENERGY STORAGE
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# ENERGY STORAGE Inspection

Hochschule für Technik und Wirtschaft Berlin

University of Applied Sciences

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

**Research study**

Energy Storage Inspection 2022

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HTW Berlin – University of Applied Sciences

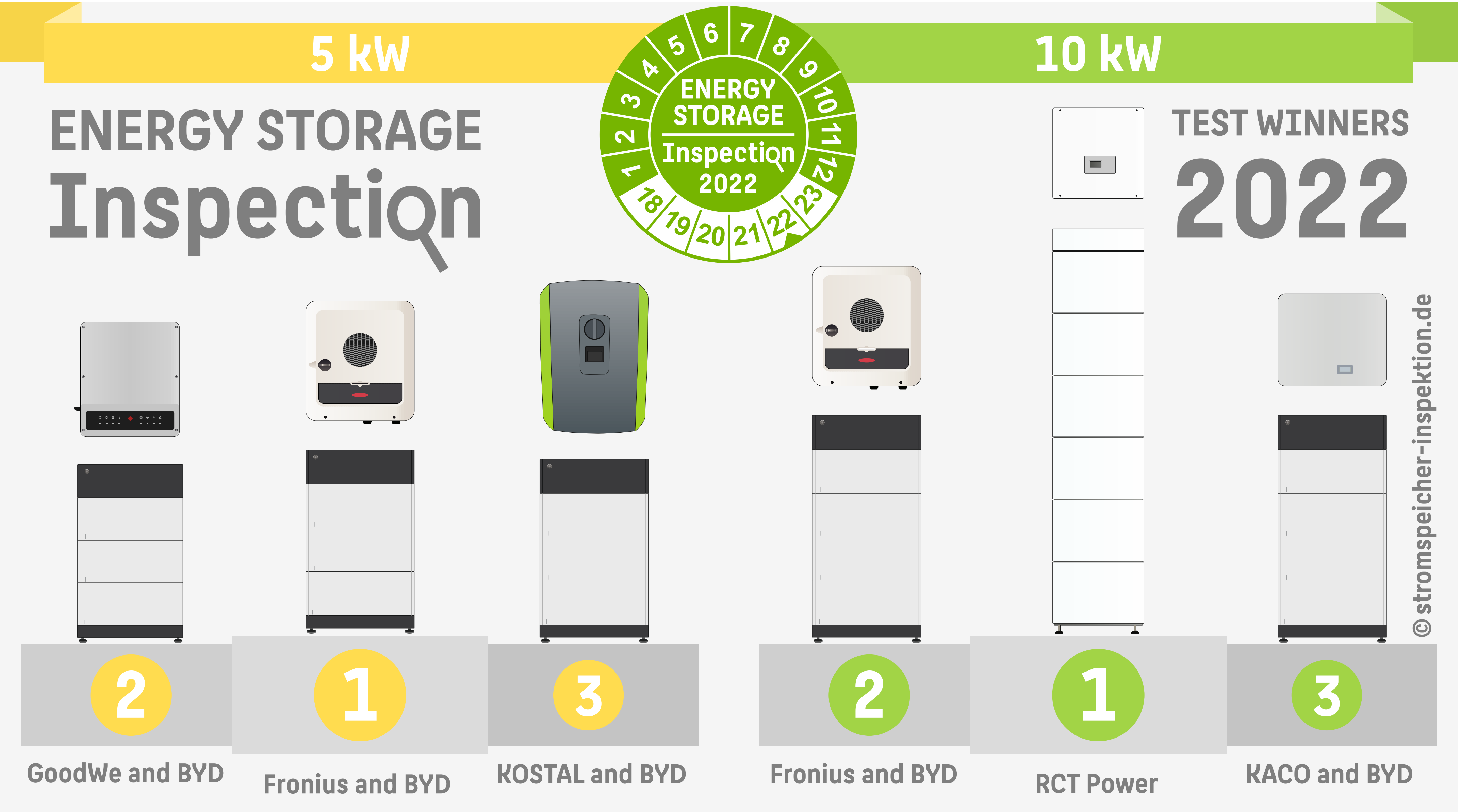
**Release**

Version 1.0 (March 2022)

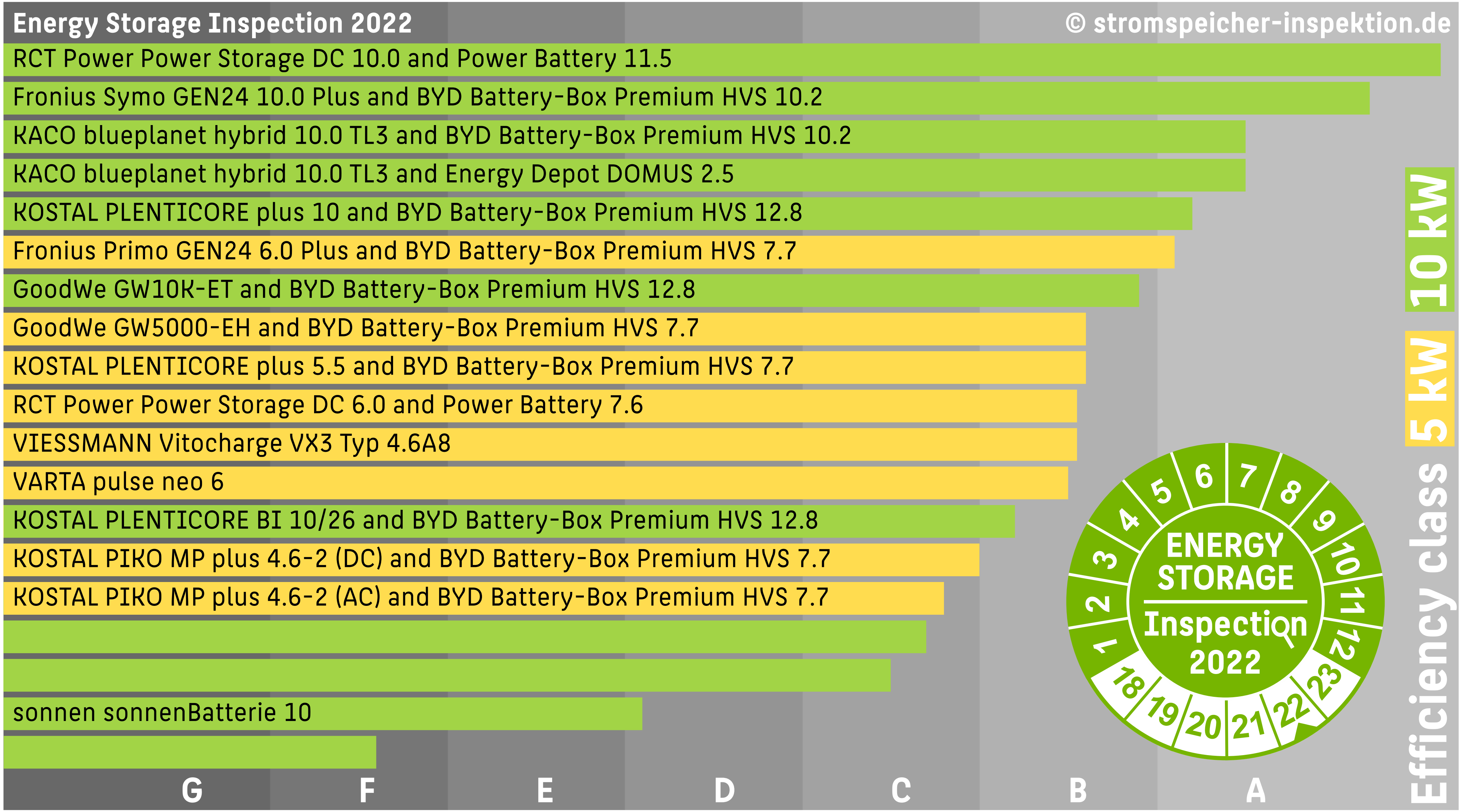
**Website**

www.stromspeicher-inspektion.de

# Test winners of the Energy Storage Inspection 2022



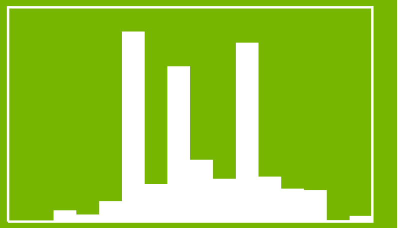
# Ranking of the Energy Storage Inspection 2022



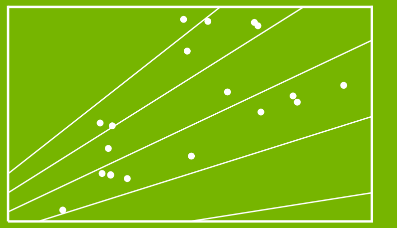

The efficiency classification is based on the System Performance Index SPI (5 kWp) and SPI (10 kWp).

# Main topics of the Energy Storage Inspection 2022

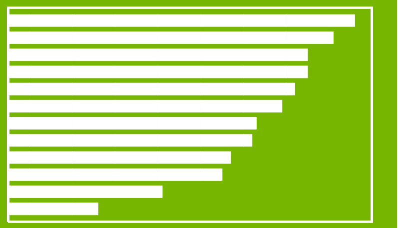
**1** Analysis of the German market for residential PV-battery systems



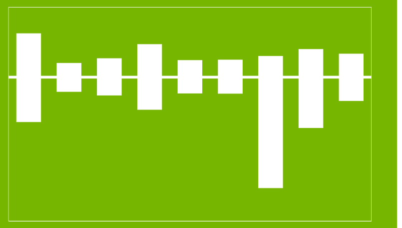
**2** Comparison of the system properties based on the test reports according to the Efficiency Guideline



**3** Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)

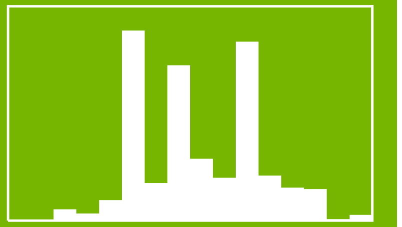


**4** FAQ: Answers to frequently asked questions concerning the efficiency and sizing of PV-battery systems



# Main topics of the Energy Storage Inspection 2022

**1** Analysis of the German market for residential PV-battery systems



**2** Comparison of the system properties based on the test reports according to the Efficiency Guideline

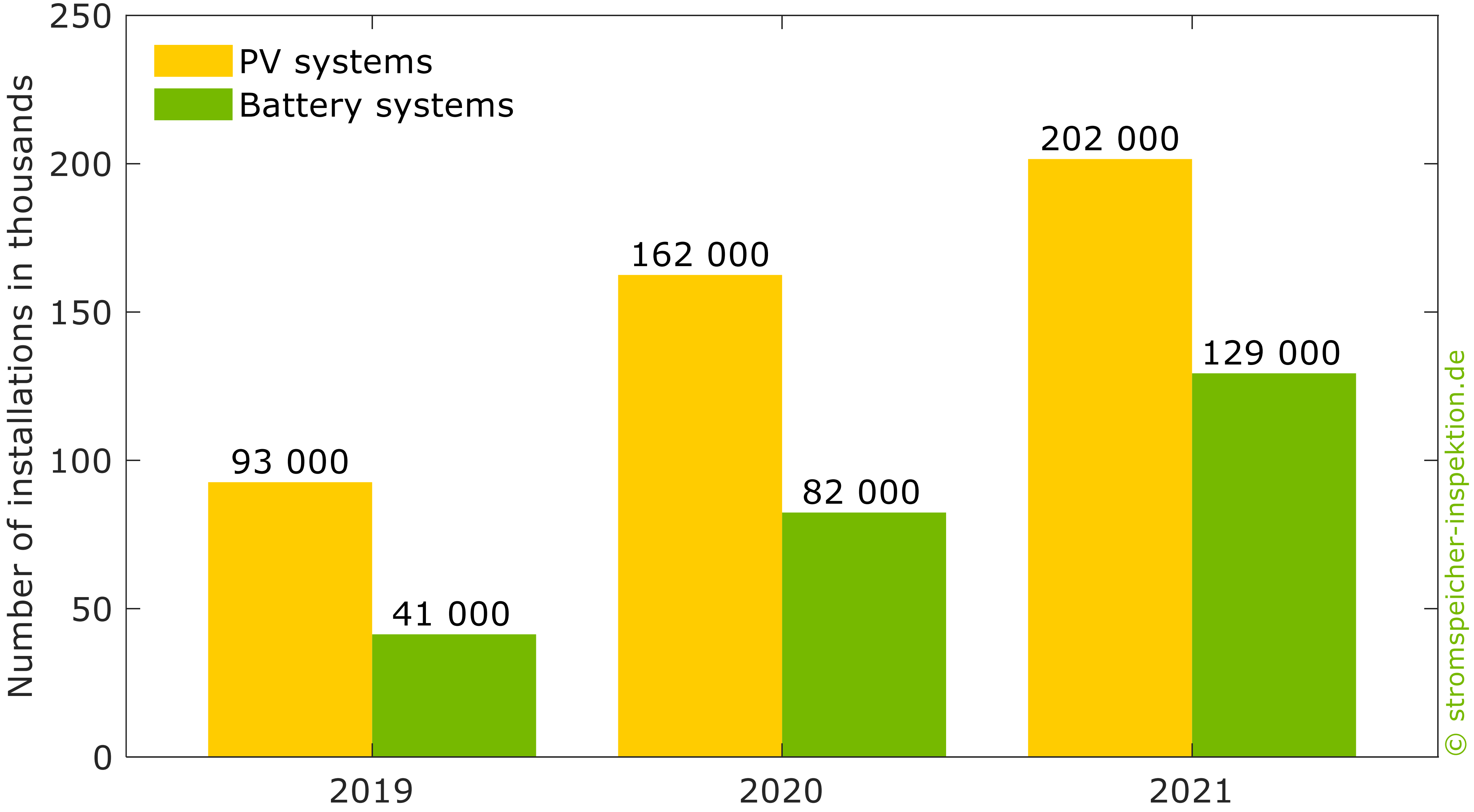


**3** Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



**4** FAQ: Answers to frequently asked questions concerning the efficiency and sizing of PV-battery systems

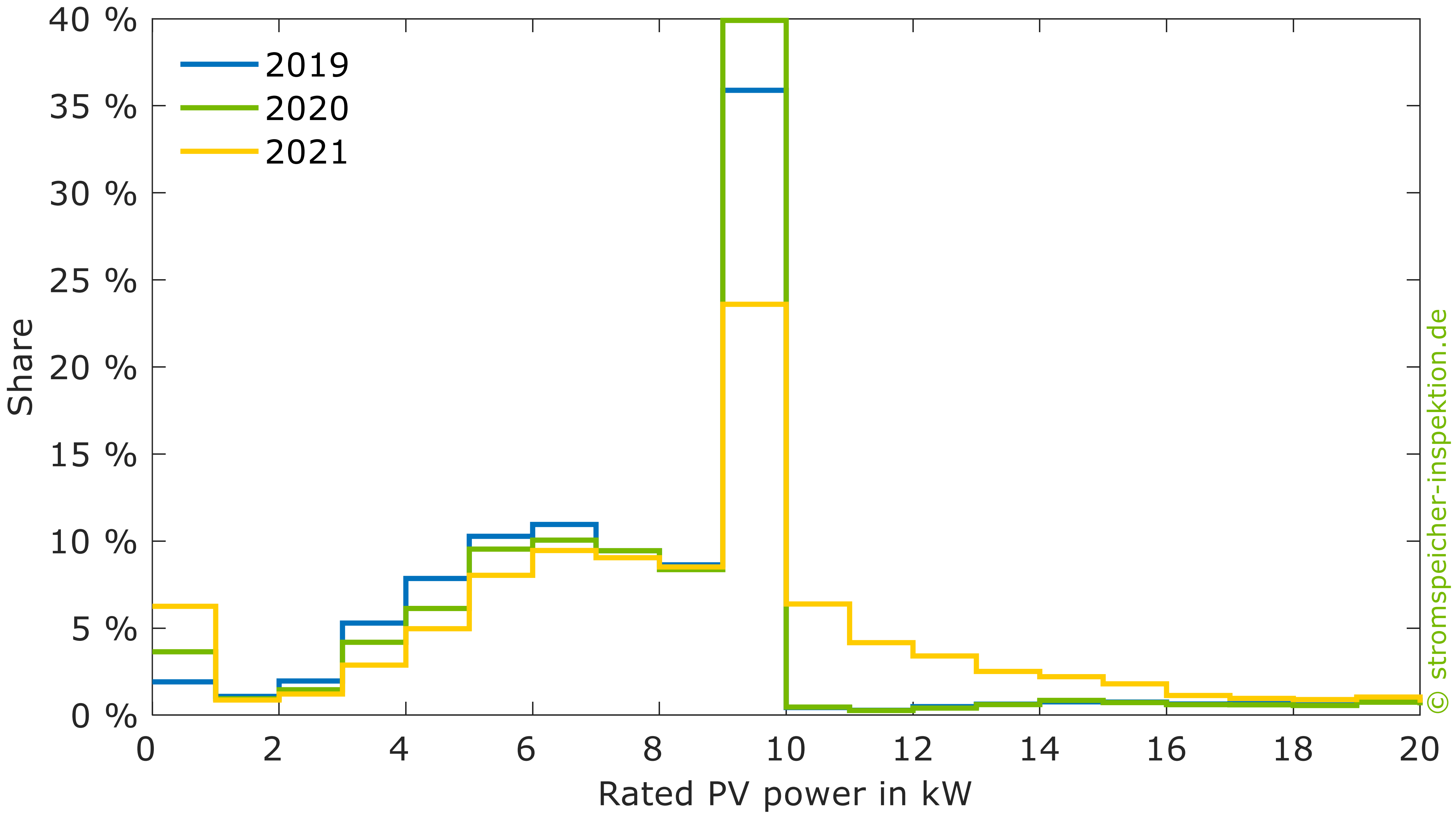
# Development of the German market for PV-battery systems




Data: Marktstammdatenregister, PV systems with less than 20 kW, battery systems smaller than 20 kWh and 20 kW


htw.

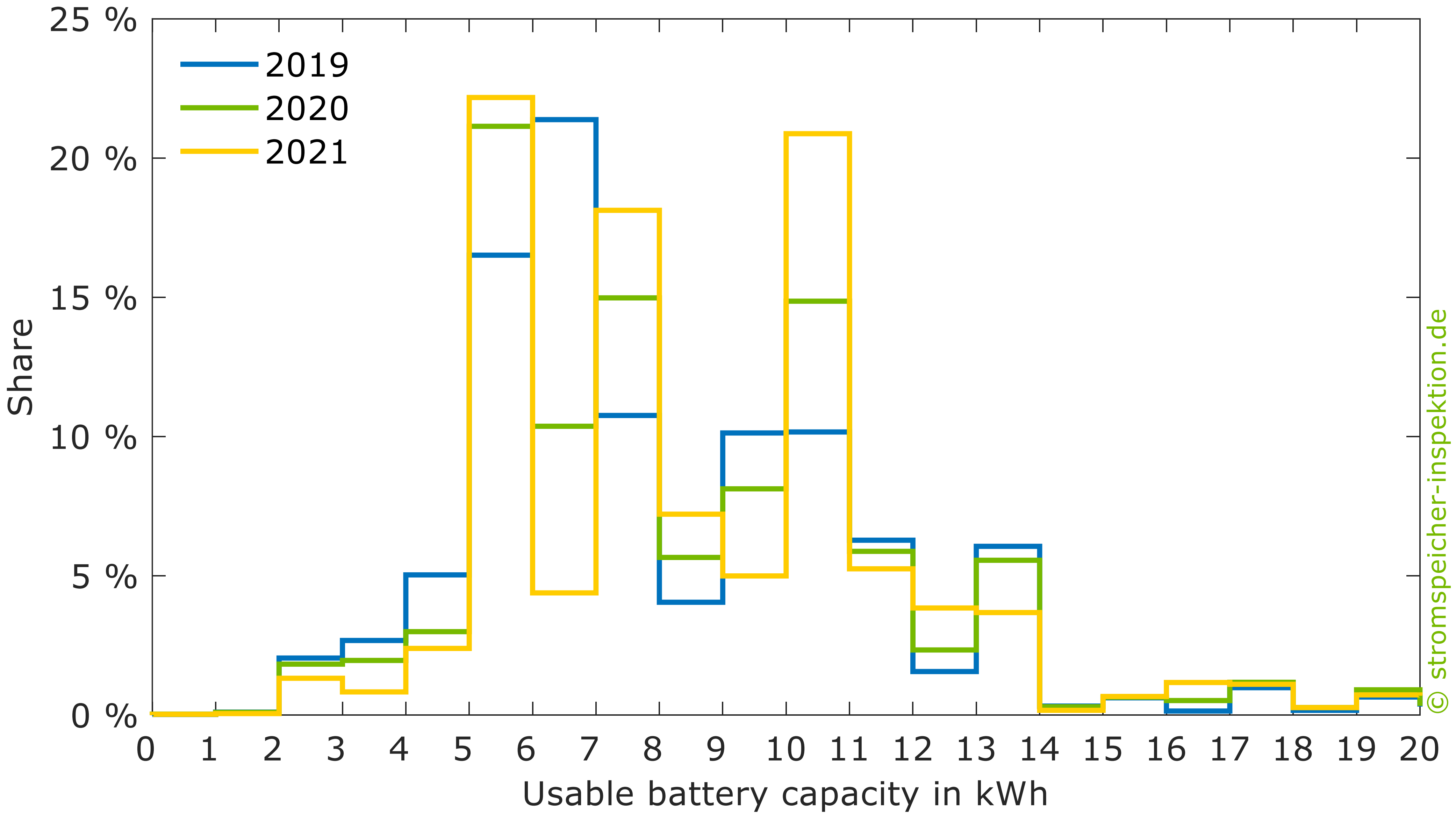
# Rated power of the installed PV systems with less than 20 kW






Data: Marktstammdatenregister

# Usable battery capacity of the battery systems up to 20 kWh





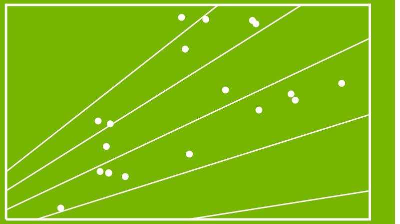

Data: Marktstammdatenregister

# Main topics of the Energy Storage Inspection 2022

**1** Analysis of the German market for residential PV-battery systems



**2** Comparison of the system properties based on the test reports according to the Efficiency Guideline



**3** Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



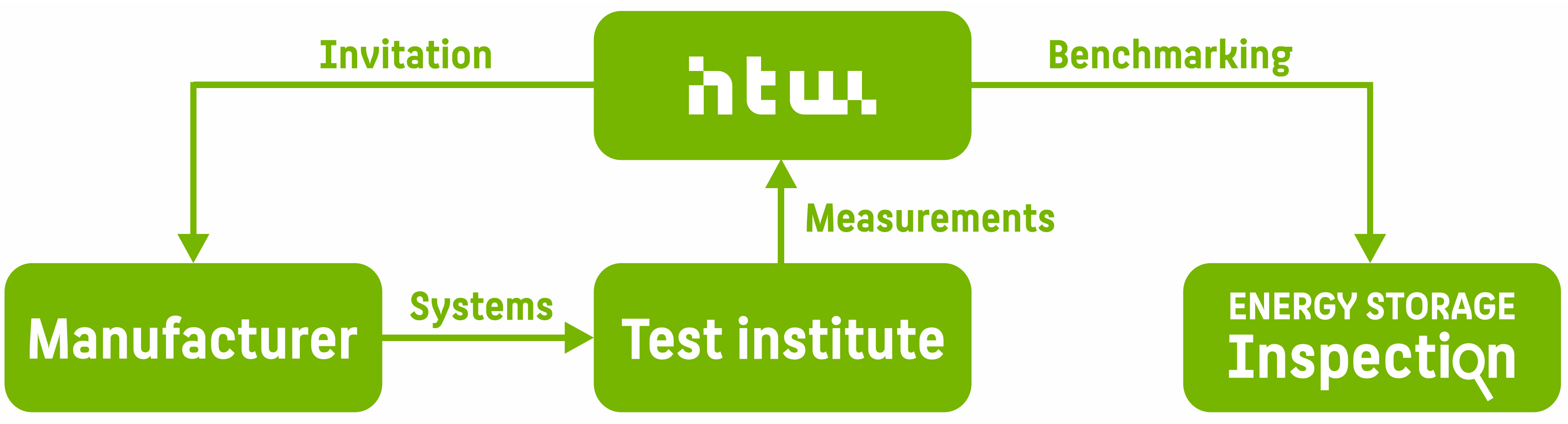
**4** FAQ: Answers to frequently asked questions concerning the efficiency and sizing of PV-battery systems

# Participants of the Energy Storage Inspection 2022

- All manufacturers of solar energy storage systems for residential buildings were invited to take part in the **Energy Storage Inspection 2022**.
- **14 manufactures** participated in the comparison of the storage systems with measurement data of **22 systems**.

# Analysis of system properties according to the Efficiency Guideline

- Laboratory tests were conducted by **independent testing institutes** in accordance with the "Efficiency Guideline for PV Storage Systems" (version 2.0).
- To each analyzed system a **system abbreviation** (e.g. A1) was assigned.
- The batteries of the **AC-coupled systems** A1 to C2 are equiped with battery inverters. The **DC-coupled systems** C3 to L1 have so called hybrid inverters.
- 2 manufacturers chose to **participate anonymously**.



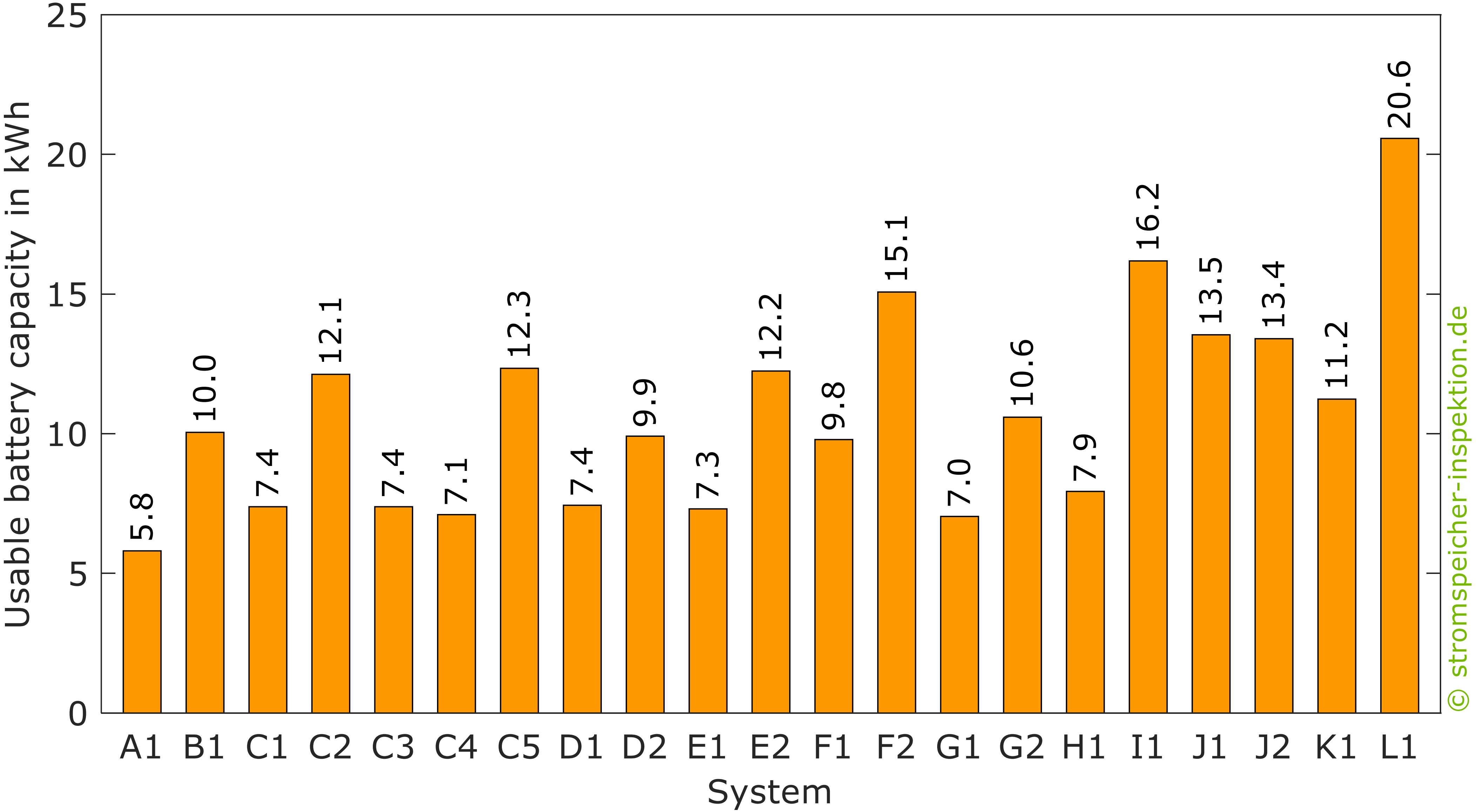
# Analyzed systems of the Energy Storage Inspection 2022

**A1** VARTA pulse neo 6
**B1** sonnen sonnenBatterie 10
**C1** KOSTAL PIKO MP plus 4.6-2 (AC) and BYD Battery-Box Premium HVS 7.7
**C2** KOSTAL PLENTICORE BI 10/26 and BYD Battery-Box Premium HVS 12.8
**C3** KOSTAL PIKO MP plus 4.6-2 (DC) and BYD Battery-Box Premium HVS 7.7
**C4** KOSTAL PLENTICORE plus 5.5 and BYD Battery-Box Premium HVS 7.7
**C5** KOSTAL PLENTICORE plus 10 and BYD Battery-Box Premium HVS 12.8
**D1** Fronius Primo GEN24 6.0 Plus and BYD Battery-Box Premium HVS 7.7
**D2** Fronius Symo GEN24 10.0 Plus and BYD Battery-Box Premium HVS 10.2
**E1** GoodWe GW5000-EH and BYD Battery-Box Premium HVS 7.7
**E2** GoodWe GW10K-ET and BYD Battery-Box Premium HVS 12.8
**F1** KACO blueplanet 10.0 TL3 and BYD Battery-Box Premium HVS 10.2
**F2** KACO blueplanet 10.0 TL3 and Energy Depot Domus 2.5
**G1** RCT Power Power Storage DC 6.0 and Power Battery 7.6
**G2** RCT Power Power Storage DC 10.0 and Power Battery 11.5
**H1** VIESSMANN Vitocharge VX3 Typ 4.6A8
**I1** Fenecon Home
**L1** SolaX X3-Hybrid-15.0-D and Triple Power T-BAT H 23.0


A1 B1 C1 C2 C3 C4 C5 D1 D2 E1 E2 F1 F2 G1 G2 H1 I1 J1 J2 K1 L1

AC-coupled systems | DC-coupled systems

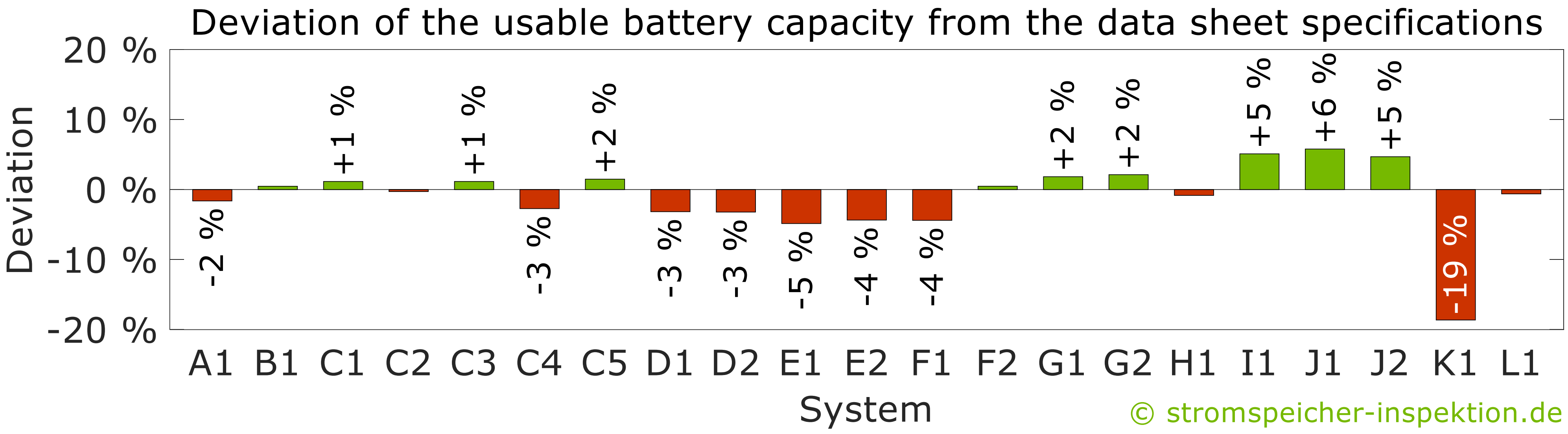
# Usable battery capacity of the analyzed systems



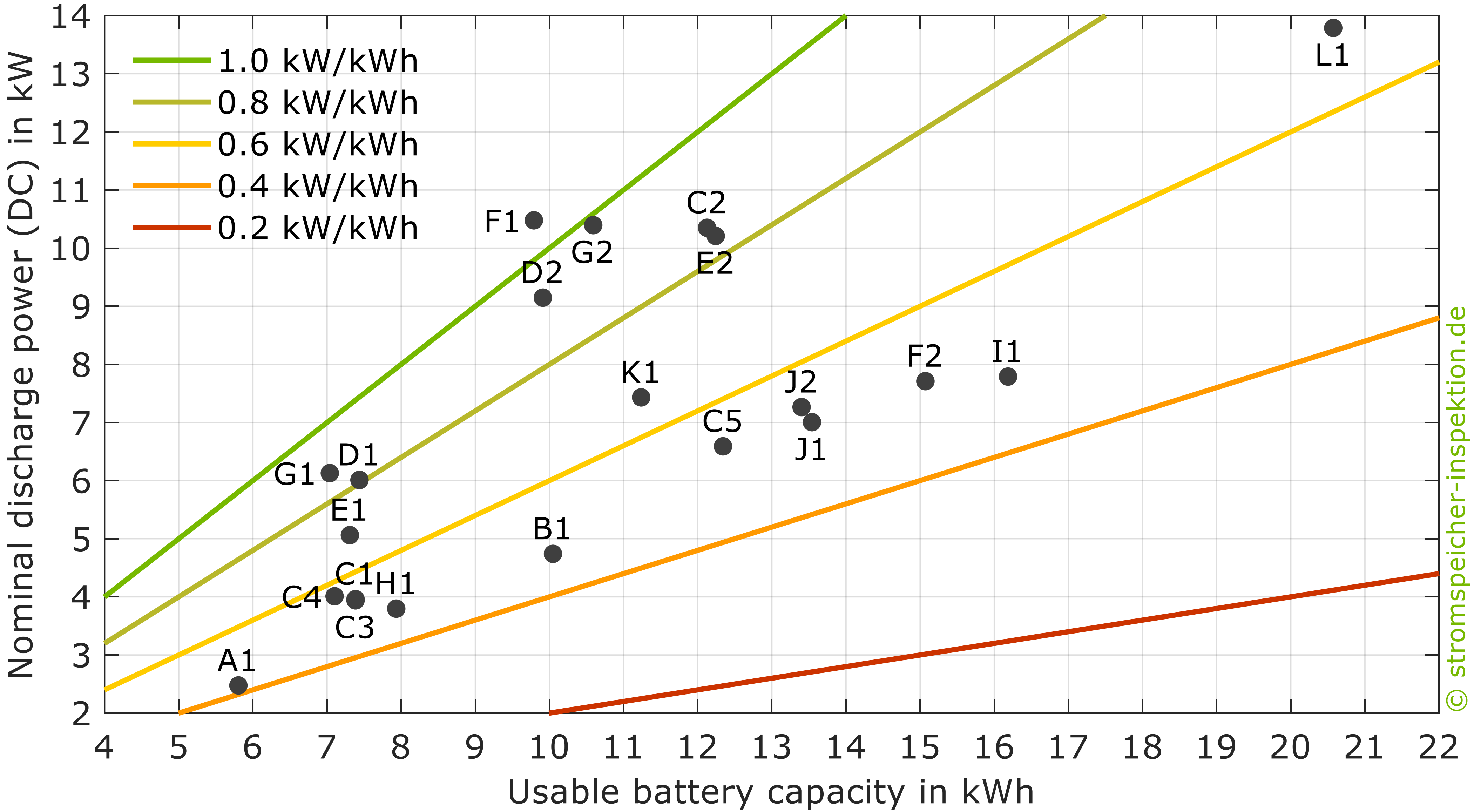

G1, G2 and J1: Due to a temperature-induced derating, the test could not be run at nominal power.

# Comparison of data sheet values and laboratory measurements

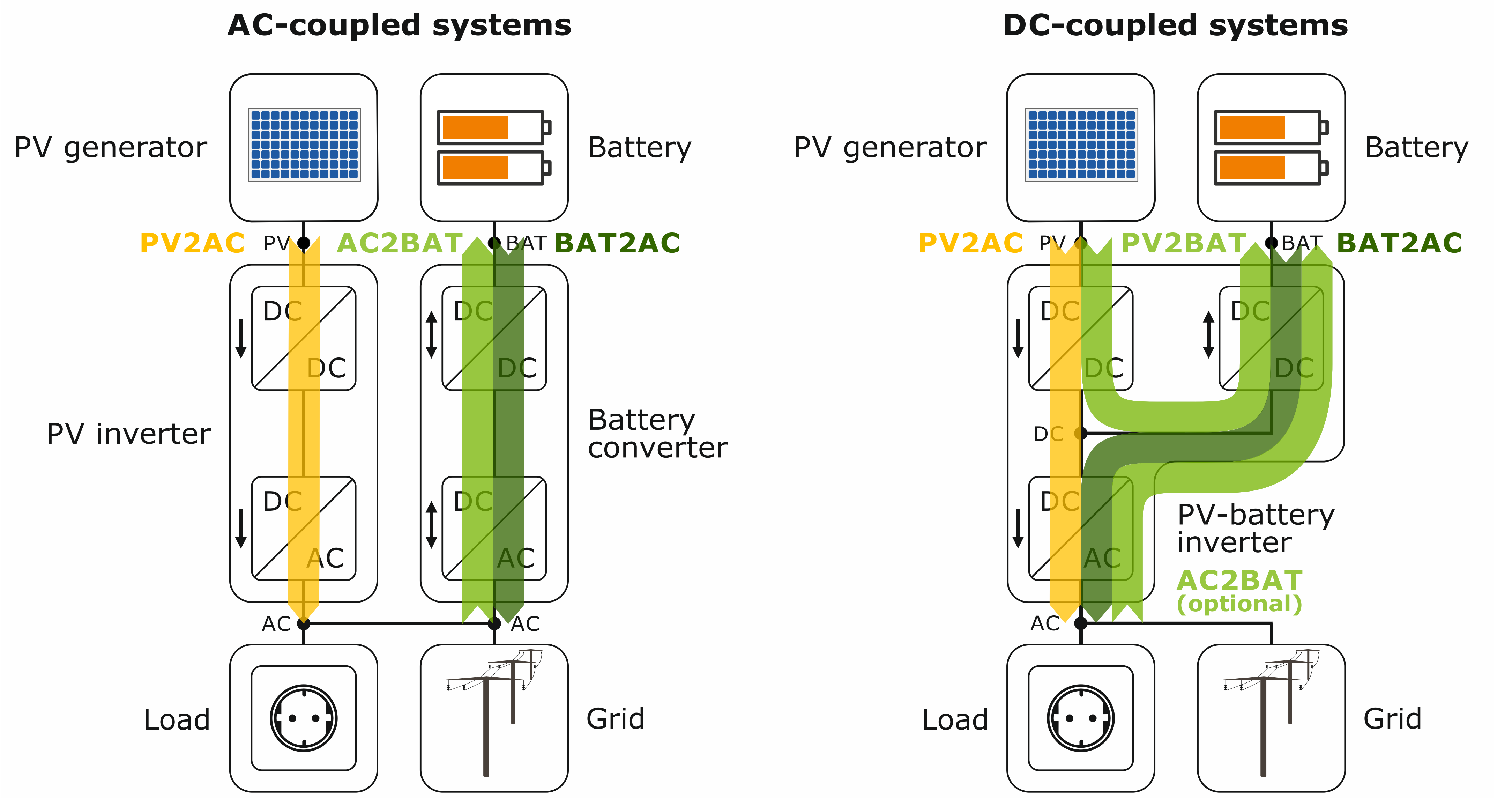
- For half of the analyzed systems **higher usable battery capacities** were measured in the laboratory test compared to the data sheet.
- The specified depth of discharge for **protection against deep discharge** is often the reason why the measured values are lower than the data sheet values.
- The usable battery capacity of the system K1 is 2.6 kWh (19 %) below the value given on the data sheet.



# Nominal discharge power of the analyzed systems



# Energy conversion pathways of the different system topologies



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# Average efficiency of the energy conversion pathways

| System | PV2AC<br>PV feed-in | PV2BAT<br>PV charging | AC2BAT<br>AC charging | BAT2AC<br>AC discharging |
|---|---|---|---|---|
| A1 | | | 92.1 % | 92.0 % |
| B1 | | | 93.9 % | 94.0 % |
| C1 | | | 95.6 % | 95.6 % |
| C2 | | | 95.7 % | 96.0 % |
| C3 | 95.1 % | 95.6 % | | 95.7 % |
| C4 | 95.5 % | 93.7 % | | 93.7 % |
| C5 | 96.3 % | 95.9 % | | 95.9 % |
| D1 | 96.6 % | 96.8 % | 95.6 % | 95.8 % |
| D2 | 97.9 % | 97.9 % | 96.5 % | 97.2 % |
| E1 | 95.3 % | 96.3 % | 95.7 % | 96.3 % |
| E2 | 96.6 % | 97.0 % | 96.7 % | 97.0 % |
| F1 | 96.8 % | 97.1 % | 96.6 % | 96.6 % |
| F2 | 97.0 % | 96.2 % | 96.3 % | 96.3 % |
| G1 | 95.9 % | 93.8 % | 93.4 % | 93.9 % |
| G2 | 97.9 % | 98.0 % | 97.2 % | 97.6 % |
| H1 | 94.8 % | 93.6 % | 93.5 % | 93.8 % |
| I1 | 96.0 % | 93.9 % | | 94.6 % |
| J1 | 96.4 % | 95.9 % | | 95.8 % |
| J2 | 95.0 % | 93.7 % | | 94.1 % |
| K1 | 95.9 % | 96.3 % | 95.4 % | 97.7 % |
| L1 | 96.5 % | 96.9 % | | 96.9 % |

Conversion pathway

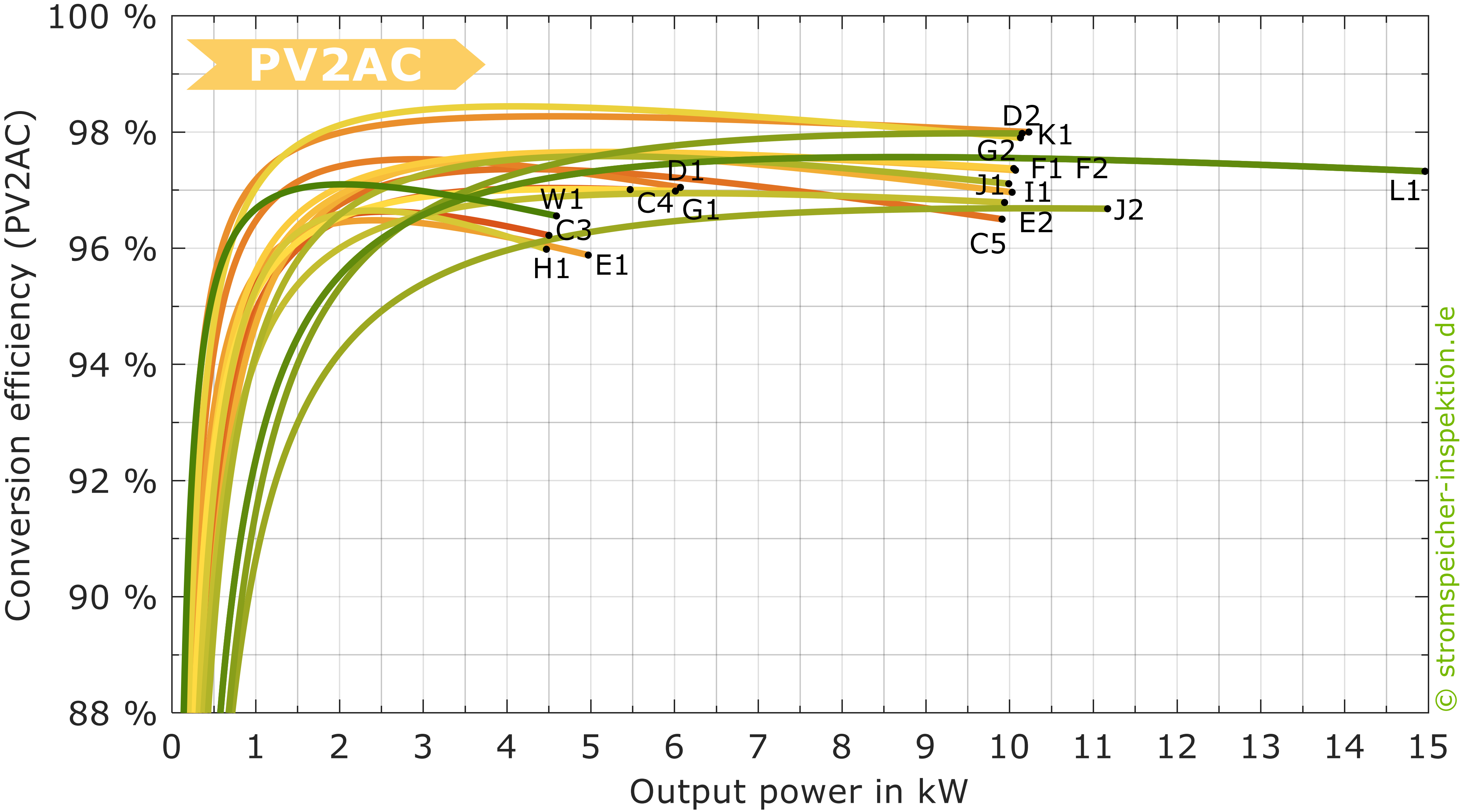
Average conversion efficiency: 98 % · 96 % · 94 % · 92 % · 90 % · 88 % · 86 %





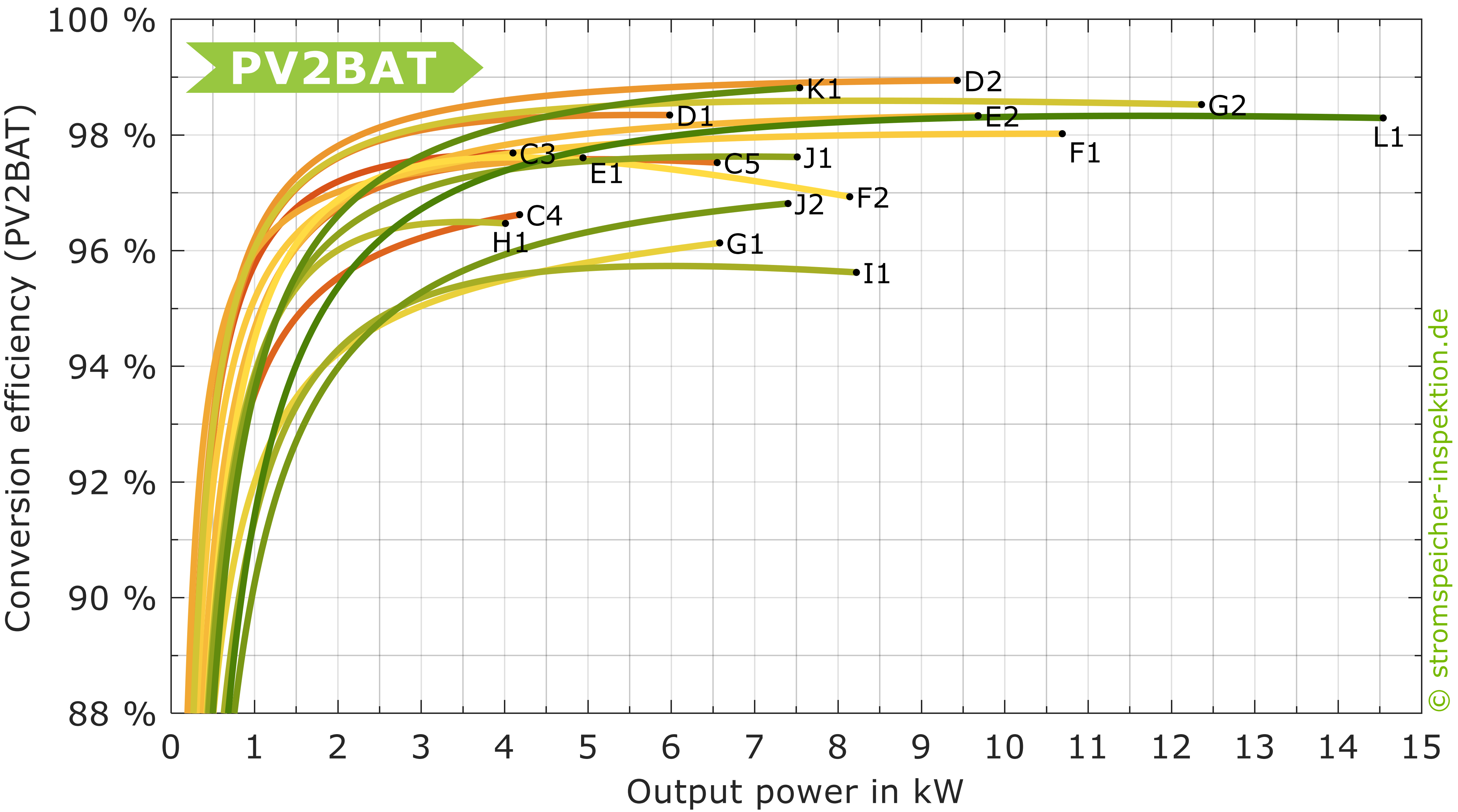
Average pathway efficiencies according to the “Efficiency Guideline for PV Storage Systems” 2.0

# PV feed-in pathway efficiency

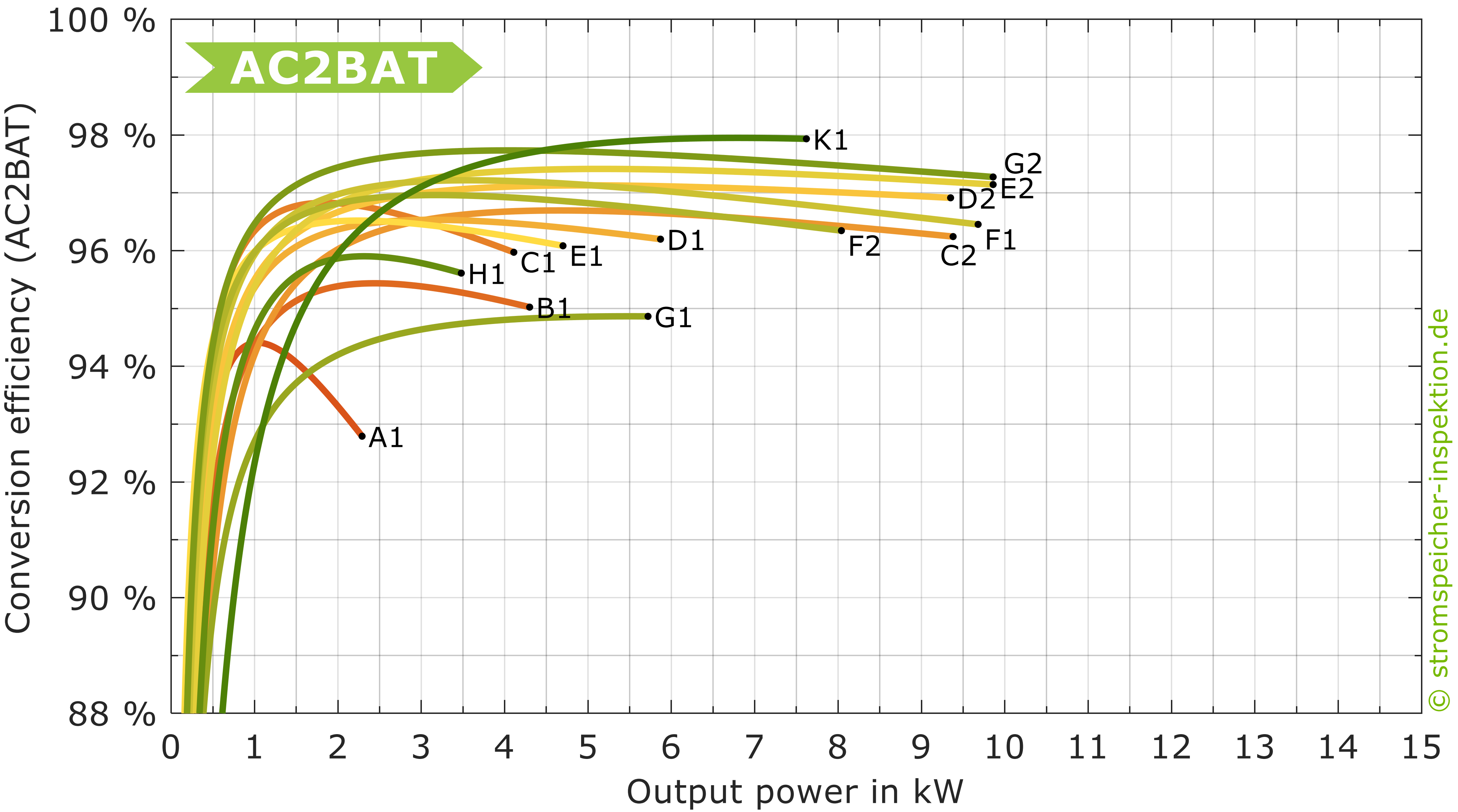



W1 and W2: PV inverter used for assessing the AC-coupled systems with SPI (5 kW) and SPI (10 kW).

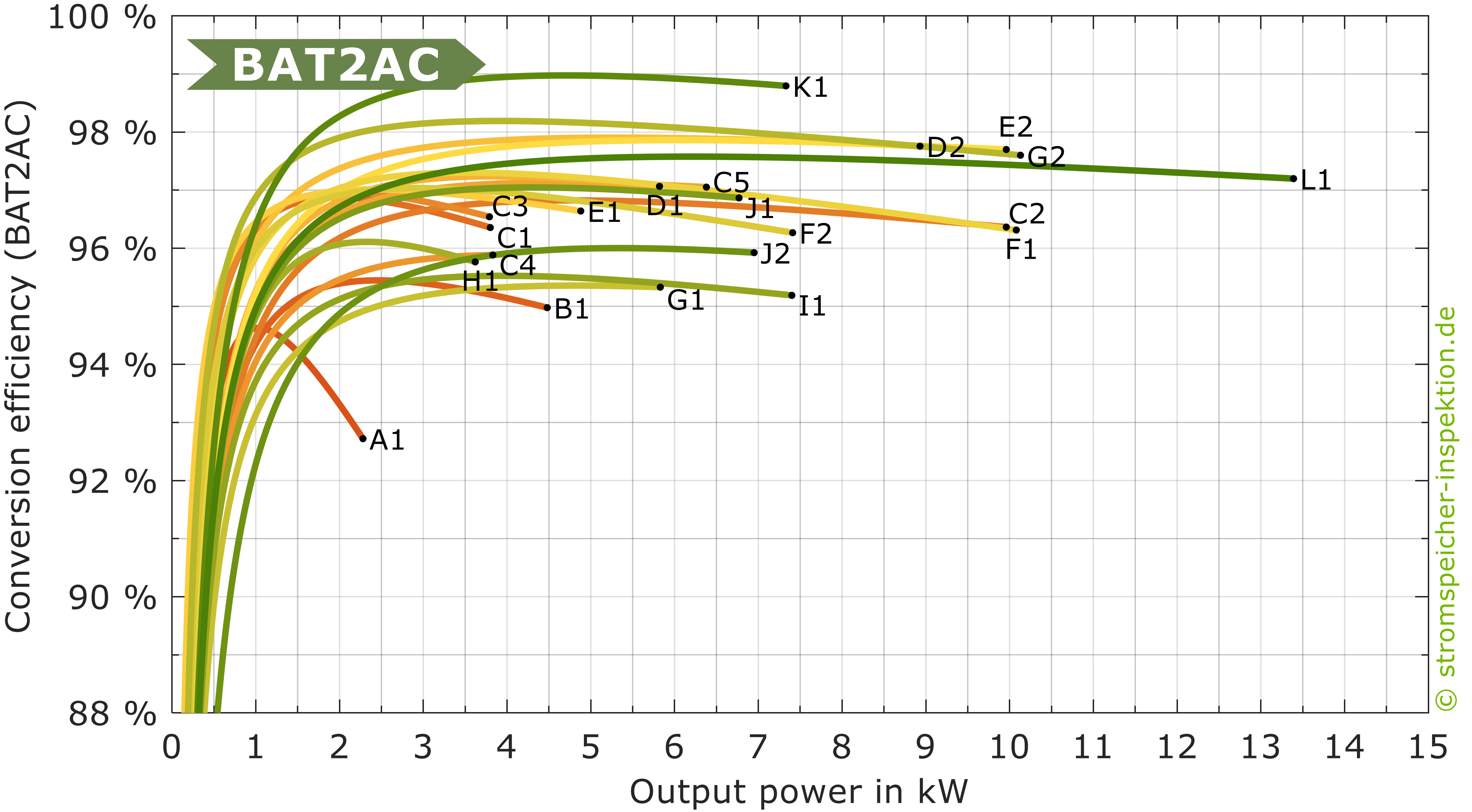
# PV battery charging pathway efficiency



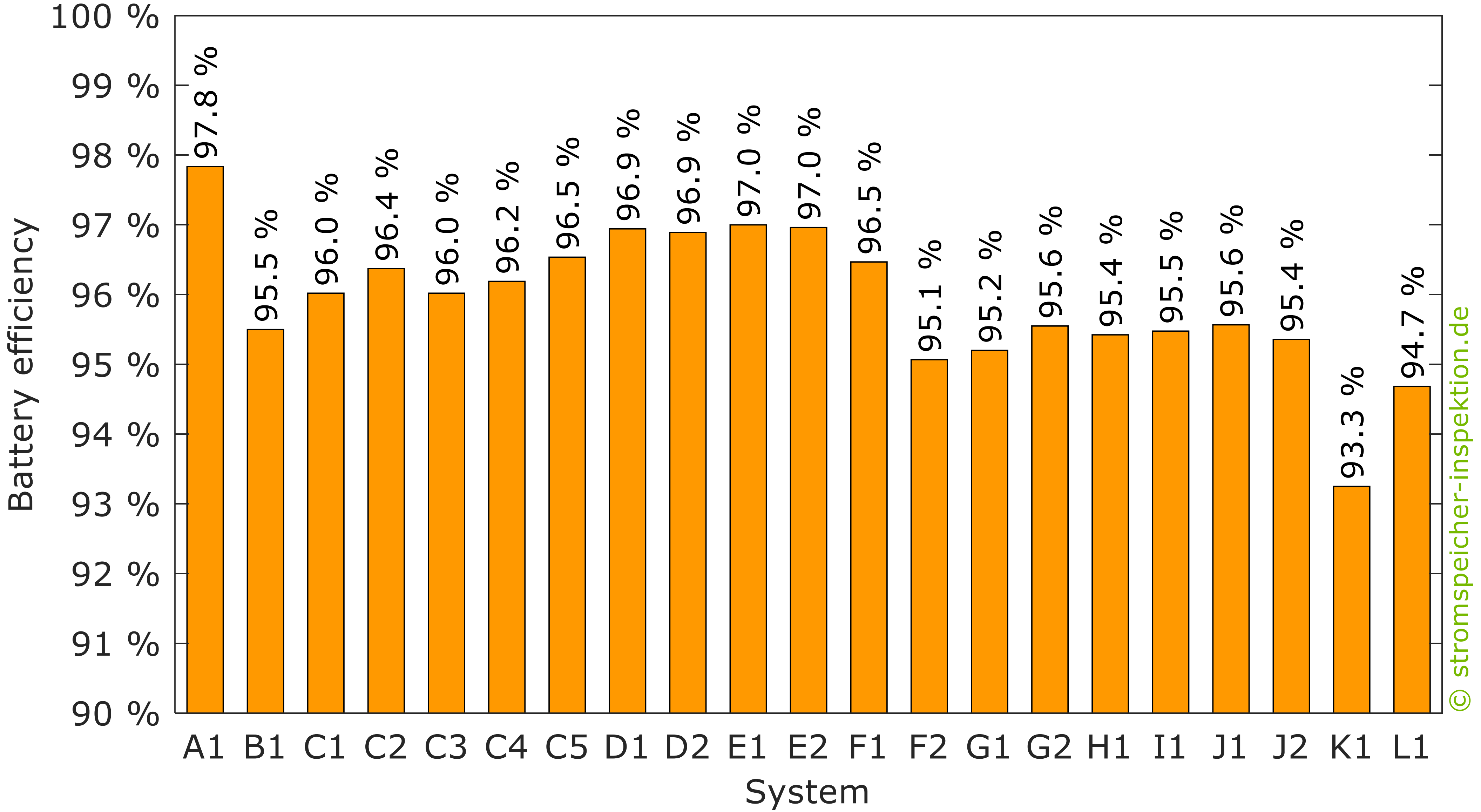
# AC battery charging pathway efficiency



# AC battery discharging pathway efficiency



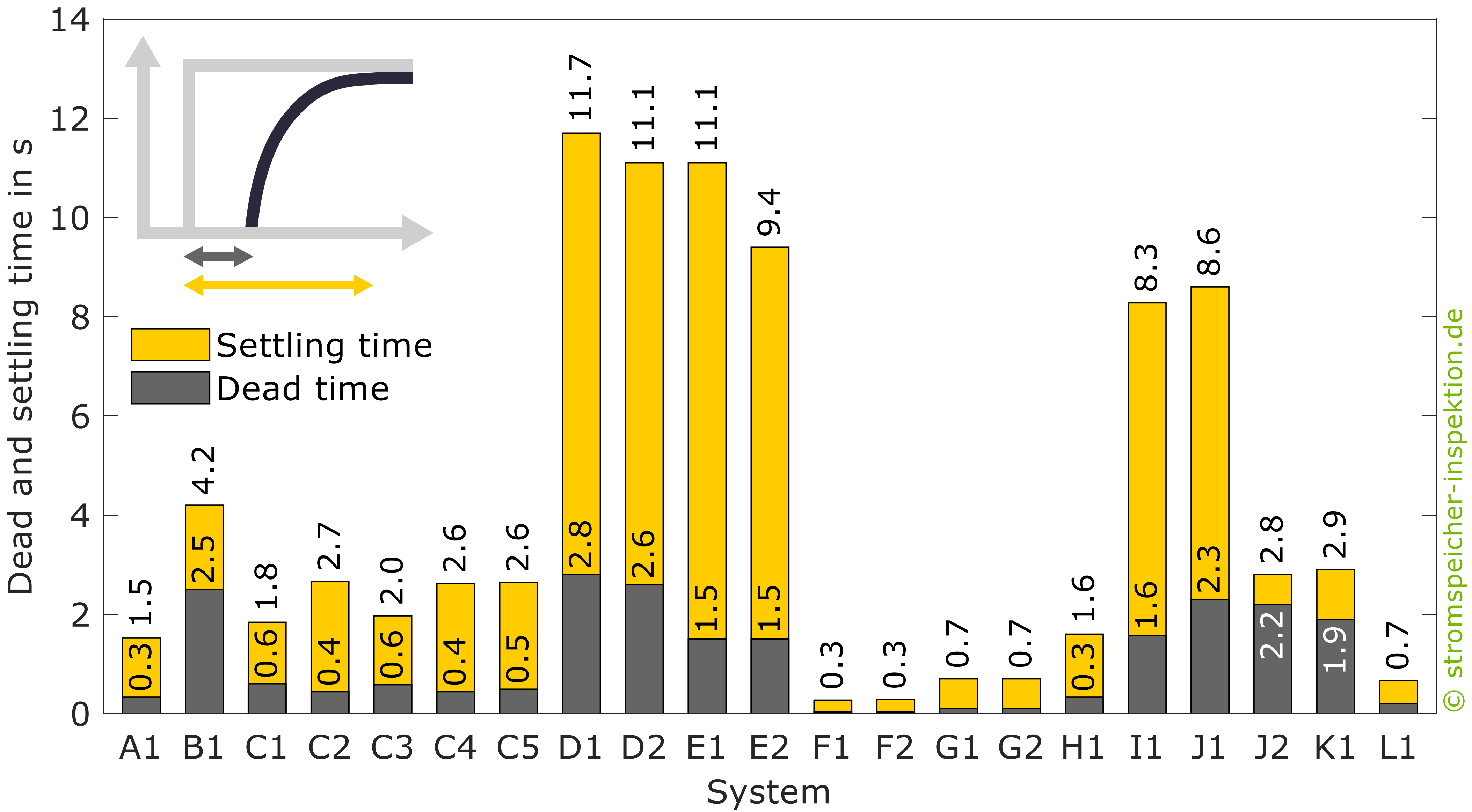
# Average battery efficiency



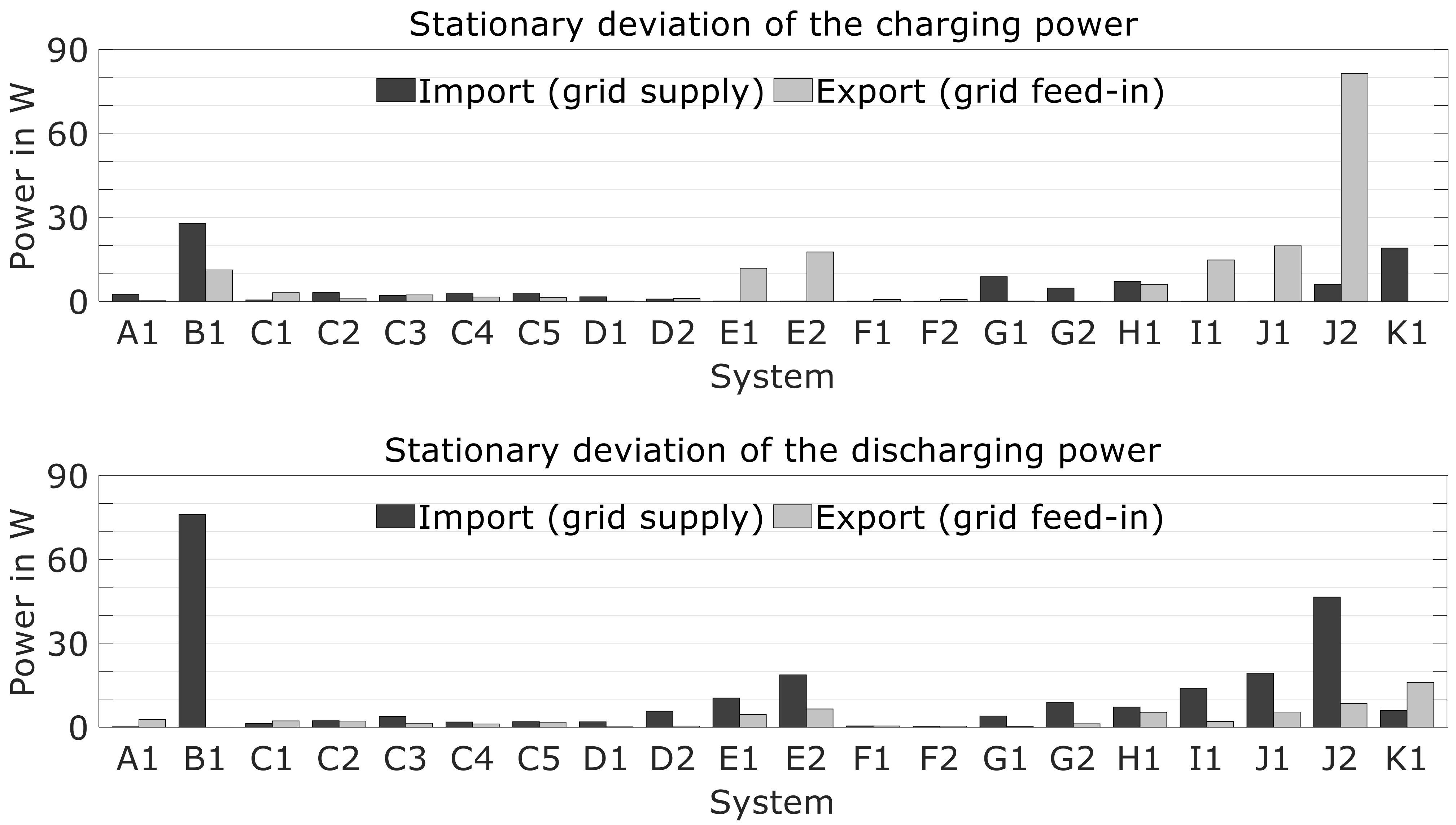



G1, G2 and J1: Due to a temperature-induced derating, the test could not be run at nominal power.

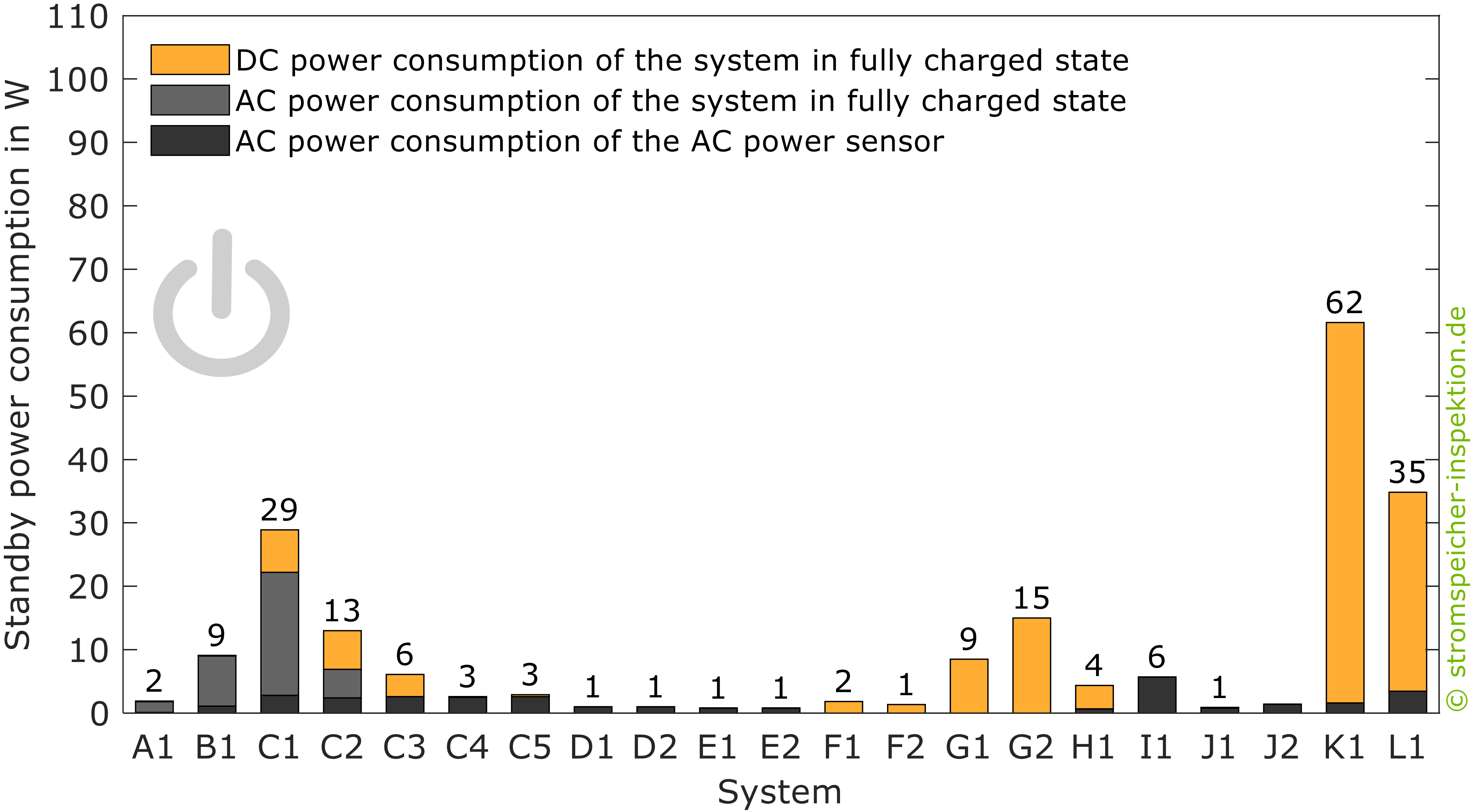
# Dynamic control deviations



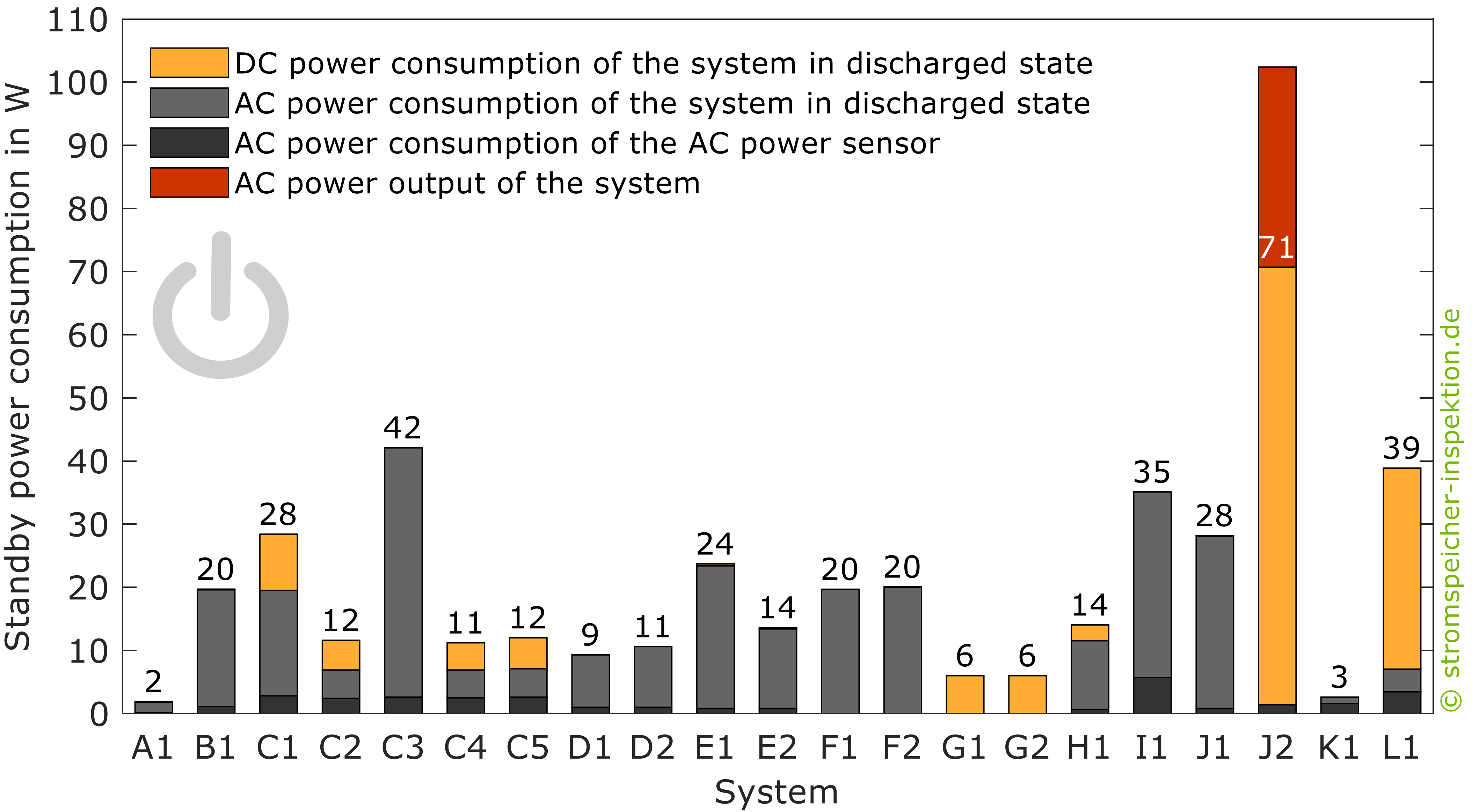
# Stationary control deviations



# Standby power consumption with fully charged battery



# Standby power consumption with discharged battery



# Main topics of the Energy Storage Inspection 2022

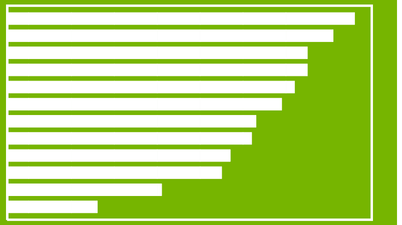
**1** Analysis of the German market for residential PV-battery systems



**2** Comparison of the system properties based on the test reports according to the Efficiency Guideline



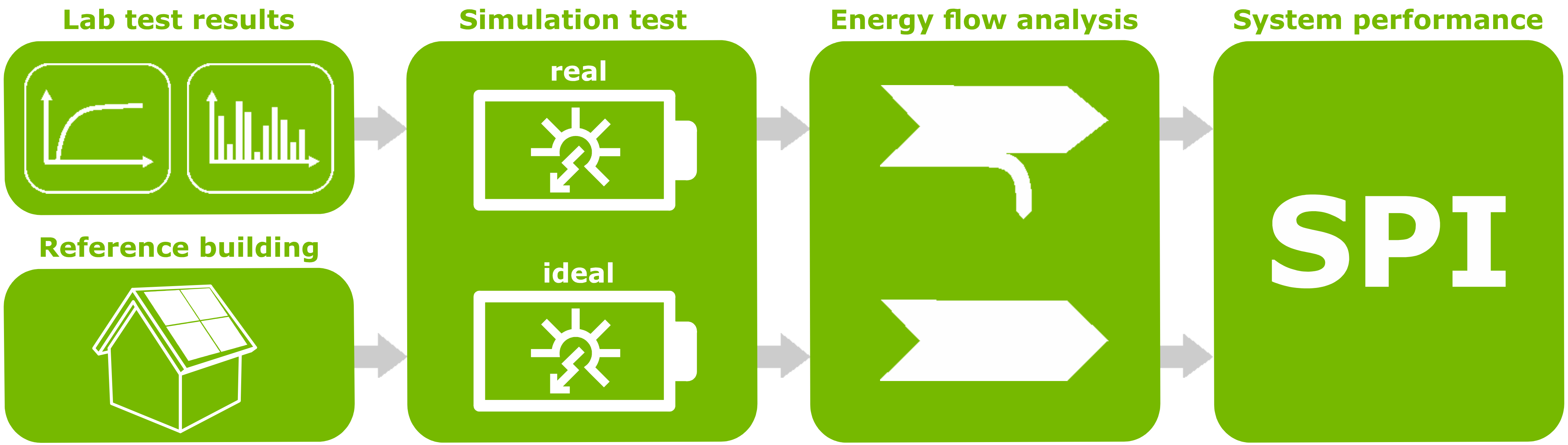
**3** Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



**4** FAQ: Answers to frequently asked questions concerning the efficiency and sizing of PV-battery systems

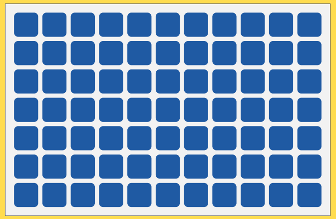
# Methodology of the simulation-based system evaluation

- **Simulation of the operational behavior** of the PV-battery systems over a period of one year.
- The System Performance Index (SPI) rates the systems based on the energy flows at the **grid connection point**.
- The **AC-coupled systems** are assessed in combination with the PV inverters SMA Sunny Boy 5.0 (5 kW) or SMA Sunny Tripower 10.0 (10 kW).



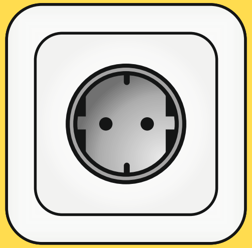
# System Performance Index SPI (5 kW) and SPI (10 kW)

## 1st reference case for the System Performance Index SPI (5 kW)



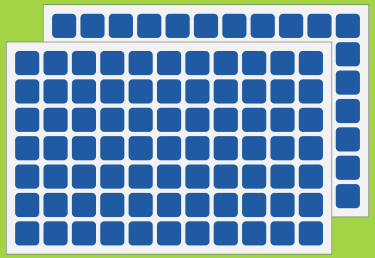
PV system
(5 kW)

+



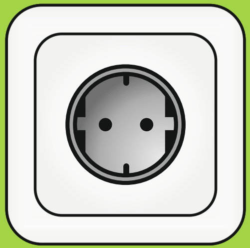
Appliances
(5010 kWh/a)

## 2nd reference case for the System Performance Index SPI (10 kW)



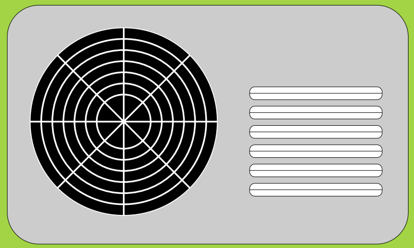
PV system
(10 kW)

+



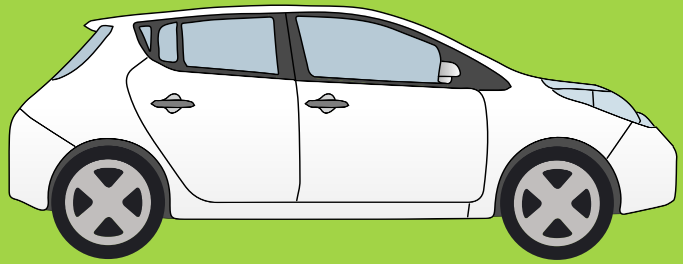
Appliances
(5010 kWh/a)

+



Heat pump
(2664 kWh/a)

+



Electric vehicle
(1690 kWh/a)

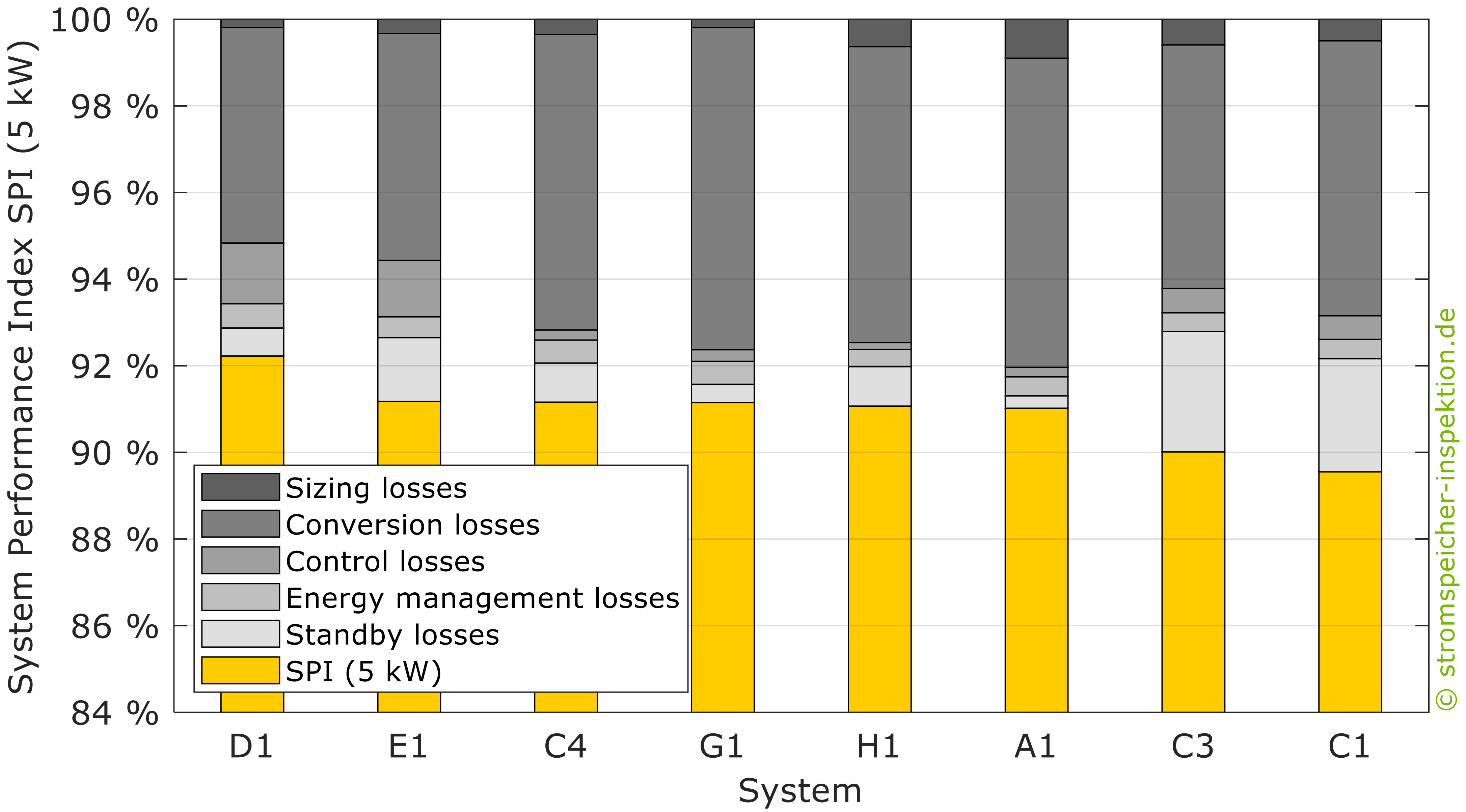
**Please note: SPI (5 kW) and SPI (10 kW) are not comparable due to the different conditions of the two reference cases.**

# Assignment of the systems to the reference cases

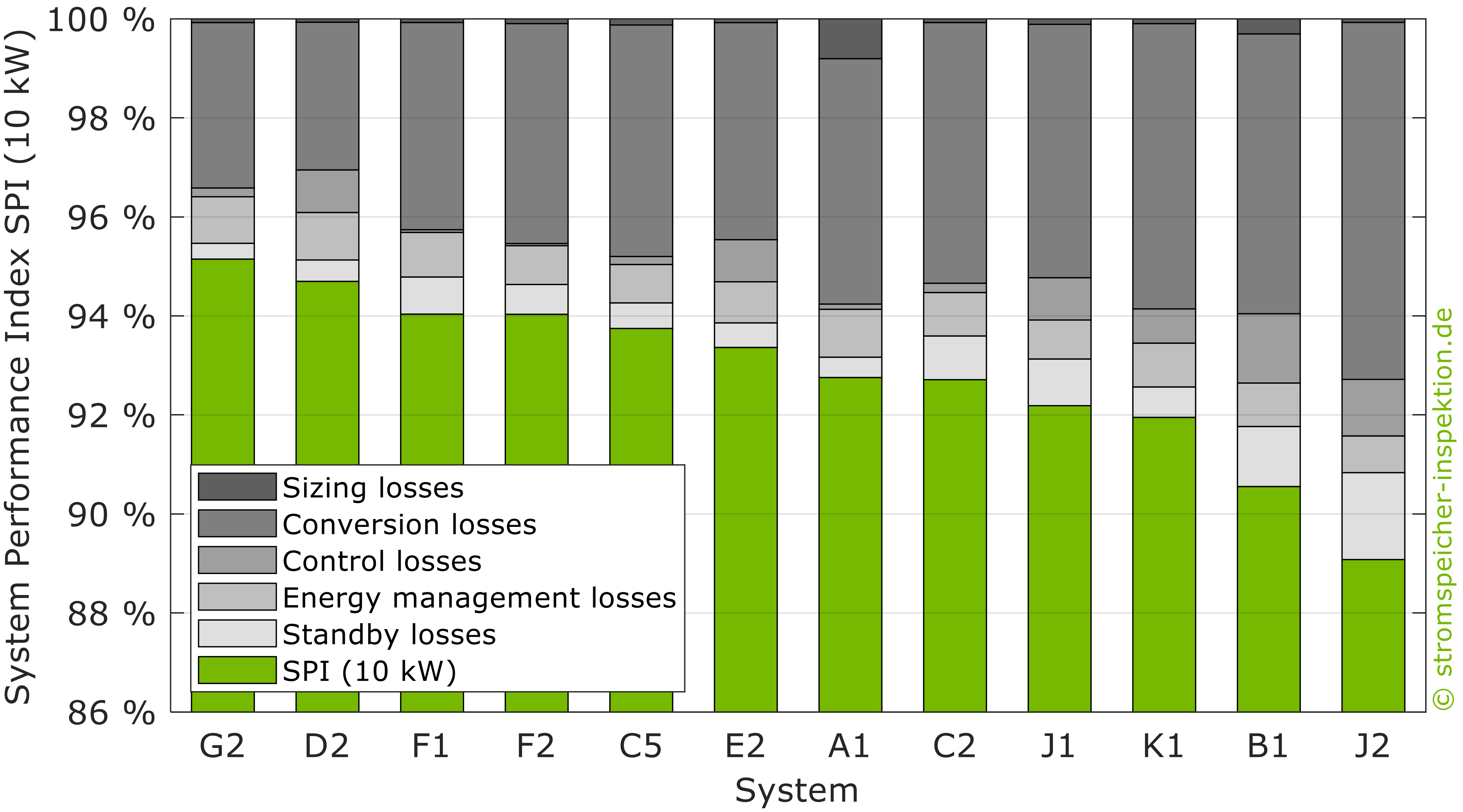
- Depending on the size of the **power electronics** and **battery storage**, the efficiency rating with the **SPI (5 kW)** or **SPI (10 kW)** is appropriate.
- Only systems with usable battery capacities smaller than **8.0 kWh** were rated with the SPI (5 kW).
- For a rating with the SPI (10 kW) an usable battery capacity smaller than **16.0 kWh** was required.
- The classification was based on the usable storage capacity determined in the **laboratory test**.
- 8 systems were rated with the SPI (5 kW) and 12 systems were rated with the SPI (10 kW). Both metrics were determined for the AC-coupled system A1.

| System | A1 | B1 | C1 | C2 | C3 | C4 | C5 | D1 | D2 | E1 | E2 | F1 | F2 | G1 | G2 | H1 | J1 | J2 | K1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPI (5 kW) | ■ | | ■ | | ■ | ■ | | ■ | | ■ | | | | ■ | | ■ | | | |
| SPI (10 kW) | ■ | ■ | | ■ | | | ■ | | ■ | | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ |

# Loss analysis of the systems assessed with the SPI (5 kW)



# Loss analysis of the systems assessed with the SPI (10 kW)



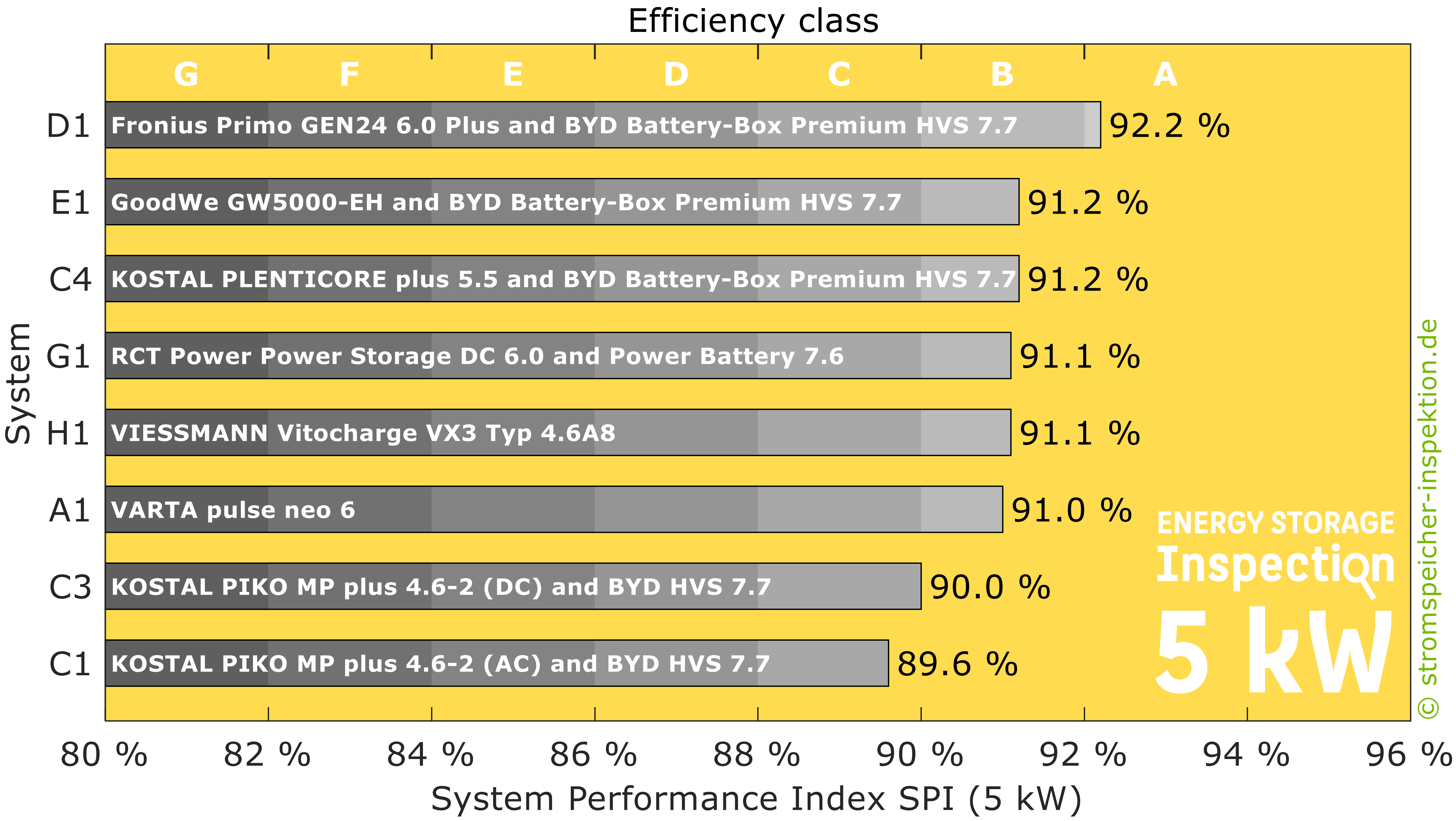
# Definition of efficiency classes for PV battery systems

| Class | SPI (5 kW) | SPI (10 kW) |
|---|---|---|
| A | ≥ 92 % | ≥ 93.5 % |
| B | ≥ 90 % | ≥ 92.5 % |
| C | ≥ 88 % | ≥ 91.5 % |
| D | ≥ 86 % | ≥ 90.5 % |
| E | ≥ 84 % | ≥ 89.5 % |
| F | ≥ 82 % | ≥ 88.5 % |
| G | < 82 % | < 88.5 % |



Source: Energy Storage Inspection 2020, HTW Berlin

# SPI (5 kW) and efficiency classes of the analyzed systems





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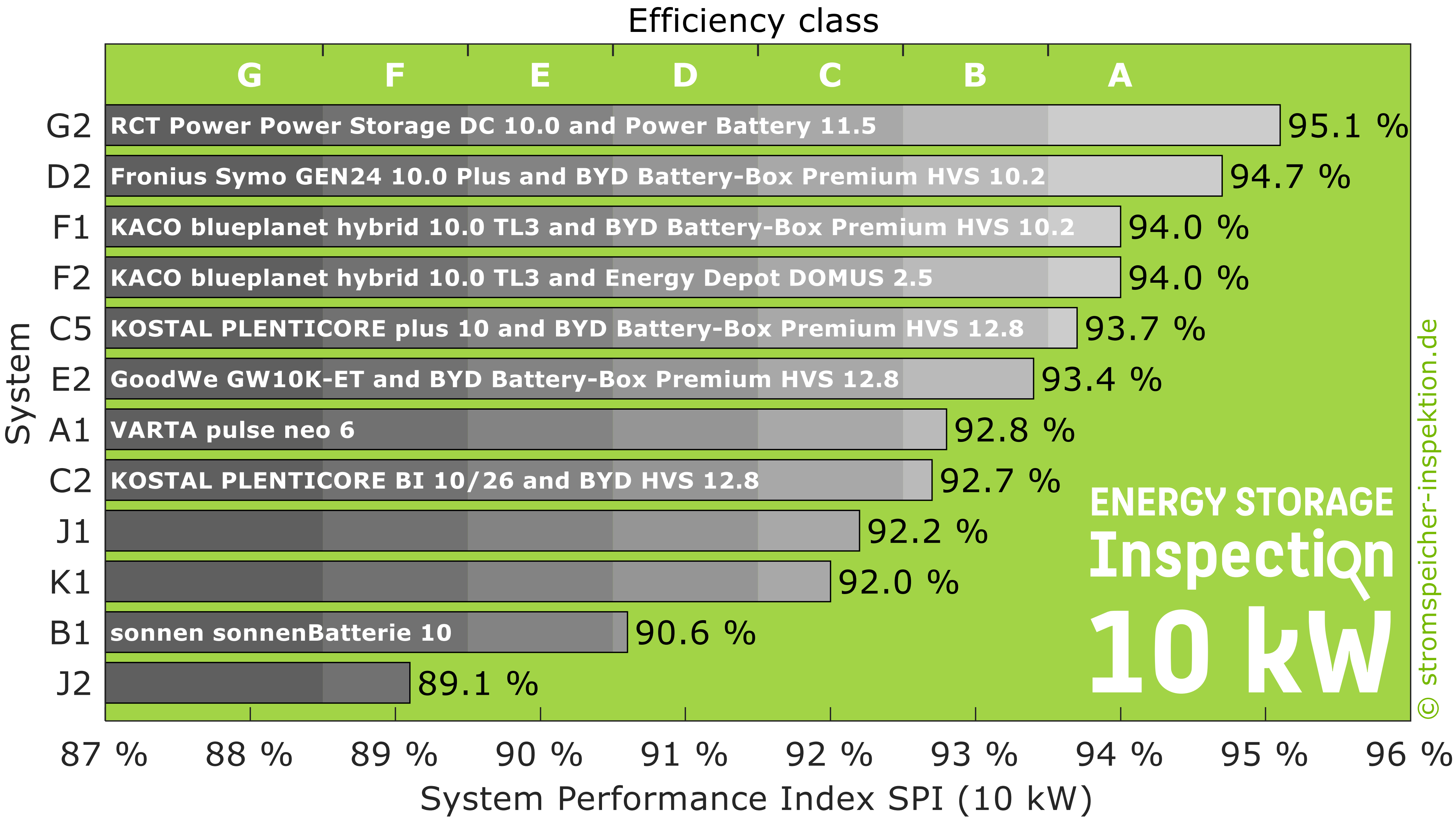
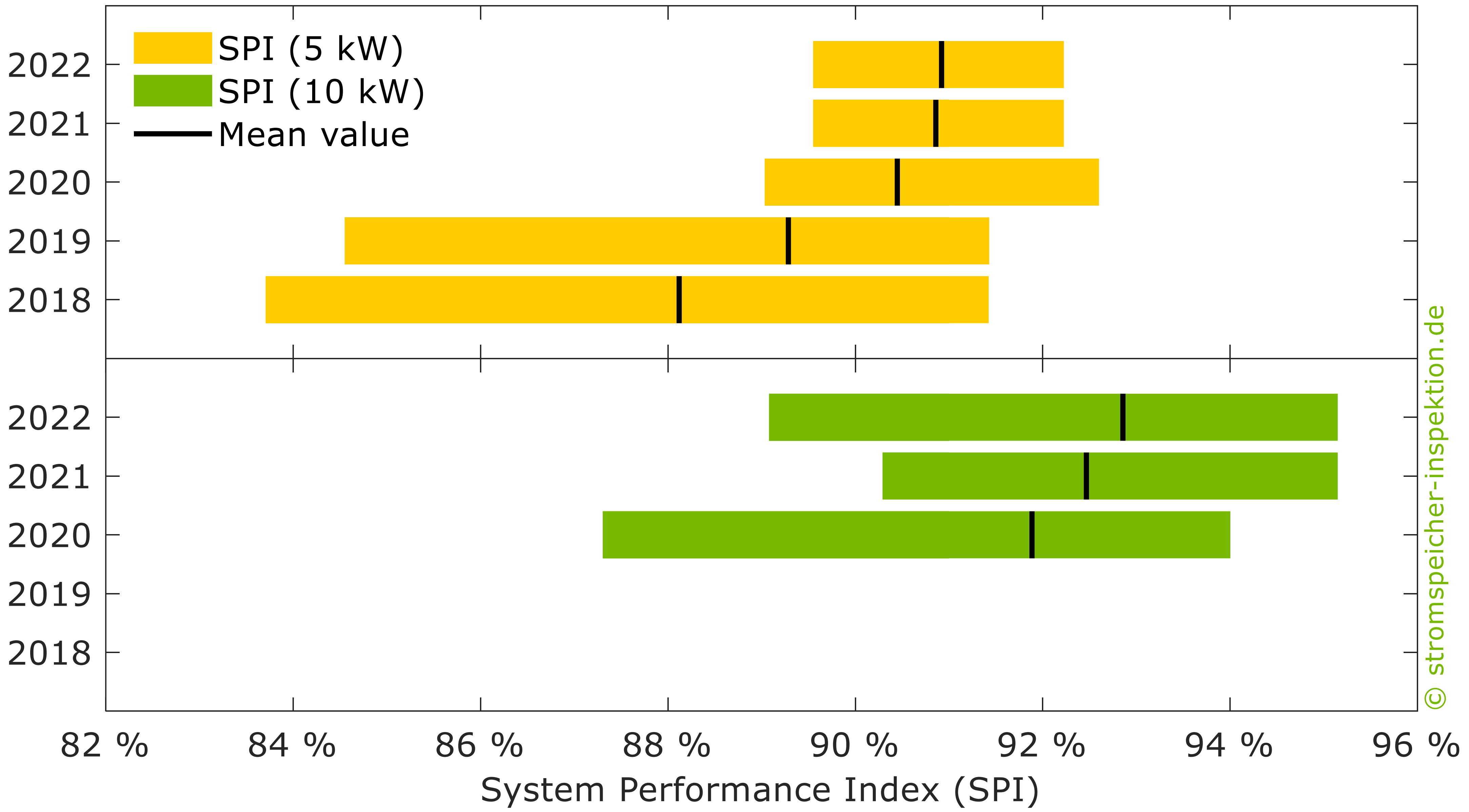
# SPI (10 kW) and efficiency classes of the analyzed systems



# Range of SPI scores in the Energy Storage Inspection since 2018



# Main topics of the Energy Storage Inspection 2022

**1** Analysis of the German market for residential PV-battery systems



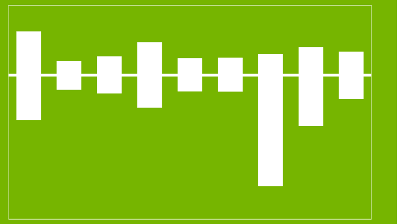
**2** Comparison of the system properties based on the test reports according to the Efficiency Guideline



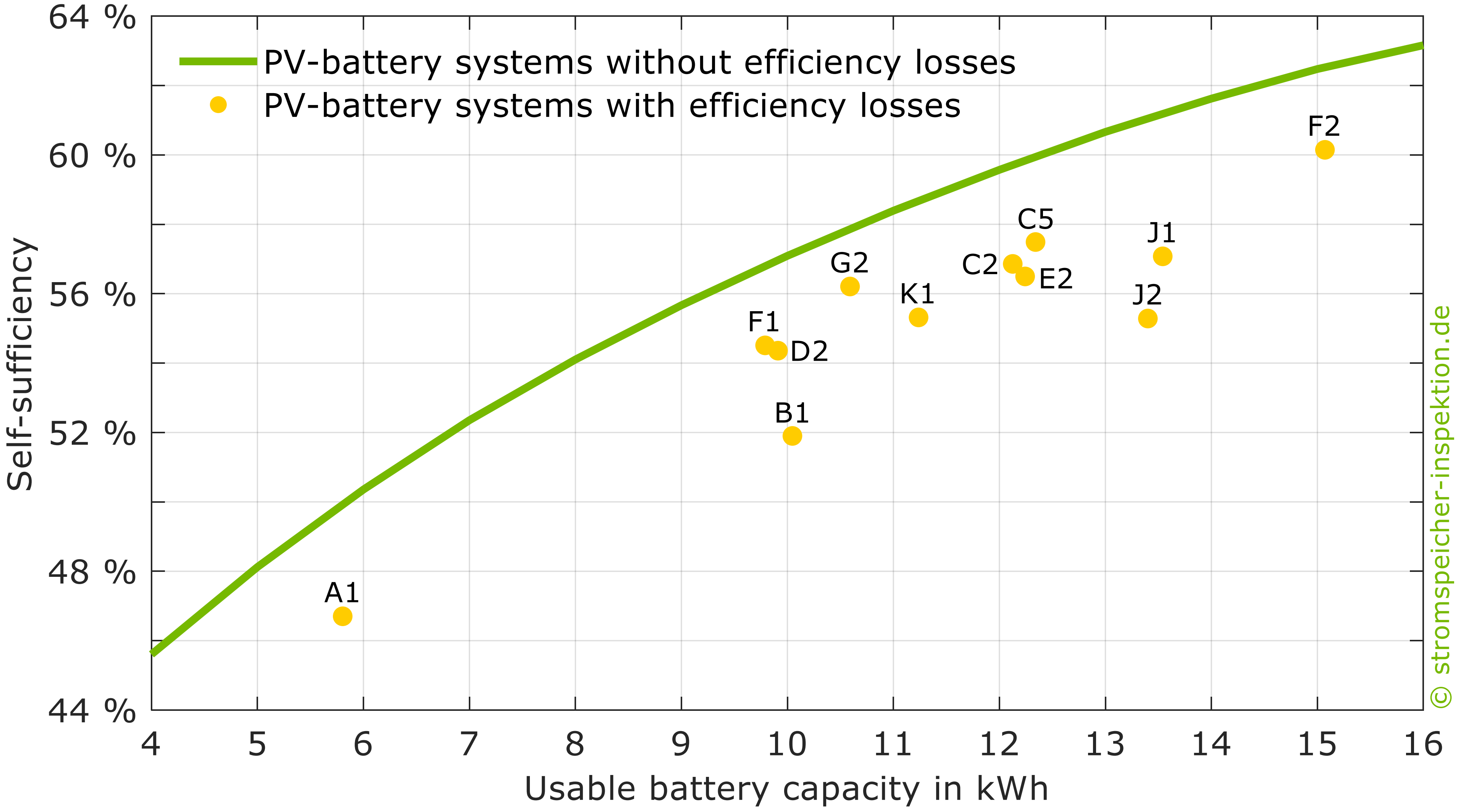
**3** Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



**4** FAQ: Answers to frequently asked questions concerning the efficiency and sizing of PV-battery systems

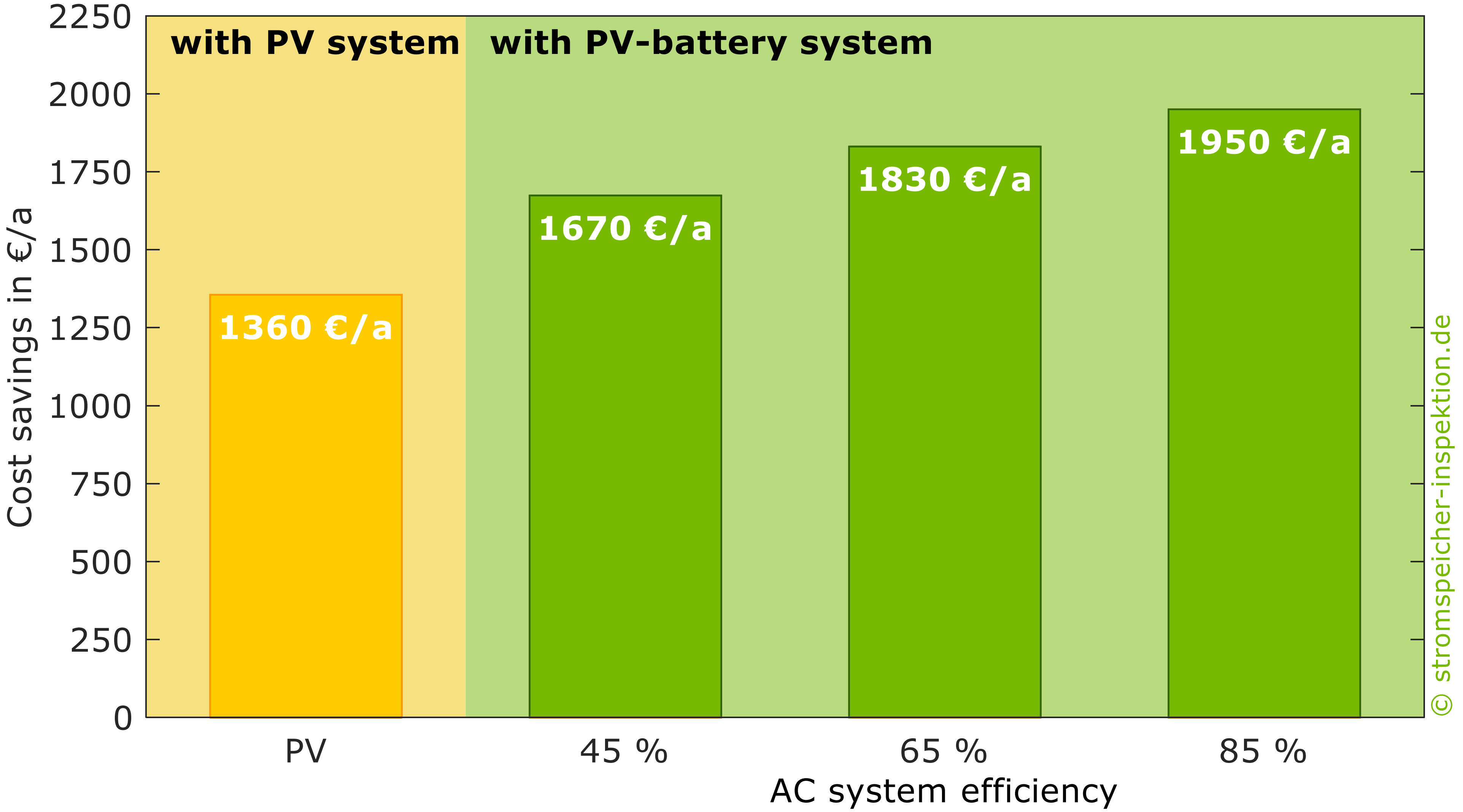


# Why is it not reasonable to focus only on battery capacity when selecting a PV-battery system?




Residential building with electric vehicle and heat pump: PV system 10 kW, demand 9363 kWh/a
The lower the efficiency losses, the higher the degree of self-sufficiency.

# How does the mean efficiency of a battery storage system influence the yearly savings?




Residential building with electric vehicle and heat pump: PV system 10 kW, usable battery capacity 10 kWh, demand 9363 kWh/a, grid feed-in 6.5 ct/kWh, grid cost 32 ct/kWh

# What is the battery storage capacity recommended for residential buildings?

Recommended upper limit of the usable battery capacity

| Rated PV power in kW \ Electrical load demand in kWh/a | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 |
|---|---|---|---|---|---|---|---|
| ≥ 10 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 7.5 kWh | 9.0 kWh | 10.5 kWh | 12.0 kWh |
| 9 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 7.5 kWh | 9.0 kWh | 10.5 kWh | 12.0 kWh |
| 8 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 7.5 kWh | 9.0 kWh | 10.5 kWh | 12.0 kWh |
| 7 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 7.5 kWh | 9.0 kWh | 10.5 kWh | 10.5 kWh |
| 6 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 7.5 kWh | 9.0 kWh | 9.0 kWh | 9.0 kWh |
| 5 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 7.5 kWh | 7.5 kWh | 7.5 kWh | 7.5 kWh |
| 4 | 3.0 kWh | 4.5 kWh | 6.0 kWh | 6.0 kWh | 6.0 kWh | 6.0 kWh | 6.0 kWh |

Electrical load demand in kWh/a



Recommended limit of the usable battery capacity in residential buildings in Germany.
Example: PV system with 10 kW, demand of 4000 kWh/a, battery capacity should not exceed 6 kWh.

# Summary

- The Energy Storage Inspection 2022 analyzed and compared the energy efficiency of **21 battery systems**.
- In the **reference case up to 5 kW** the hybrid inverter Fronius Primo GEN24 6.0 Plus and the BYD Battery-Box Premium HVS 7.7 scored best.
- Twice in a row the Power Storage DC 10.0 from RCT Power won the **10 kW reference case** with an SPI (10 kW) of 95,1 % .
- In 2020 only one system scored an **SPI (10 kW) over 93 %**, this year already six systems managed to do so.
- Compared to the top performers, the **total losses** of a less efficient system are more than twice as high.
- The majority of the 21 analyzed PV-battery systems achieved efficiency classes A and B and scored with a **very good system efficiency**.

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