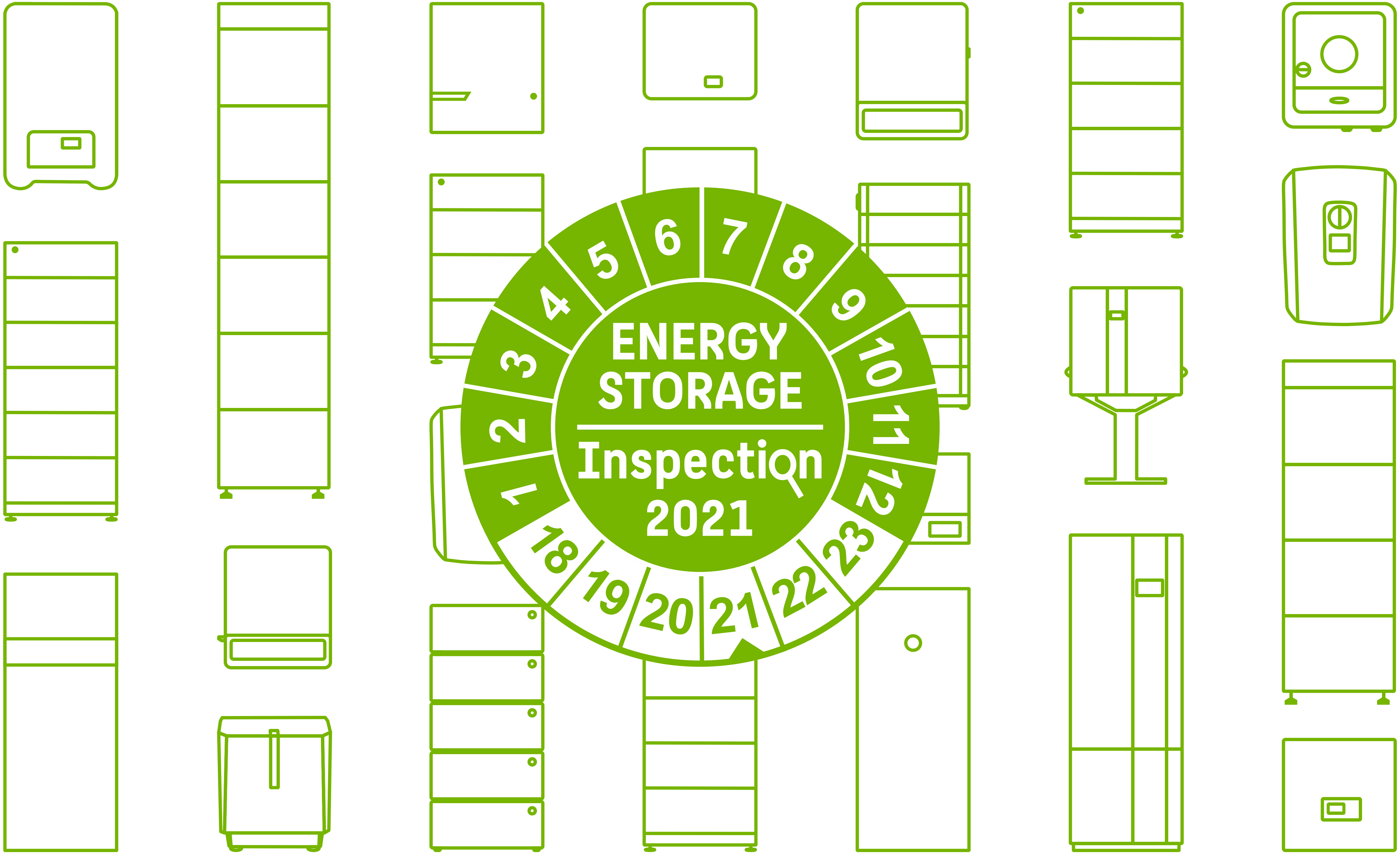
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# ENERGY STORAGE Inspection

Hochschule für Technik
und Wirtschaft Berlin

University of Applied Sciences

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

**Research study**

Energy Storage Inspection 2021

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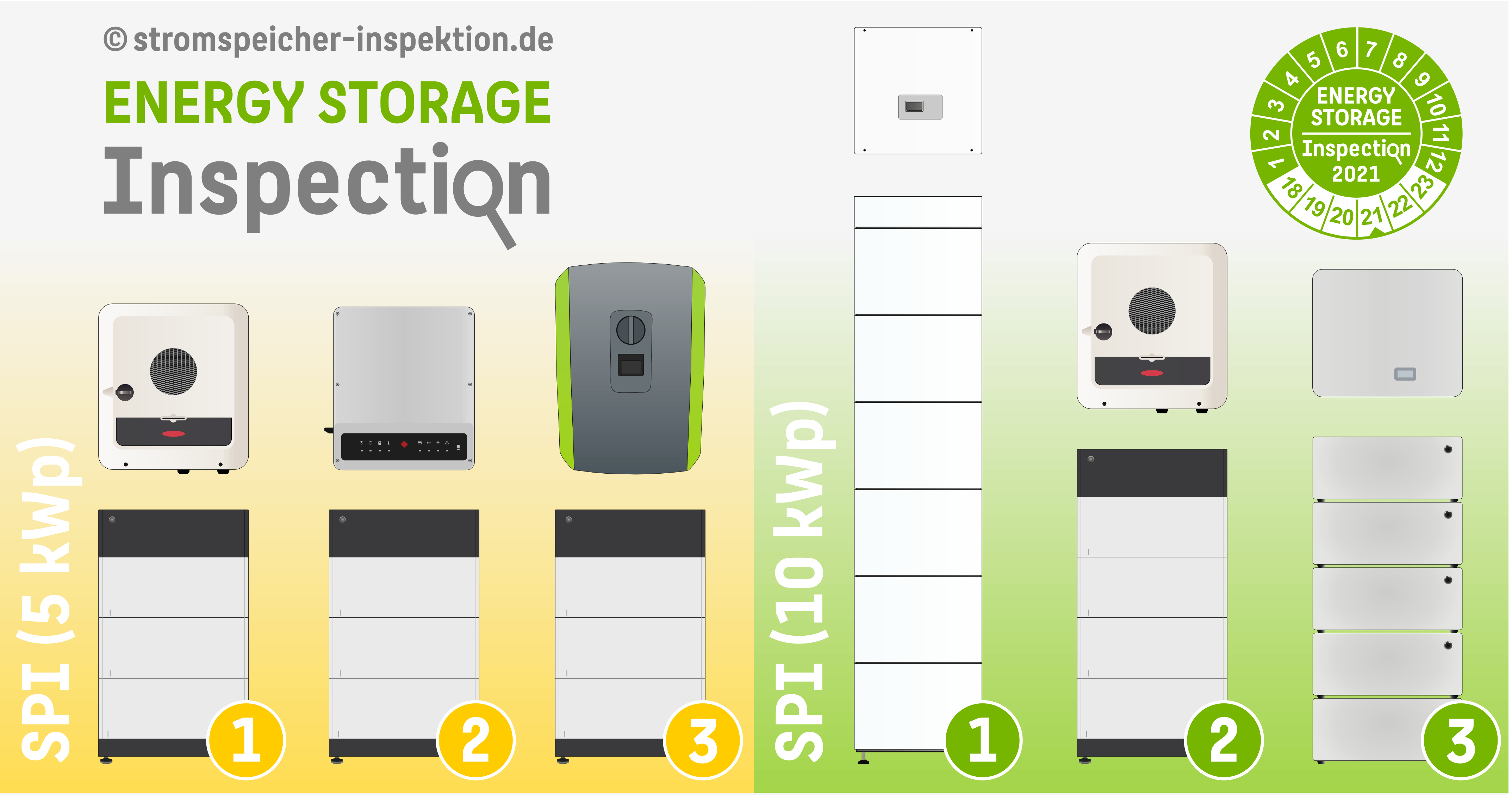
**Release**

Version 1.0 (June 2021)

**Website**

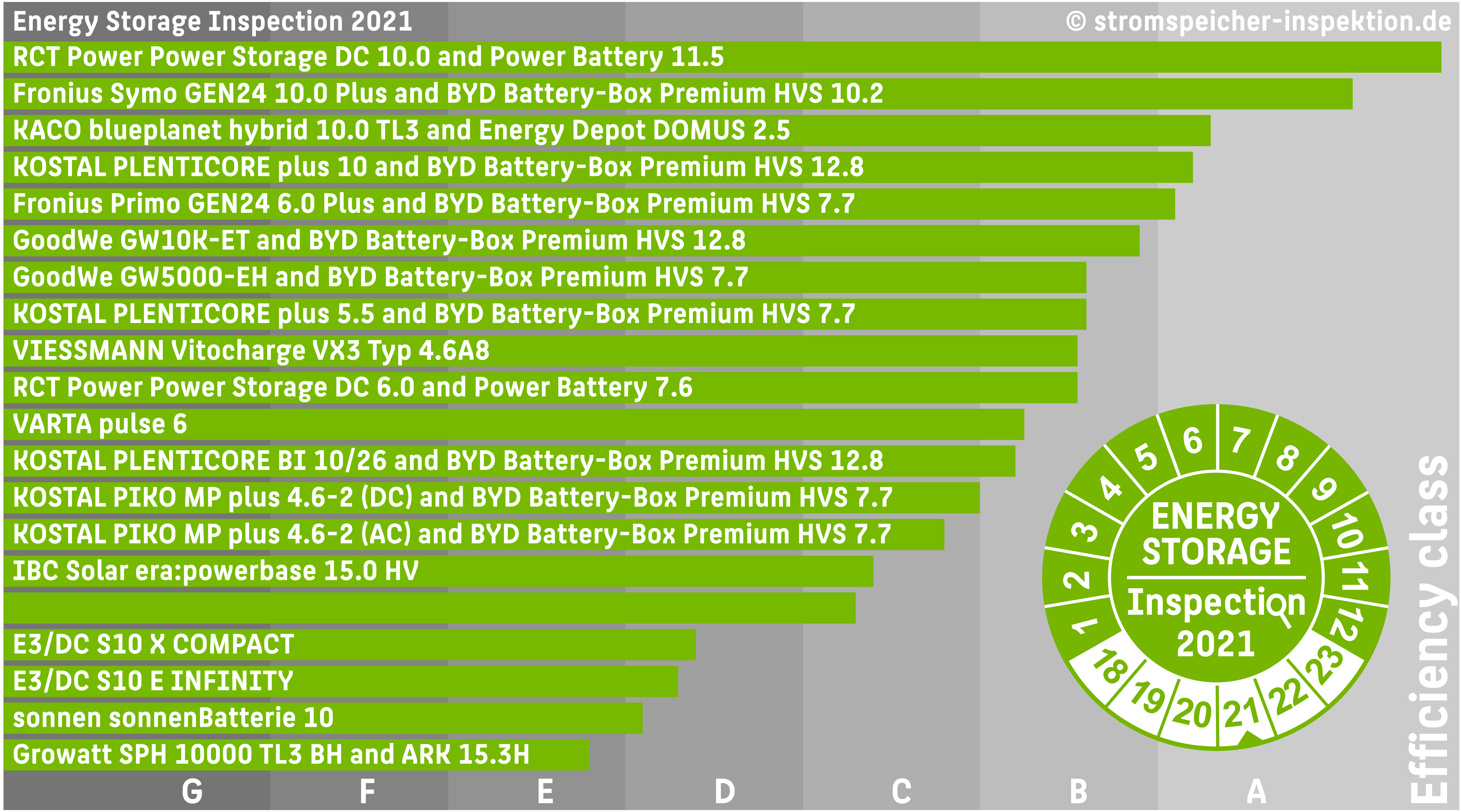
www.stromspeicher-inspektion.de

# Test winners of the Energy Storage Inspection 2021



Benchmarking of 20 battery storage systems with the System Performance Index (SPI)

# Ranking of the Energy Storage Inspection 2021

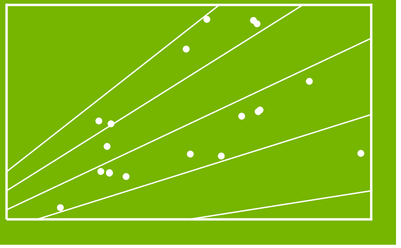


The efficiency classification is based on the System Performance Index SPI (5 kWp) and SPI (10 kWp).

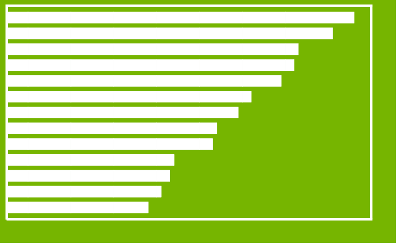
# Main topics of the Energy Storage Inspection 2021

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)

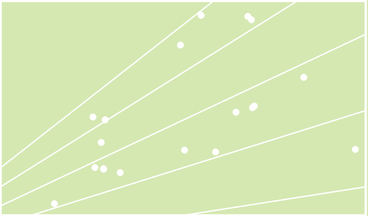


4 FAQ: Answers to questions concerning the sizing of PV-battery systems

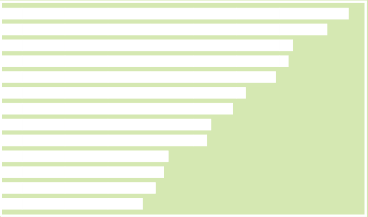
# Main topics of the Energy Storage Inspection 2021

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

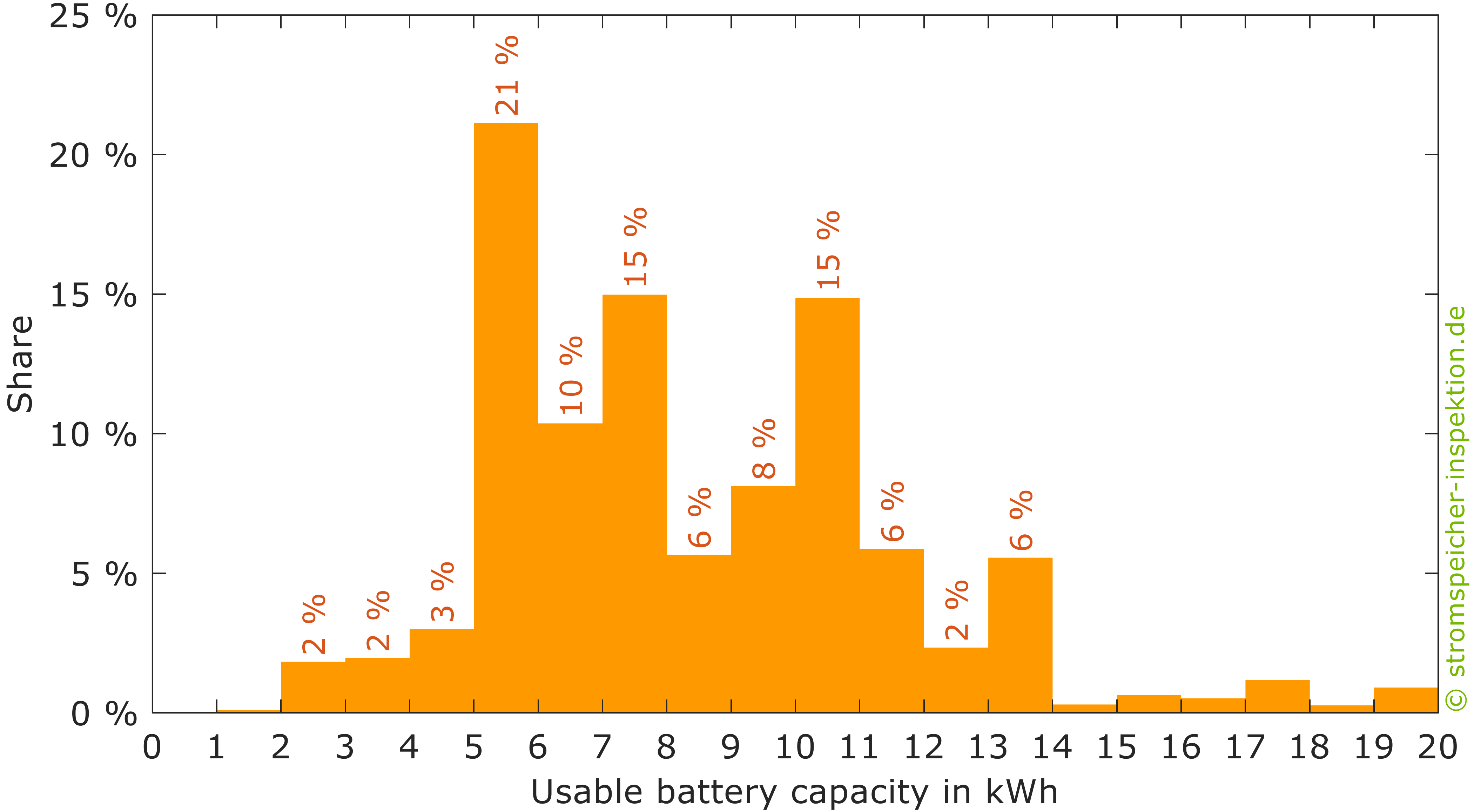


3 Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



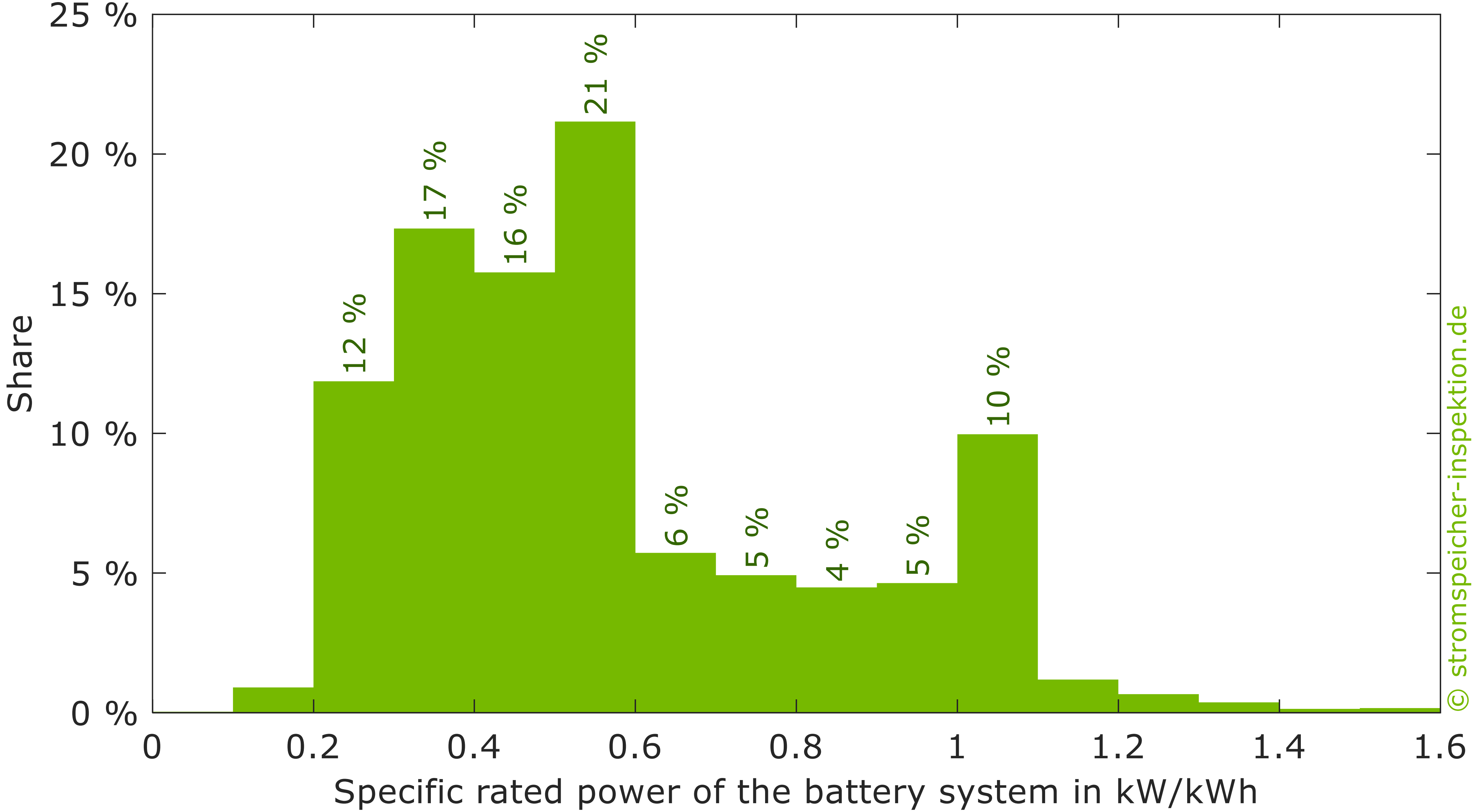
4 FAQ: Answers to questions concerning the sizing of PV-battery systems

# Usable battery capacity of the battery systems installed in 2020



Data: German core energy market data register, 82,479 systems with less than 20 kW and 20 kWh

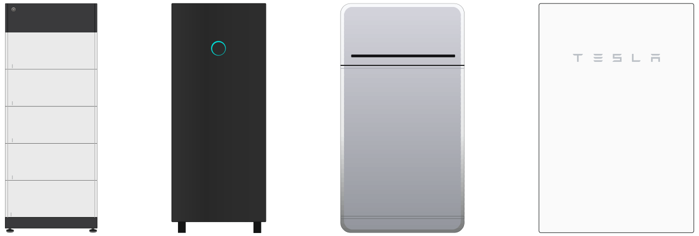
# Rated power of the battery systems installed in 2020



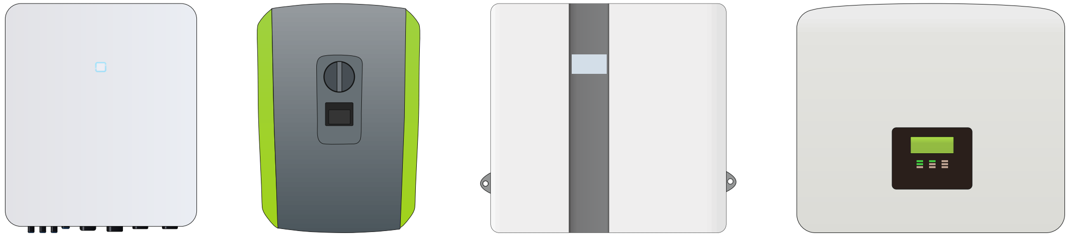
Data: German core energy market data register, 82,479 systems with less than 20 kW and 20 kWh

# Technology trends in the energy storage market

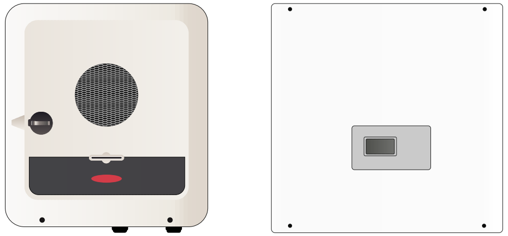
## #1 Larger battery systems



## #2 More powerful inverters

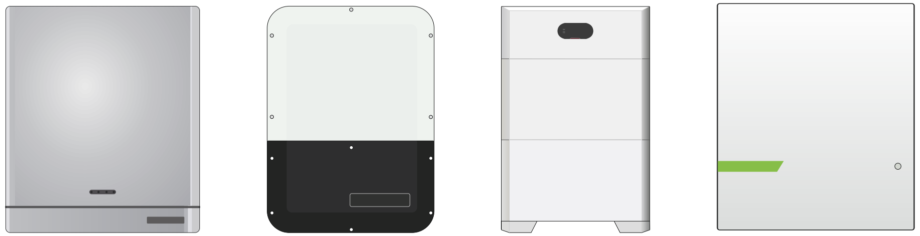


## #3 More efficient inverters

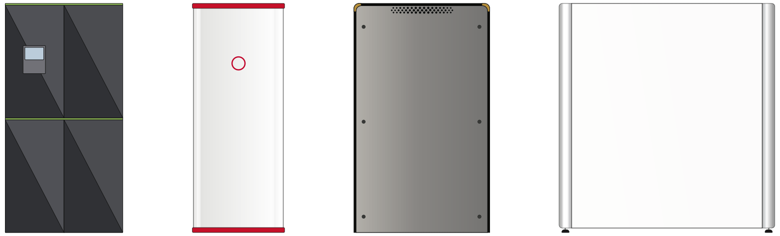


## #4 More hybrid inverters

## #5 More flexible system solutions



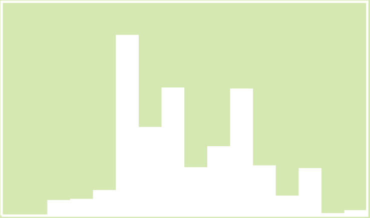
## #6 Diverse battery technologies



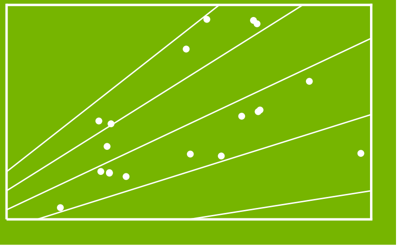
The examples of products were selected regardless of the participation of the manufacturers in the Energy Storage Inspection.

# Main topics of the Energy Storage Inspection 2021

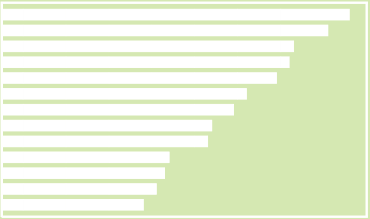
1. Analysis of the German market for residential PV-battery systems



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



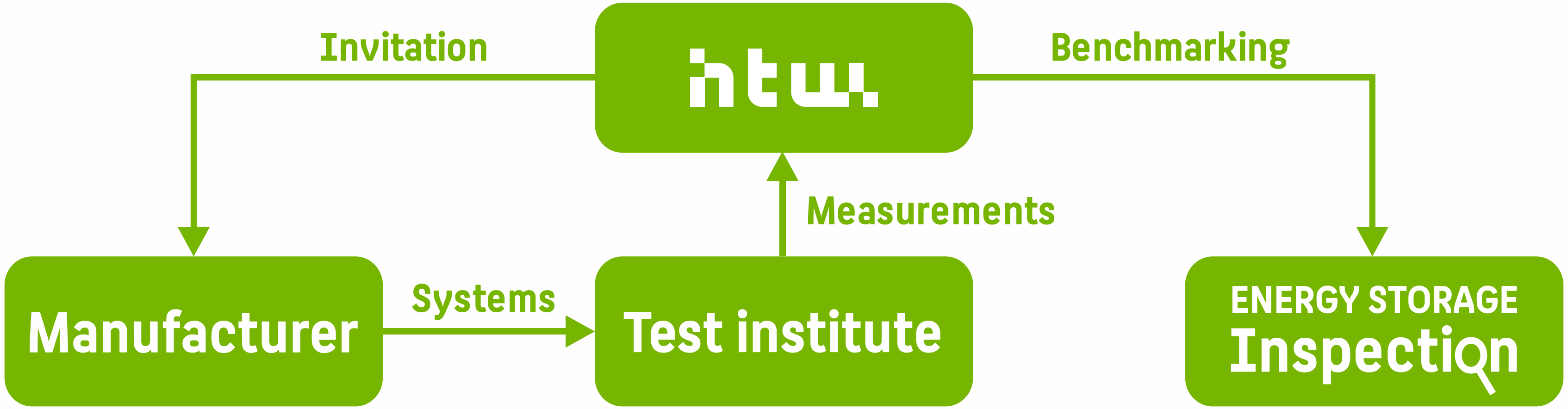
3. Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



4. FAQ: Answers to questions concerning the sizing of PV-battery systems

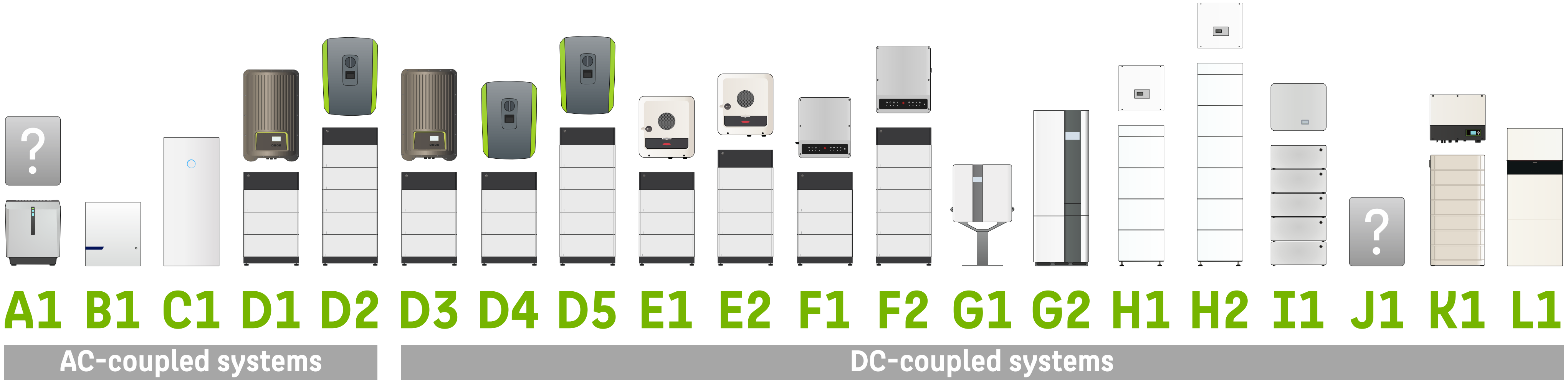
# Analysis of system properties according to the Efficiency Guideline

- All manufacturers of solar energy storage systems for residential buildings were invited to take part in the **Energy Storage Inspection 2021**.
- **15 manufactures** participated in the comparison of the storage systems with measurement data of **20 systems**.
- Laboratory tests were conducted by **independent testing institutes** in accordance with the "Efficiency Guideline for PV Storage Systems" (version 2.0).
- Each analyzed system has been assigned to a **system abbreviation** (e.g. A1).
- 2 manufacturers chose to **participate anonymously**.

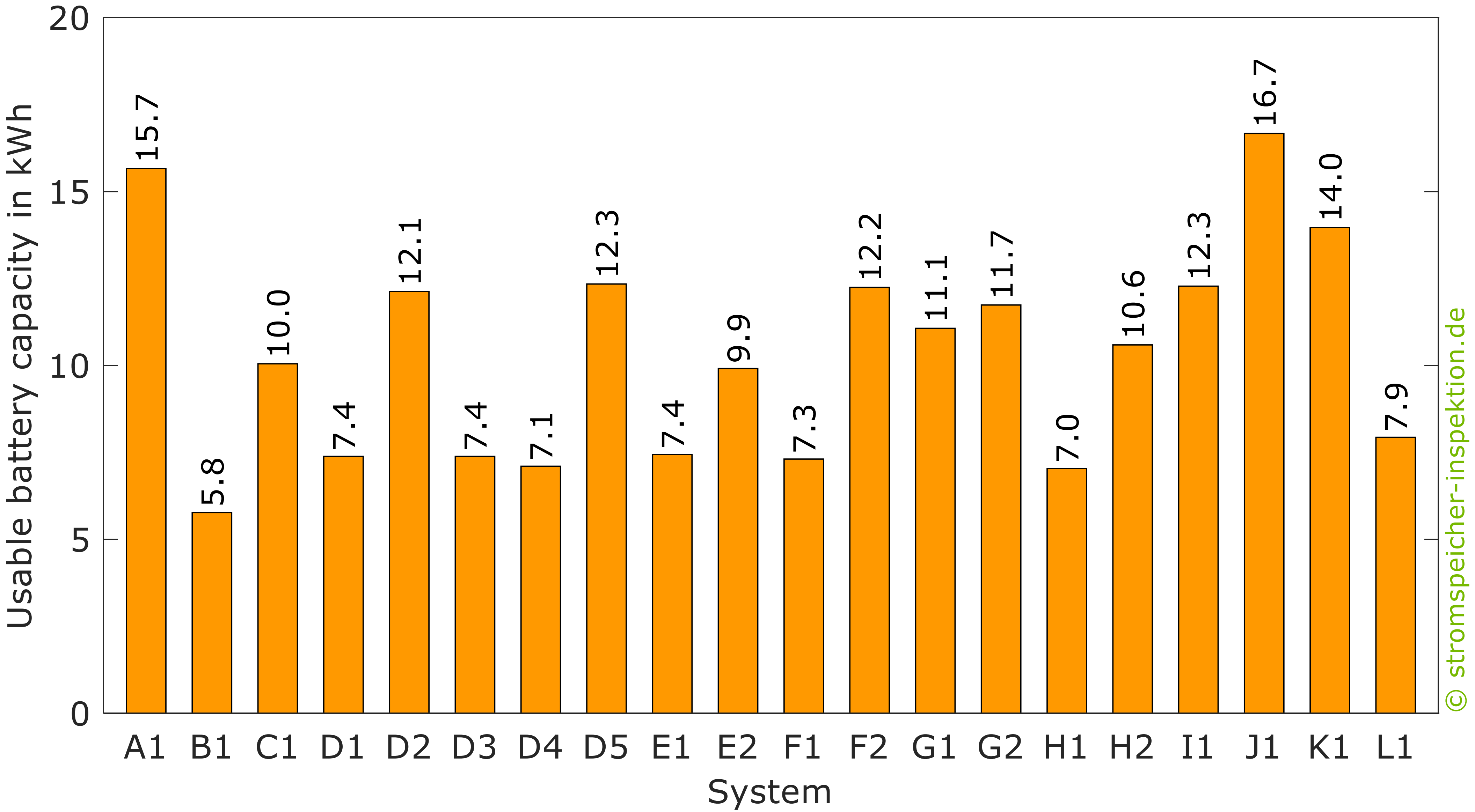


# Analyzed systems of the Energy Storage Inspection 2021

| | |
|---|---|
| **A1** | IBC Solar era:powerbase 15.0 HV with a compatible battery inverter |
| **B1** | VARTA pulse 6 |
| **C1** | sonnen sonnenBatterie 10 |
| **D1** | KOSTAL PIKO MP plus 4.6-2 (AC) and BYD Battery-Box Premium HVS 7.7 |
| **D2** | KOSTAL PLENTICORE BI 10/26 and BYD Battery-Box Premium HVS 12.8 |
| **D3** | KOSTAL PIKO MP plus 4.6-2 (DC) and BYD Battery-Box Premium HVS 7.7 |
| **D4** | KOSTAL PLENTICORE plus 5.5 and BYD Battery-Box Premium HVS 7.7 |
| **D5** | KOSTAL PLENTICORE plus 10 and BYD Battery-Box Premium HVS 12.8 |
| **E1** | Fronius Primo GEN24 6.0 Plus and BYD Battery-Box Premium HVS 7.7 |
| **E2** | Fronius Symo GEN24 10.0 Plus and BYD Battery-Box Premium HVS 10.2 |
| **F1** | GoodWe GW5000-EH and BYD Battery-Box Premium HVS 7.7 |
| **F2** | GoodWe GW10K-ET and BYD Battery-Box Premium HVS 12.8 |
| **G1** | E3/DC S10 E INFINITY |
| **G2** | E3/DC S10 X COMPACT |
| **H1** | RCT Power Power Storage DC 6.0 and Power Battery 7.6 |
| **H2** | RCT Power Power Storage DC 10.0 and Power Battery 11.5 |
| **I1** | KACO blueplanet hybrid 10.0 TL3 and Energy Depot DOMUS 2.5 |
| **J1** | DC-coupled system from a manufacturer participating anonymously |
| **K1** | Growatt SPH 10000 TL3 BH and ARK 15.3H |
| **L1** | VIESSMANN Vitocharge VX3 Typ 4.6A8 |



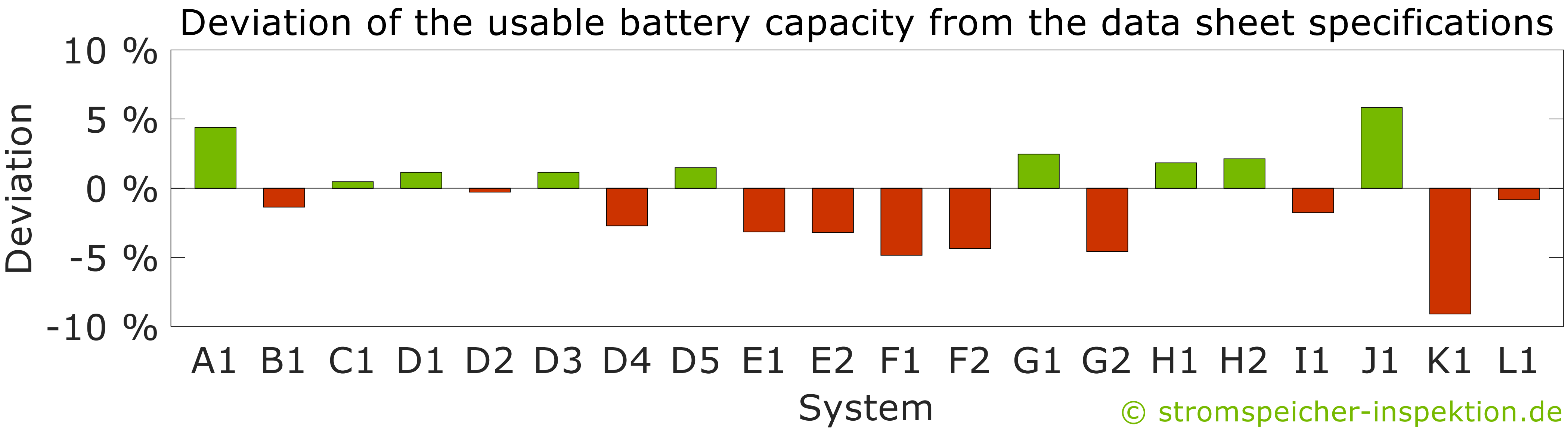
# Usable battery capacity of the analyzed systems



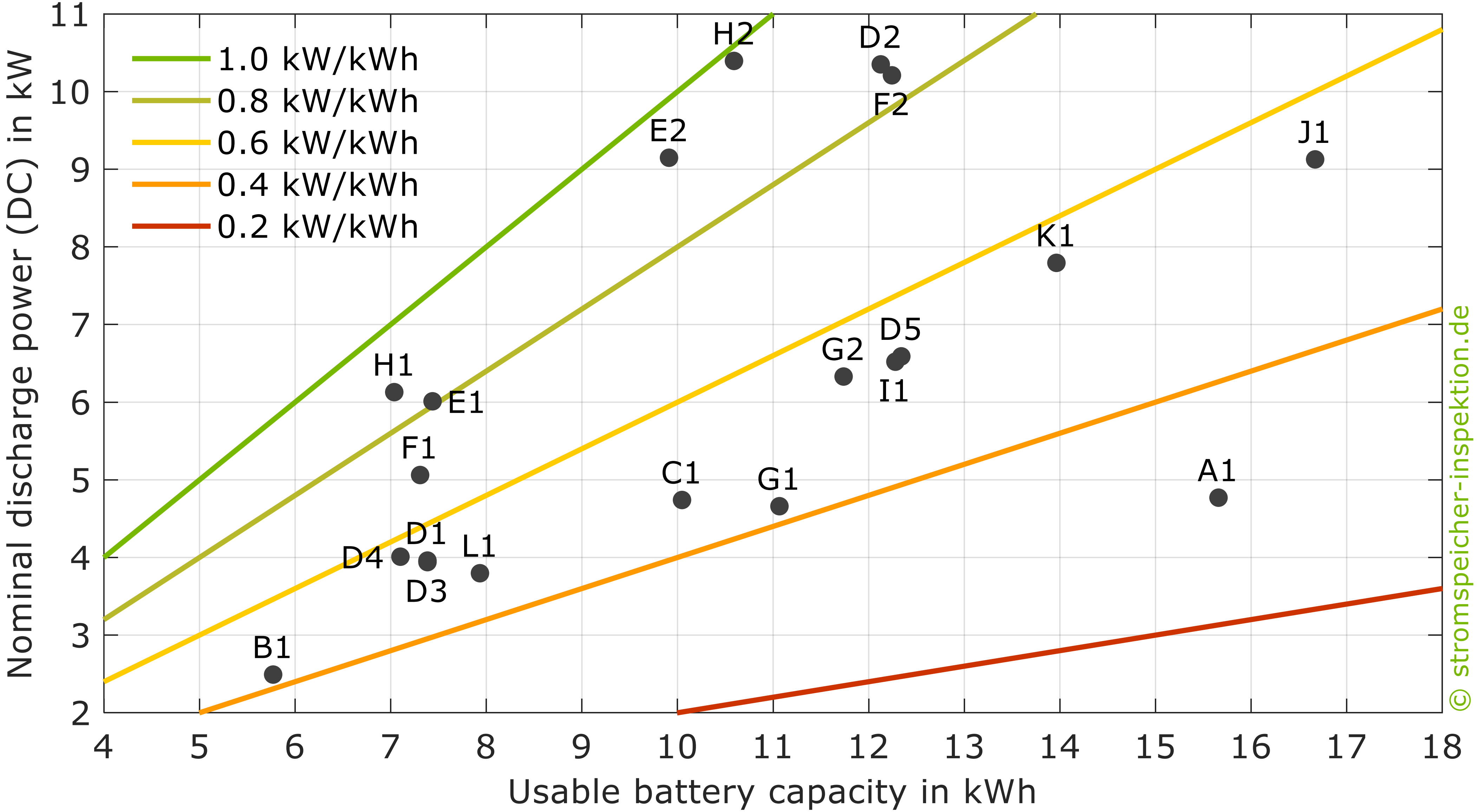
H1 and H2: Due to a temperature-induced derating, the test could not be run at nominal power.

# Comparison of data sheet values and laboratory measurements

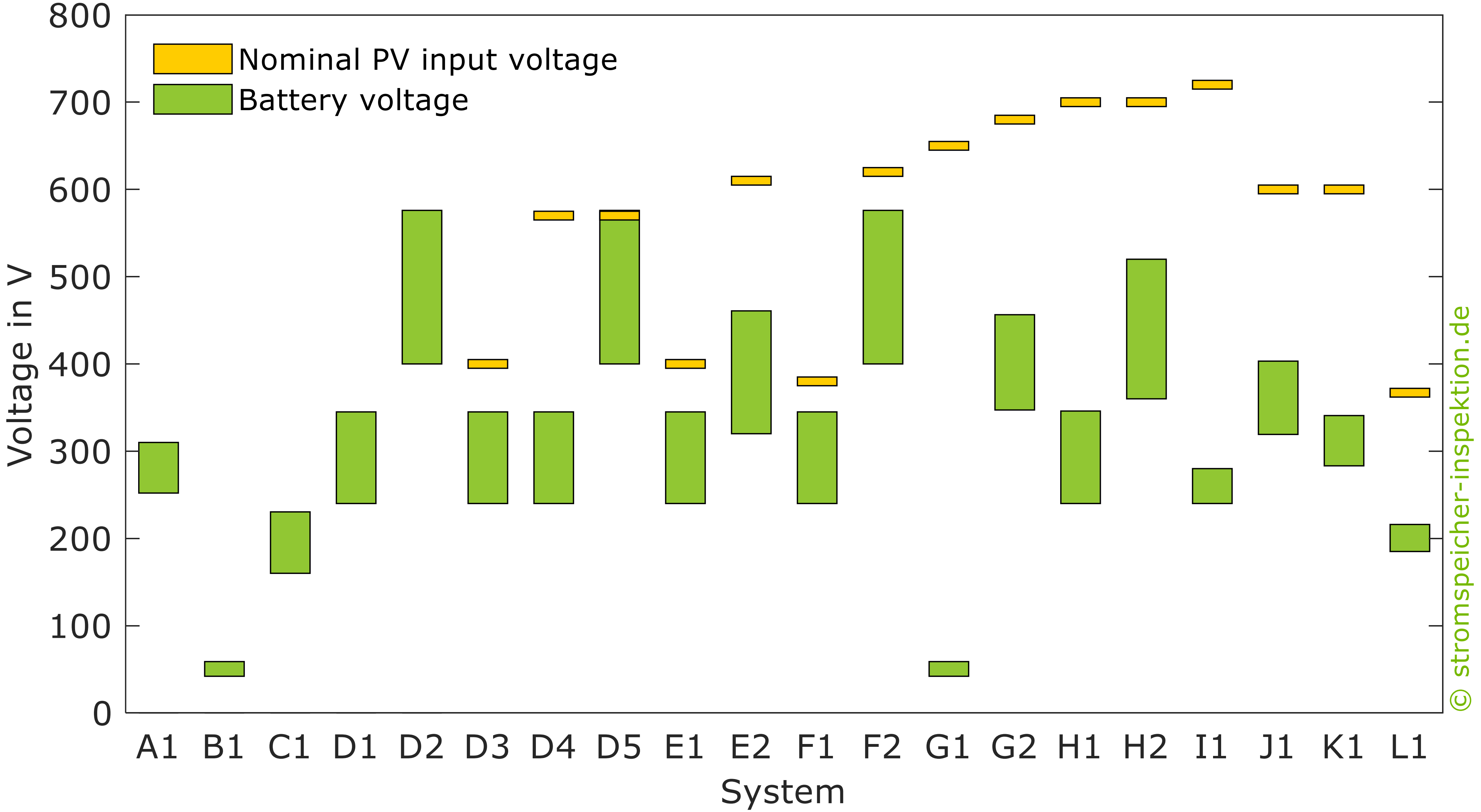
- For half of the analyzed systems **lower usable battery capacities** were measured in the laboratory test compared with the data sheet.
- The specified depth of discharge for **protection against deep discharge** is often the reason why the measured values are lower than the data sheet values.
- Compared with the Energy Storage Inspection 2020 the **differences between the measured values and data sheet values** are significantly smaller.



# Nominal discharge power of the analyzed systems

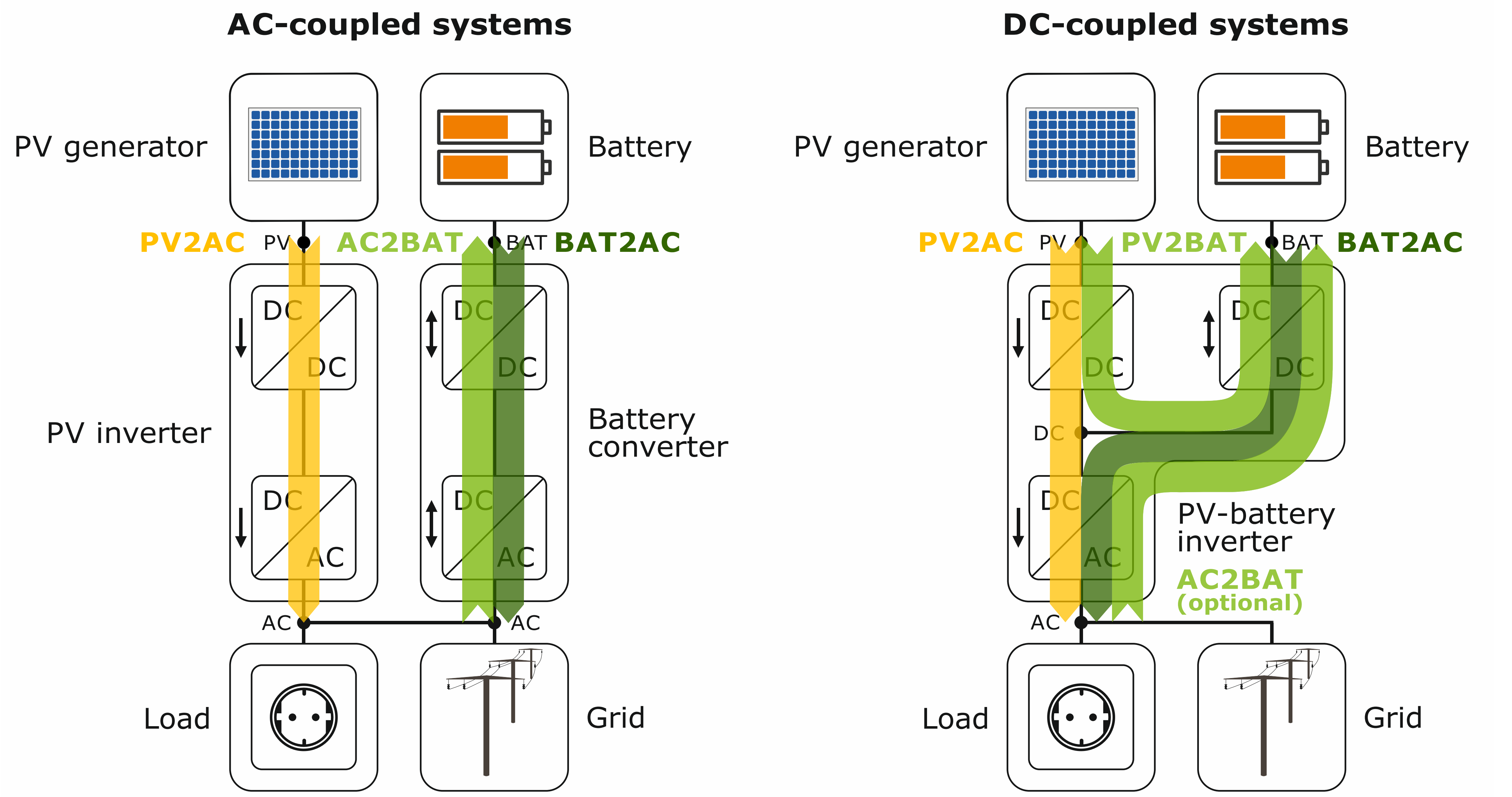


# Voltage level of the analyzed systems

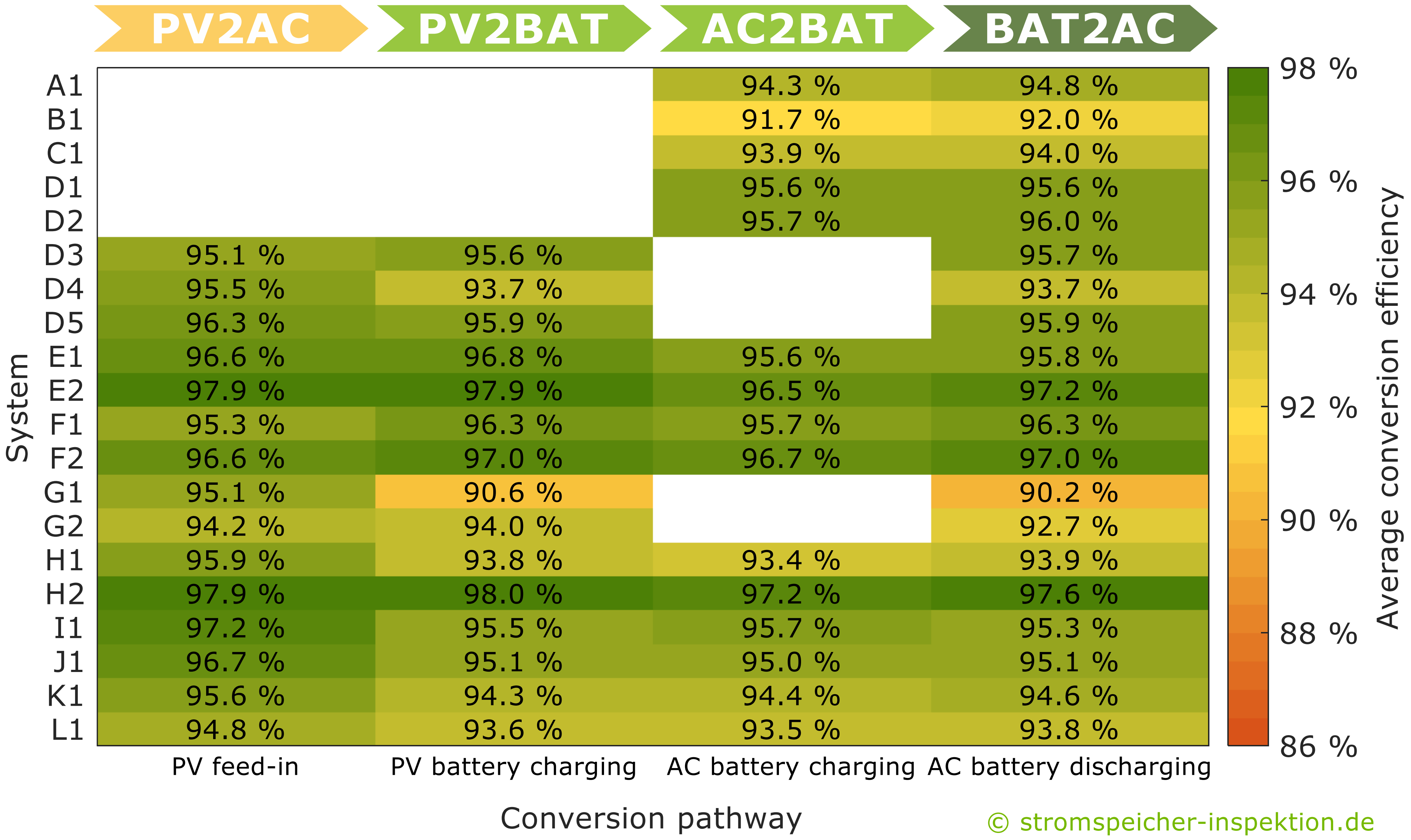


No information of the nominal PV input voltage for the AC-coupled systems A1 to D2.

# Energy conversion pathways of the different system topologies



# Average efficiency of the different energy conversion pathways



| | PV2AC | PV2BAT | AC2BAT | BAT2AC |
|---|---|---|---|---|
| System | PV feed-in | PV battery charging | AC battery charging | AC battery discharging |
| A1 | | | 94.3 % | 94.8 % |
| B1 | | | 91.7 % | 92.0 % |
| C1 | | | 93.9 % | 94.0 % |
| D1 | | | 95.6 % | 95.6 % |
| D2 | | | 95.7 % | 96.0 % |
| D3 | 95.1 % | 95.6 % | | 95.7 % |
| D4 | 95.5 % | 93.7 % | | 93.7 % |
| D5 | 96.3 % | 95.9 % | | 95.9 % |
| E1 | 96.6 % | 96.8 % | 95.6 % | 95.8 % |
| E2 | 97.9 % | 97.9 % | 96.5 % | 97.2 % |
| F1 | 95.3 % | 96.3 % | 95.7 % | 96.3 % |
| F2 | 96.6 % | 97.0 % | 96.7 % | 97.0 % |
| G1 | 95.1 % | 90.6 % | | 90.2 % |
| G2 | 94.2 % | 94.0 % | | 92.7 % |
| H1 | 95.9 % | 93.8 % | 93.4 % | 93.9 % |
| H2 | 97.9 % | 98.0 % | 97.2 % | 97.6 % |
| I1 | 97.2 % | 95.5 % | 95.7 % | 95.3 % |
| J1 | 96.7 % | 95.1 % | 95.0 % | 95.1 % |
| K1 | 95.6 % | 94.3 % | 94.4 % | 94.6 % |
| L1 | 94.8 % | 93.6 % | 93.5 % | 93.8 % |

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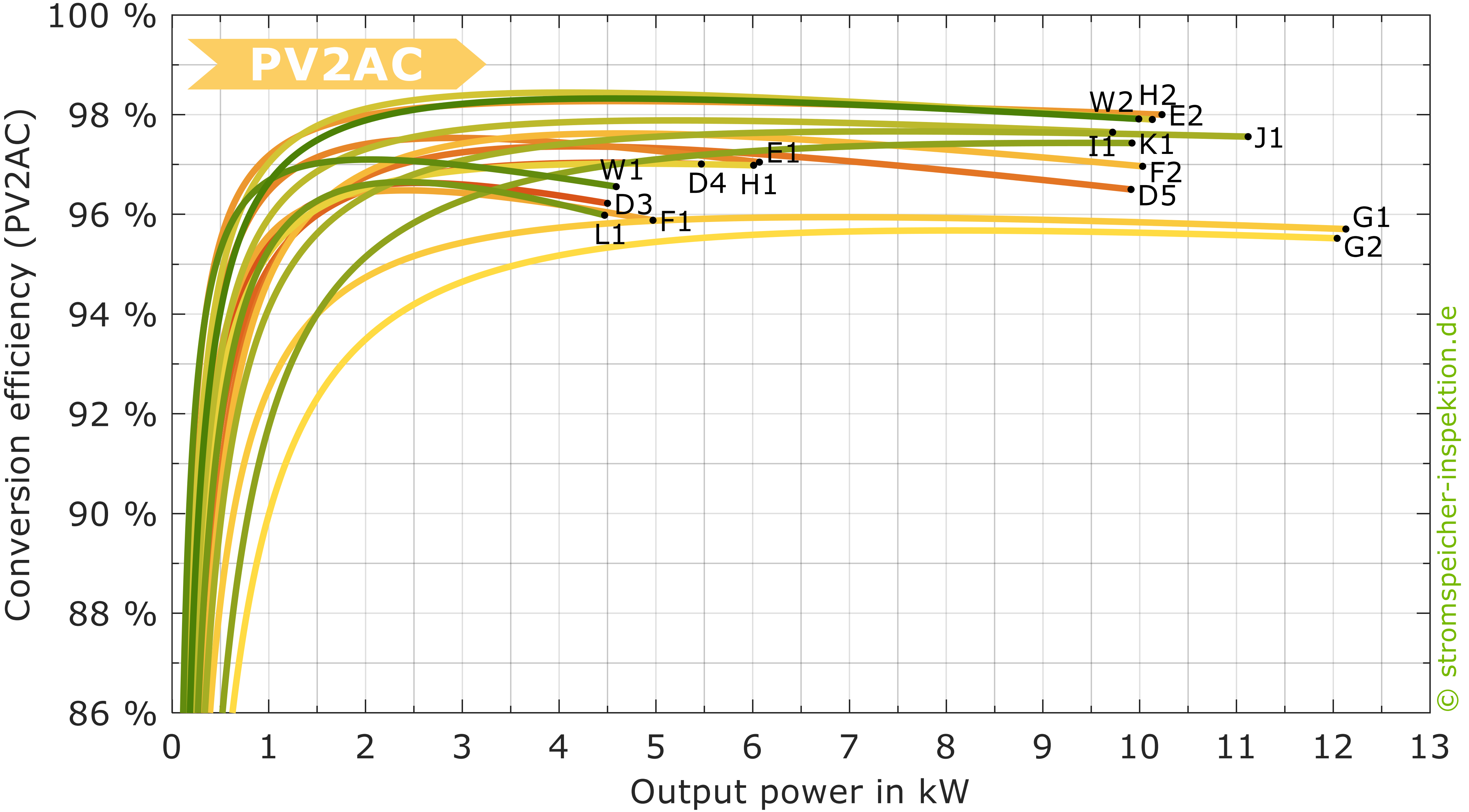
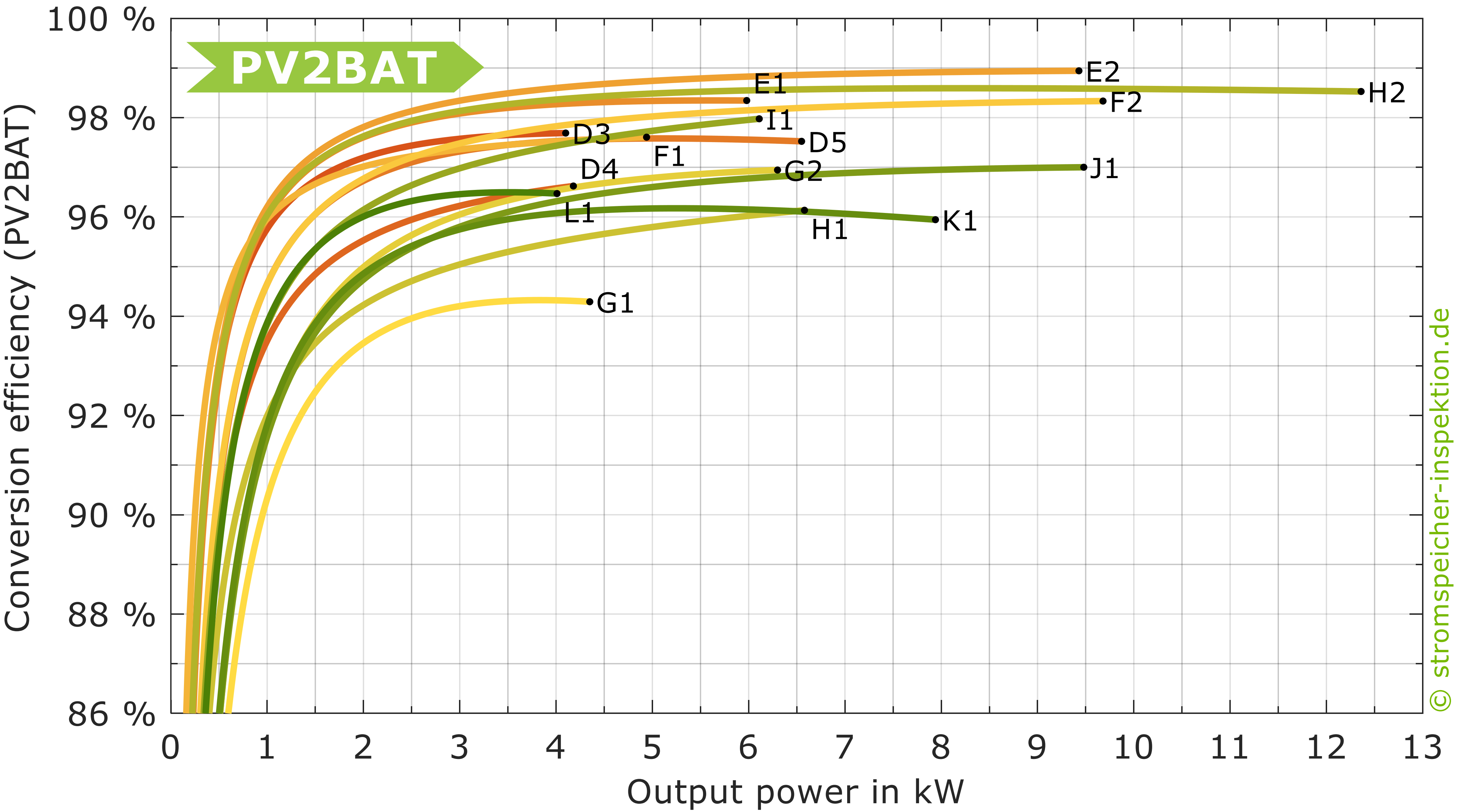
Average pathway efficiencies according to the “Efficiency Guideline for PV Storage Systems” 2.0

# PV feed-in pathway efficiency

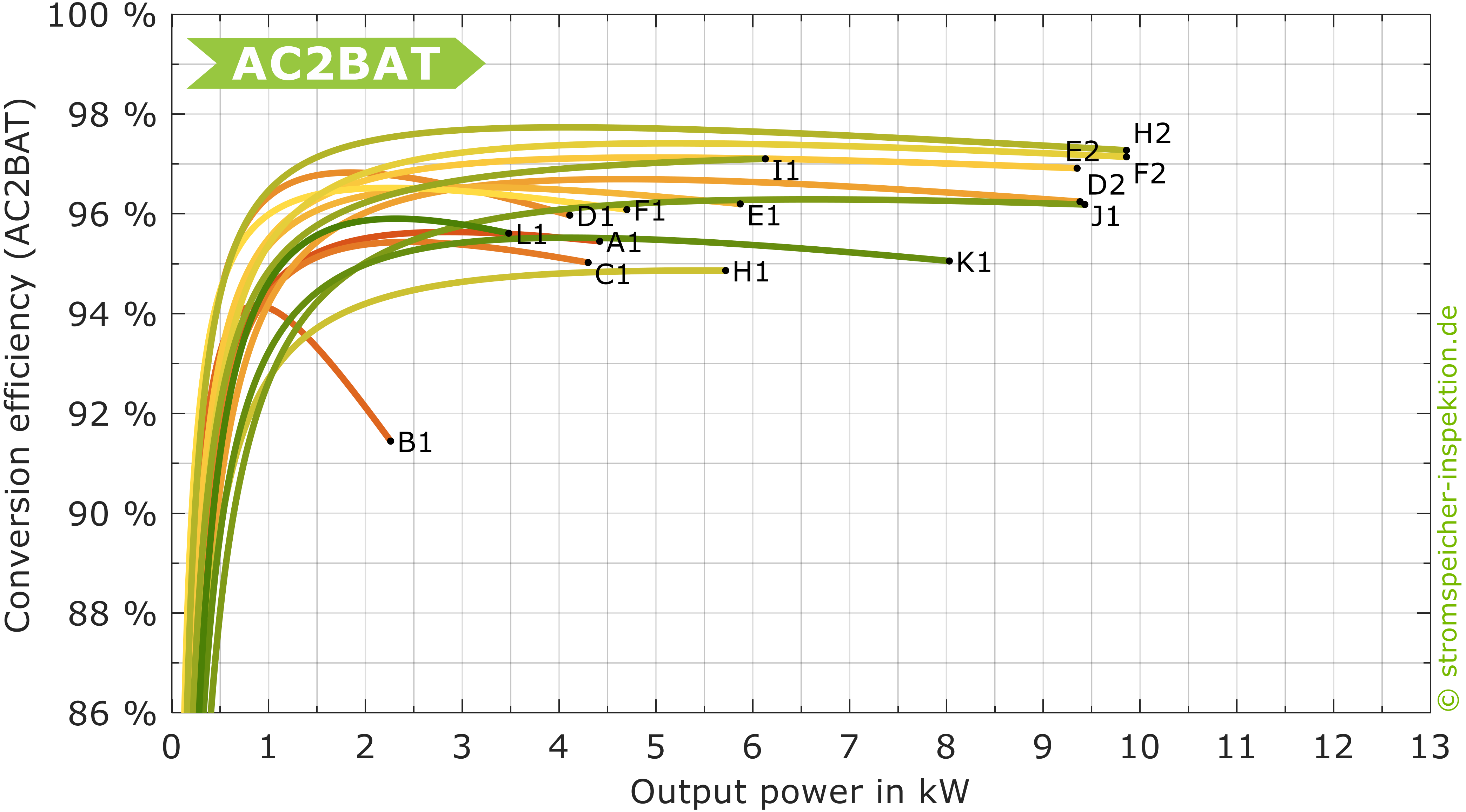


W1 and W2: PV inverter used for assessing the AC-coupled systems with SPI (5 kWp) and SPI (10 kWp).

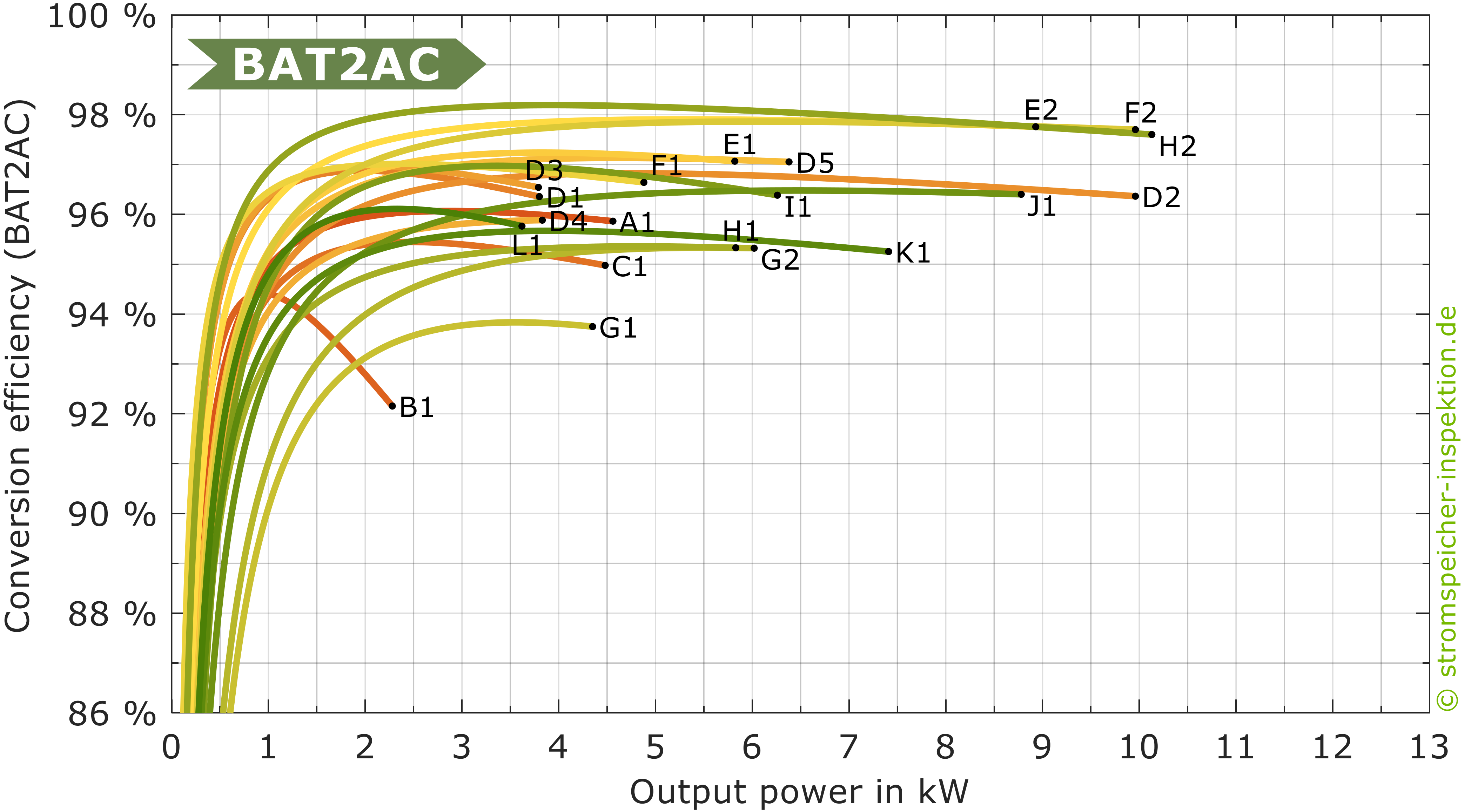
# PV battery charging pathway efficiency



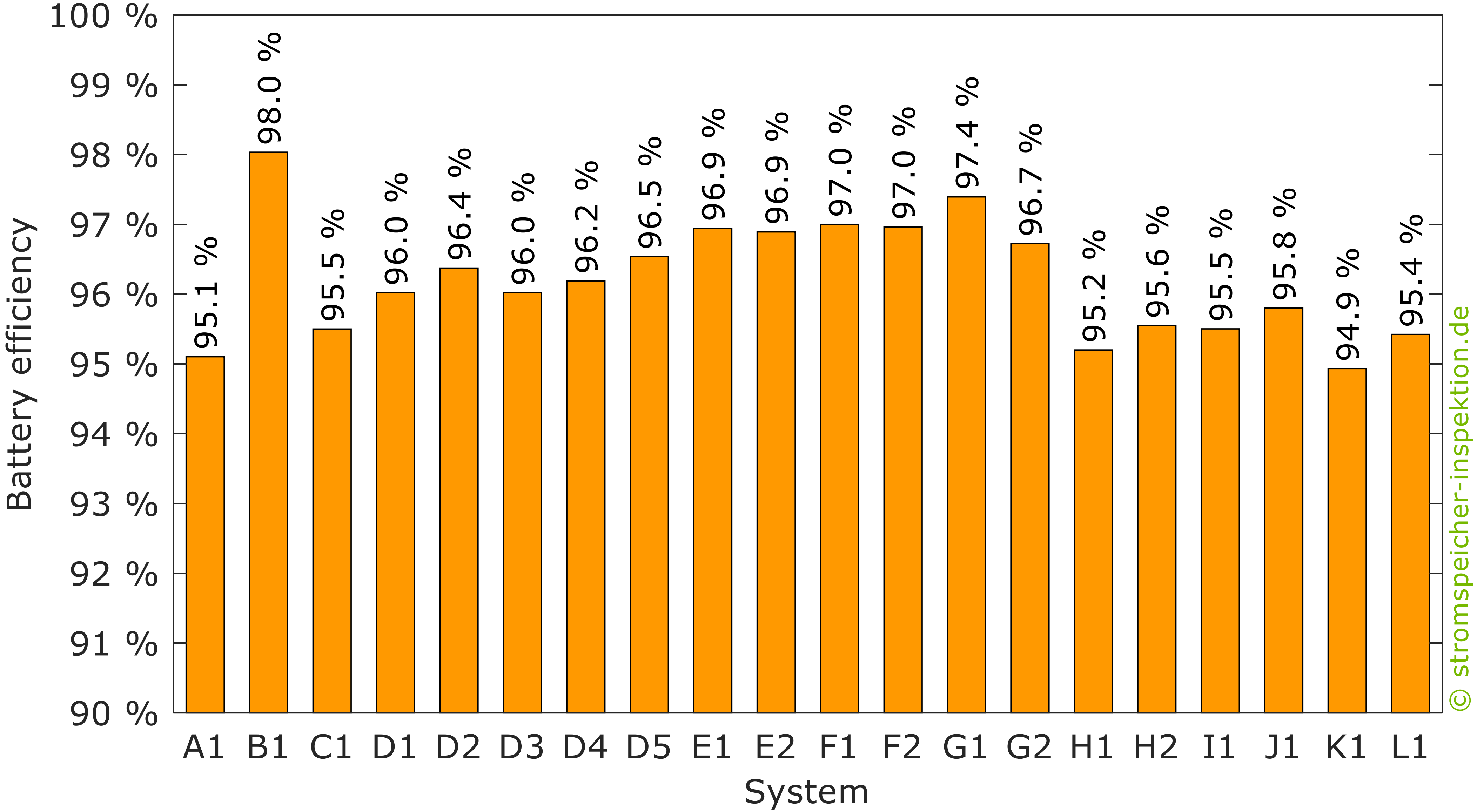
# AC battery charging pathway efficiency



# AC battery discharging pathway efficiency

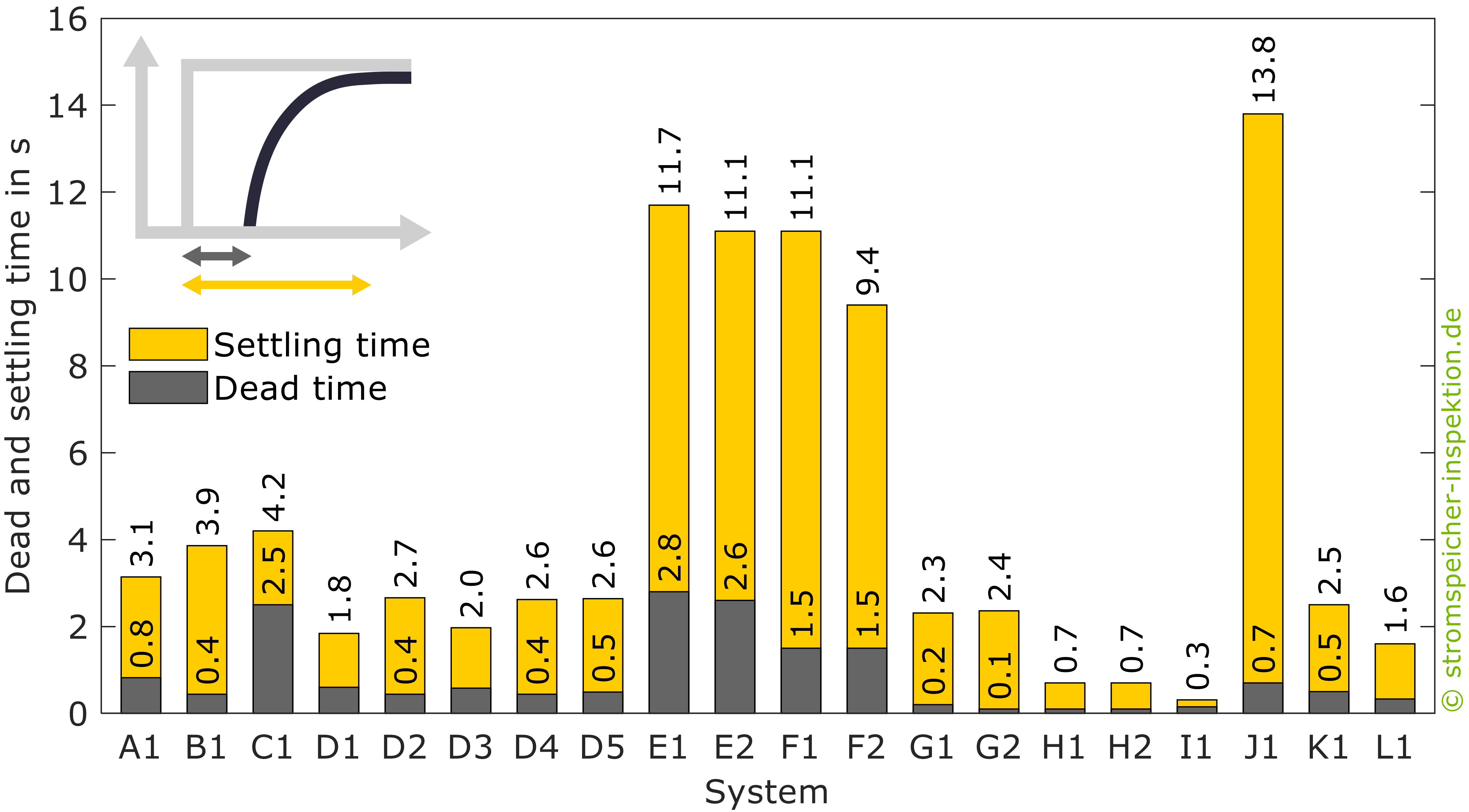


# Average battery efficiency

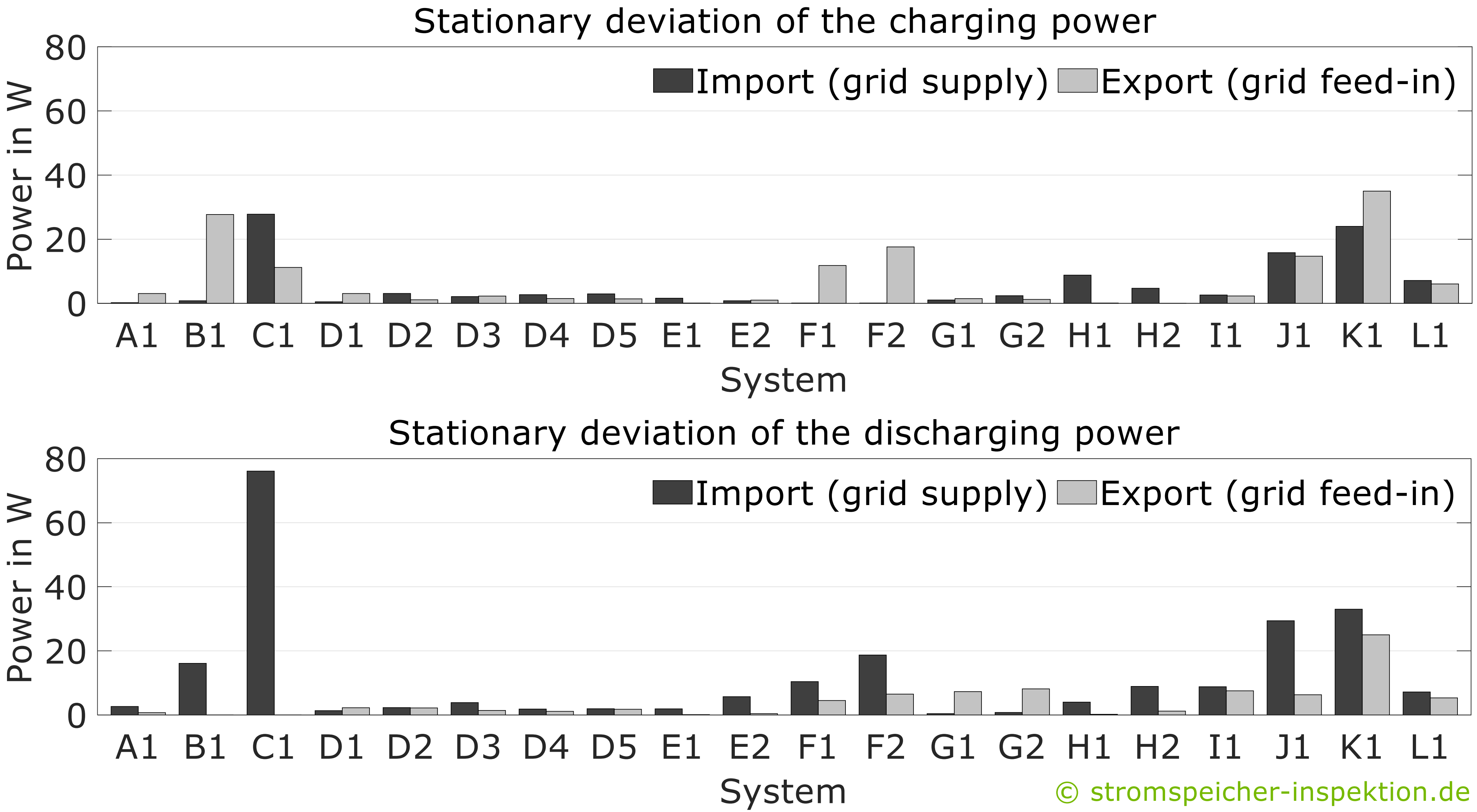


H1 and H2: Due to a temperature-induced derating, the test could not be run at nominal power.

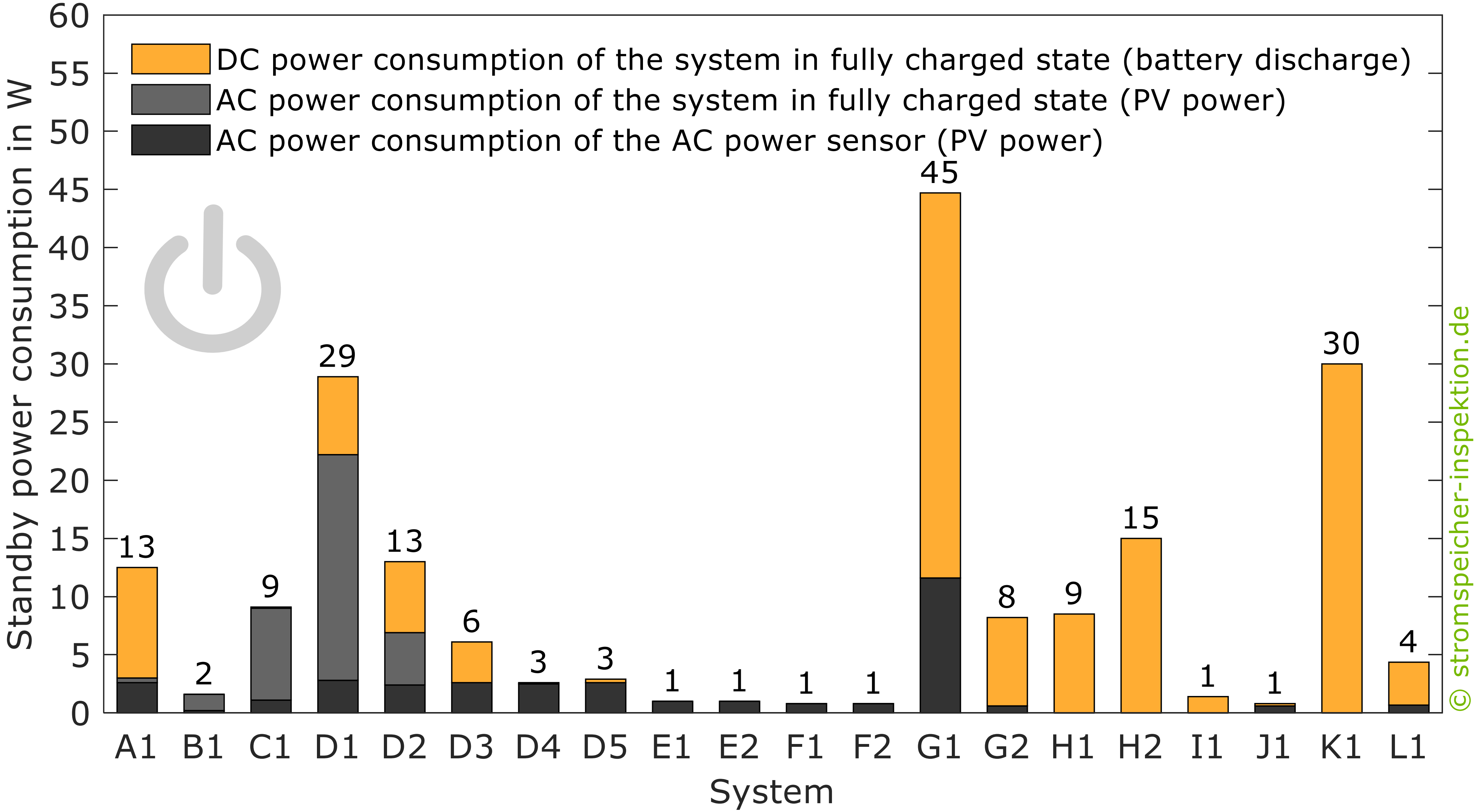
# Dynamic control deviations



# Stationary control deviations

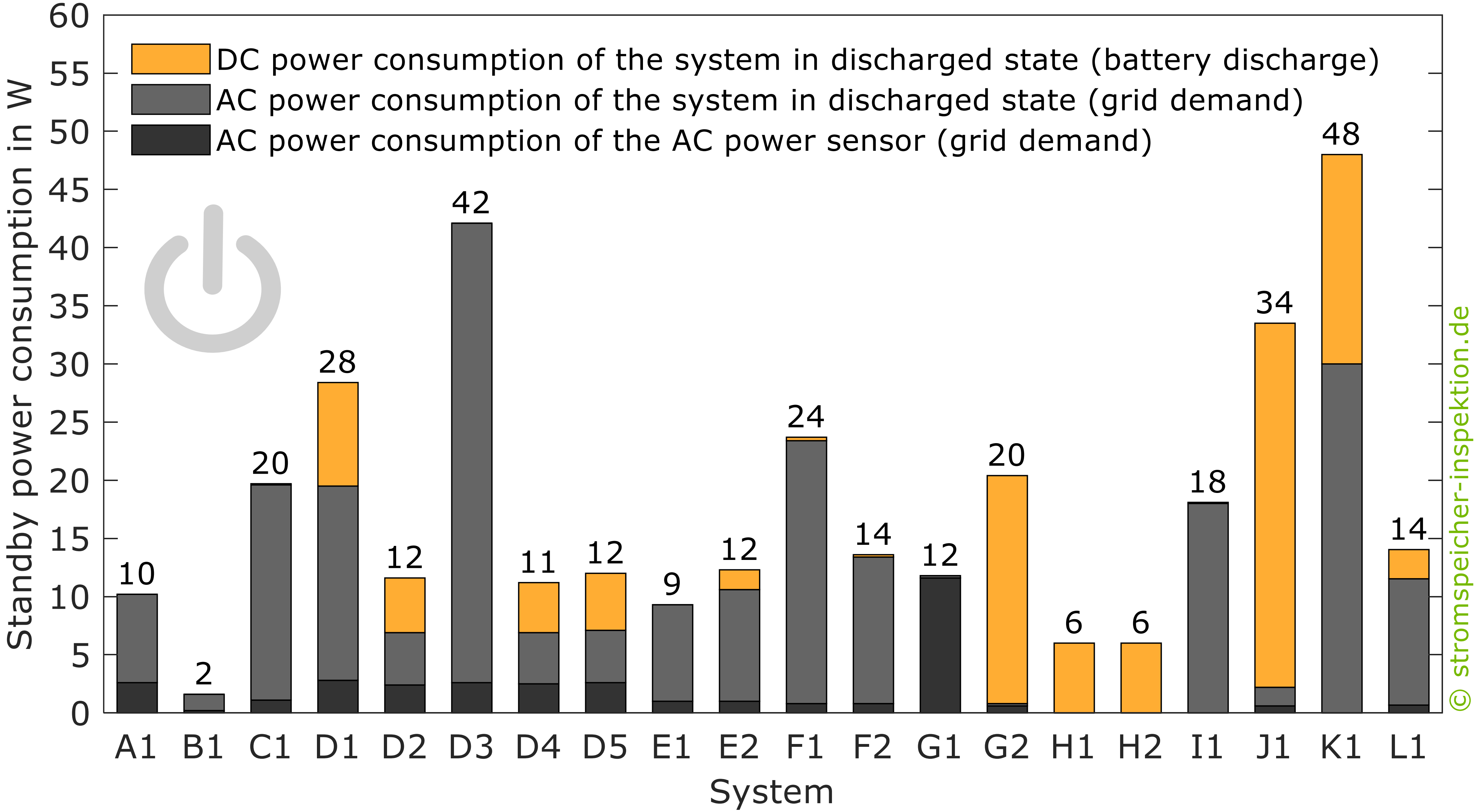


# Standby power consumption of the systems in fully charged state



System G1 includes a separate power supply whose power consumption is assigned to the AC sensor consumption.

# Standby power consumption of the systems in discharged state



System G1 includes a separate power supply whose power consumption is assigned to the AC sensor consumption.

# Range of the most important efficiency characteristics

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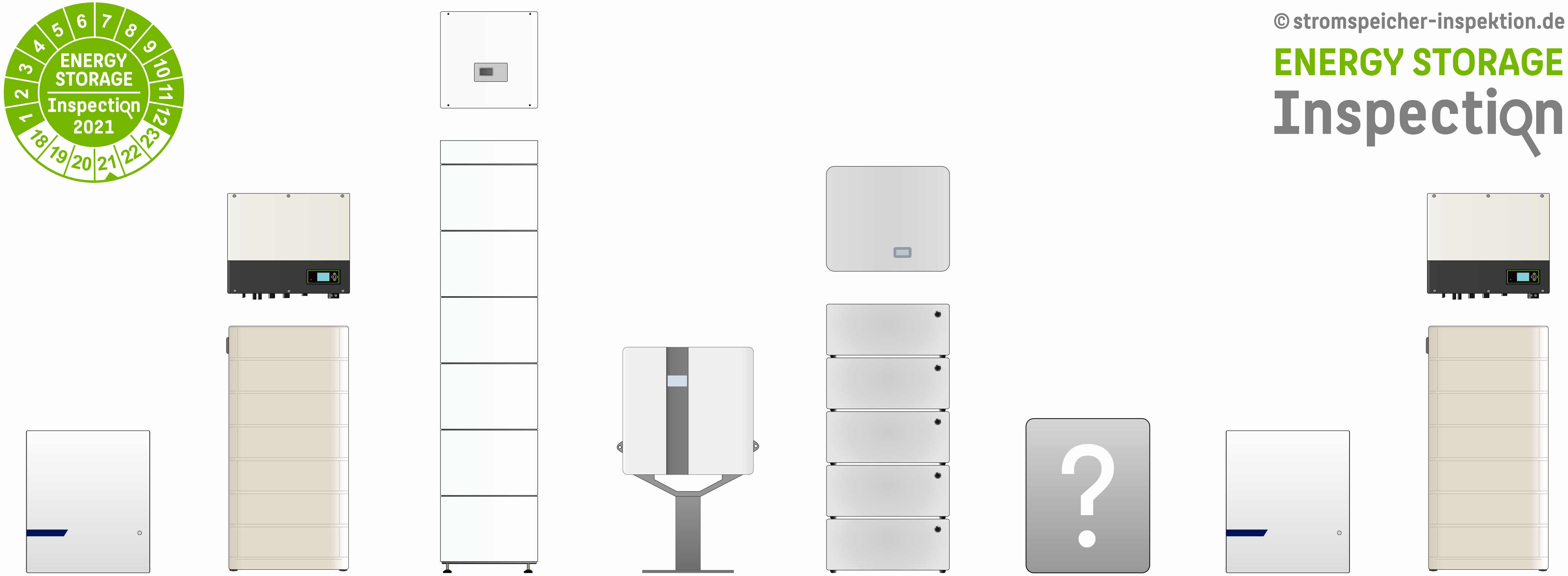
ENERGY STORAGE Inspection



98.0 % 94.9 %

**Battery efficiency**

97.6 % 90.2 %

**Inverter efficiency**

0.3 s 13.8 s

**Settling time**

2 W 48 W

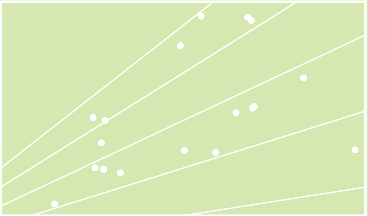
**Standby consumption**

Inverter efficiency: average efficiency in discharge mode, standby consumption: consumption when the battery is discharged.

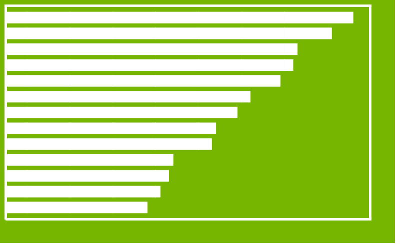
# Main topics of the Energy Storage Inspection 2021

**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



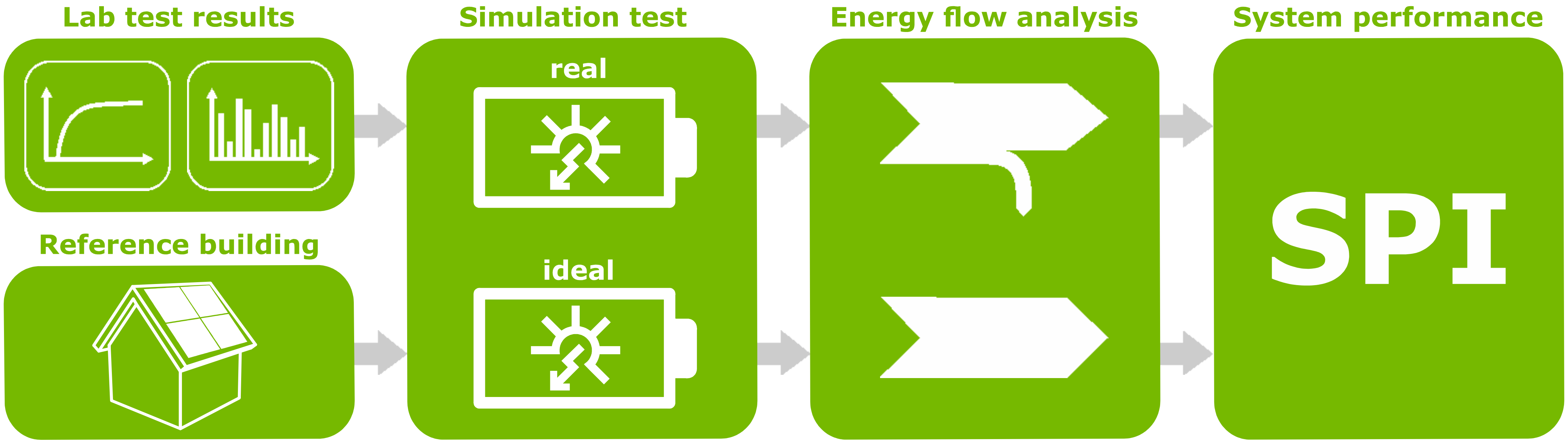
**3** Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



**4** FAQ: Answers to questions concerning the sizing of PV-battery systems

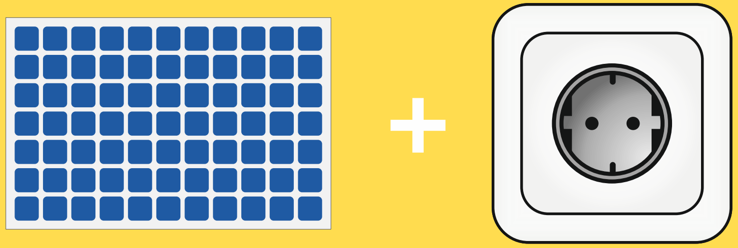
# Methodology of the simulation-based benchmarking

- **Simulation of the operational behavior** of the PV-battery systems in identical framework conditions 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 kWp) or SMA Sunny Tripower 10.0 (10 kWp).



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

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

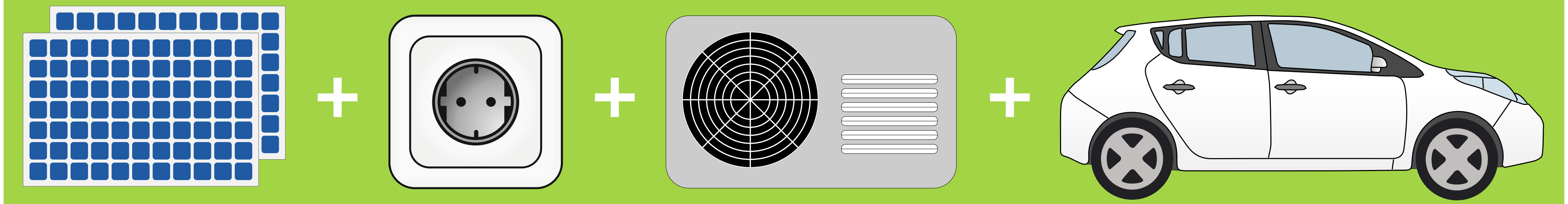


PV system
(5 kWp)

+

Appliances
(5010 kWh/a)

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



PV system
(10 kWp)

+

Appliances
(5010 kWh/a)

+

Heat pump
(2664 kWh/a)

+

Electric vehicle
(1690 kWh/a)

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

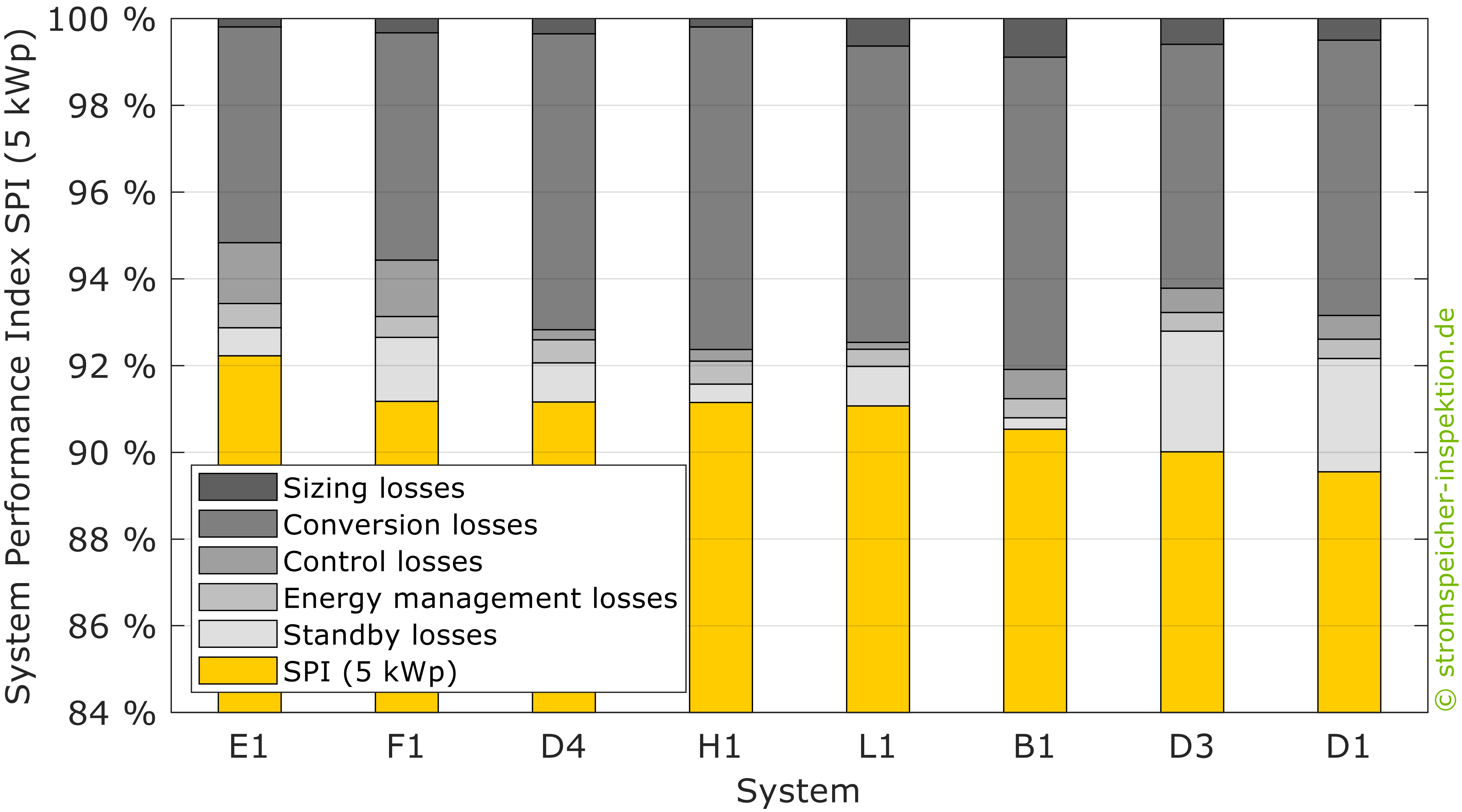
# Assignment of the systems to the reference cases

- Depending on the size of the **power electronics** and **battery storage**, the efficiency rating with the **SPI (5 kWp)** or **SPI (10 kWp)** is appropriate.
- Only systems with usable battery capacities smaller than **8.0 kWh** were rated with the SPI (5 kWp).
- A usable battery capacity smaller than **16.0 kWh** was required for a rating with the SPI (10 kWp).
- 8 systems were rated with the SPI (5 kWp) and 13 systems were rated with the SPI (10 kWp). The AC-coupled system B1 were evaluated with both indicators.

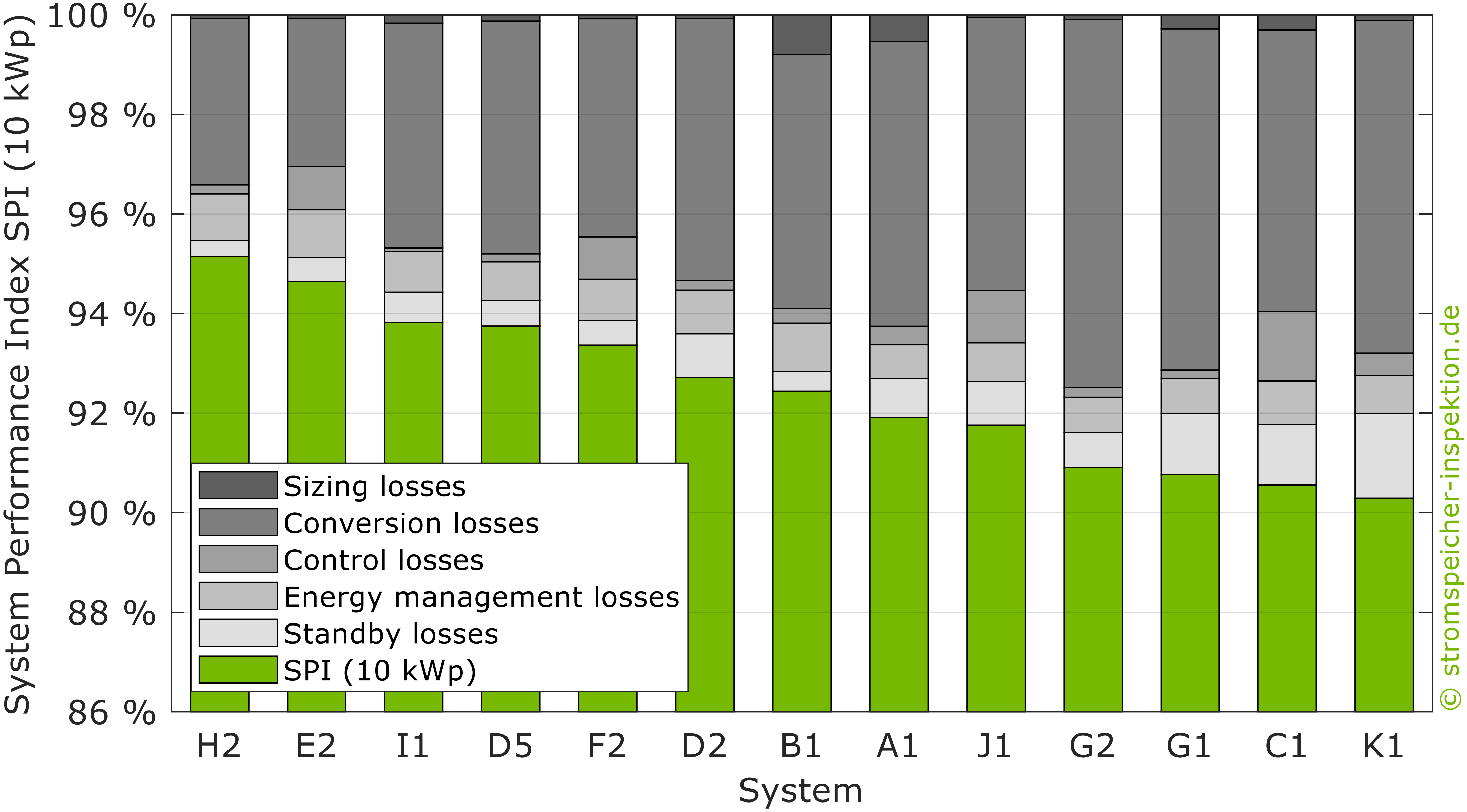
| System | A1 | B1 | C1 | D1 | D2 | D3 | D4 | D5 | E1 | E2 | F1 | F2 | G1 | G2 | H1 | H2 | I1 | J1 | K1 | L1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPI (5 kWp) | | 🟧 | | 🟧 | | 🟧 | 🟧 | | 🟧 | | 🟧 | | | | 🟧 | | | | | 🟧 |
| SPI (10 kWp) | 🟩 | 🟩 | 🟩 | | 🟩 | | | 🟩 | | 🟩 | | 🟩 | 🟩 | 🟩 | | 🟩 | 🟩 | 🟩 | 🟩 | |

The assignment is based on the data sheet specifications for the usable battery capacity.

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



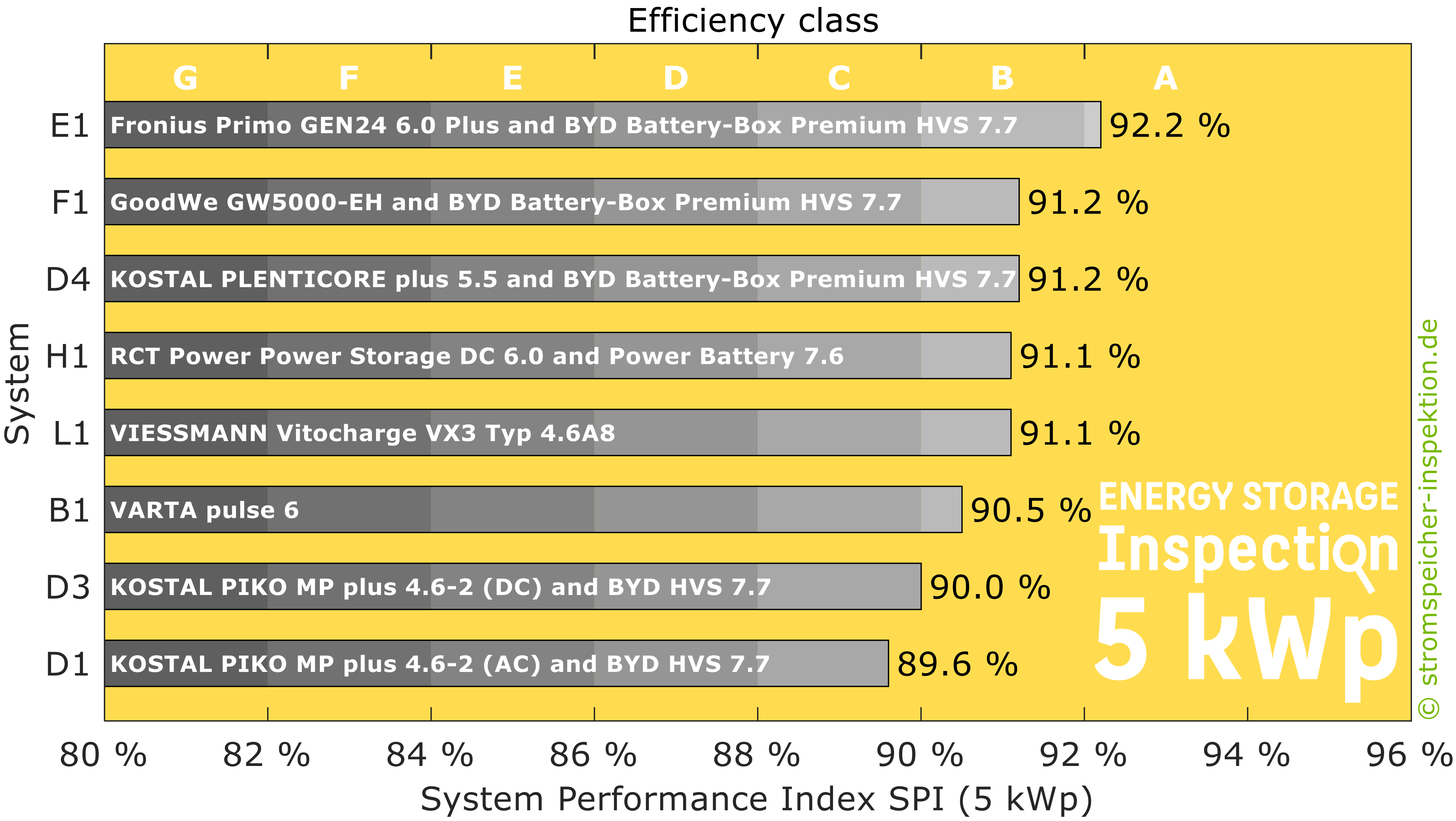
# Loss analysis of the systems assessed with the SPI (10 kWp)



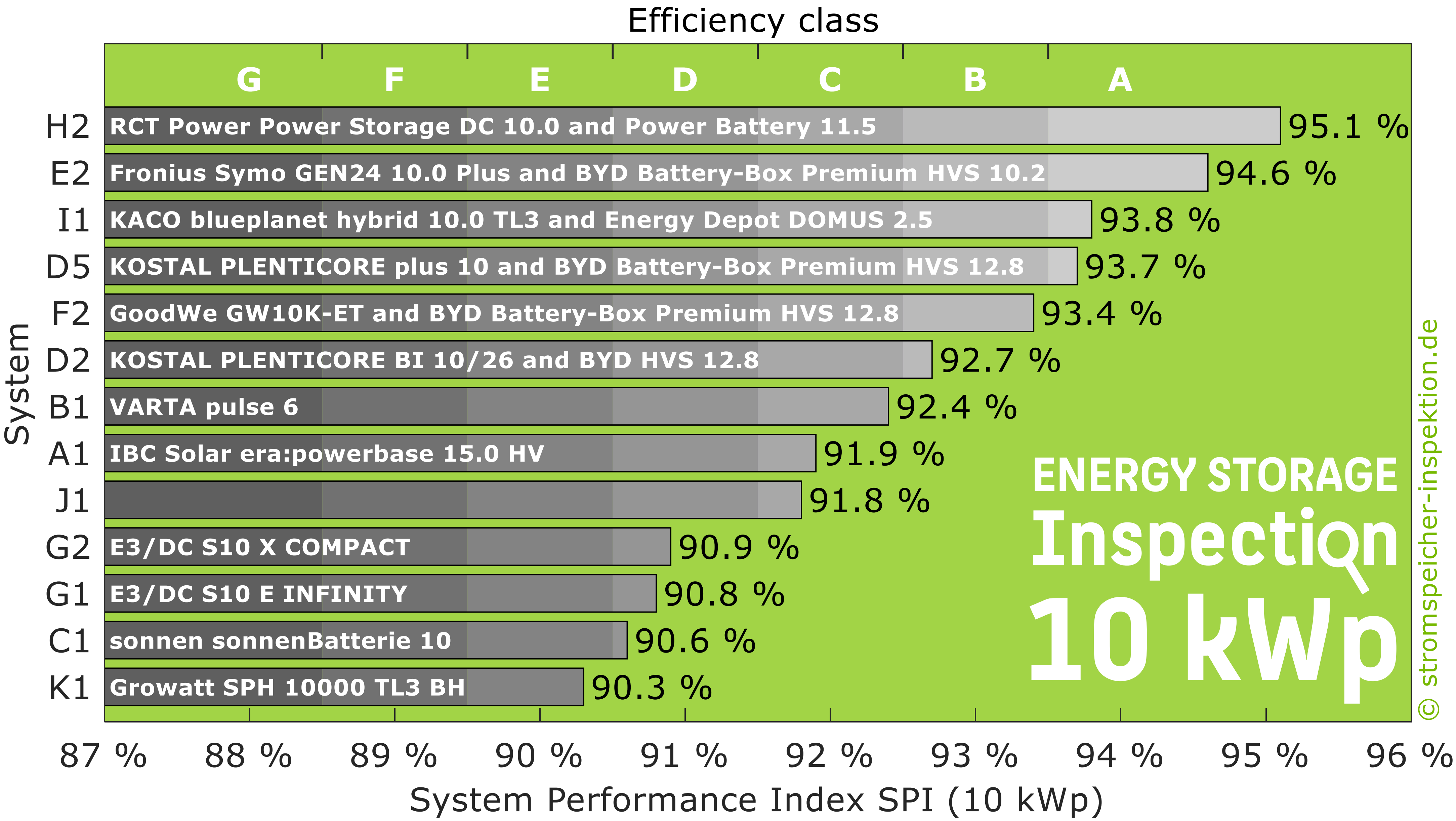
# Definition of efficiency classes for PV-battery systems

| Class | SPI (5 kWp) | SPI (10 kWp) |
|---|---|---|
| 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 % |

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



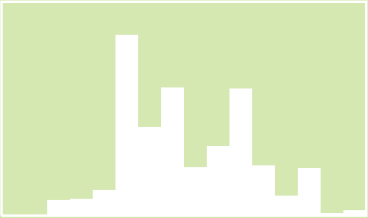
# SPI (10 kWp) and efficiency classes of the analyzed systems



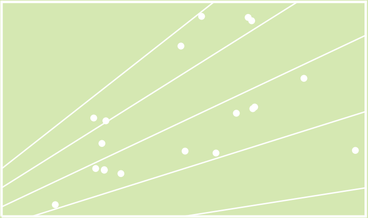
System A1: incl. compatible battery inverter, System K1: incl. Growatt ARK 15.3H

# Main topics of the Energy Storage Inspection 2021

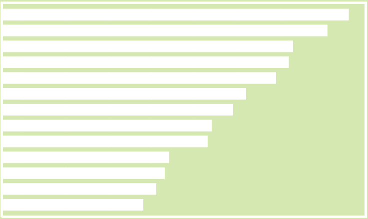
1. Analysis of the German market for residential PV-battery systems



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

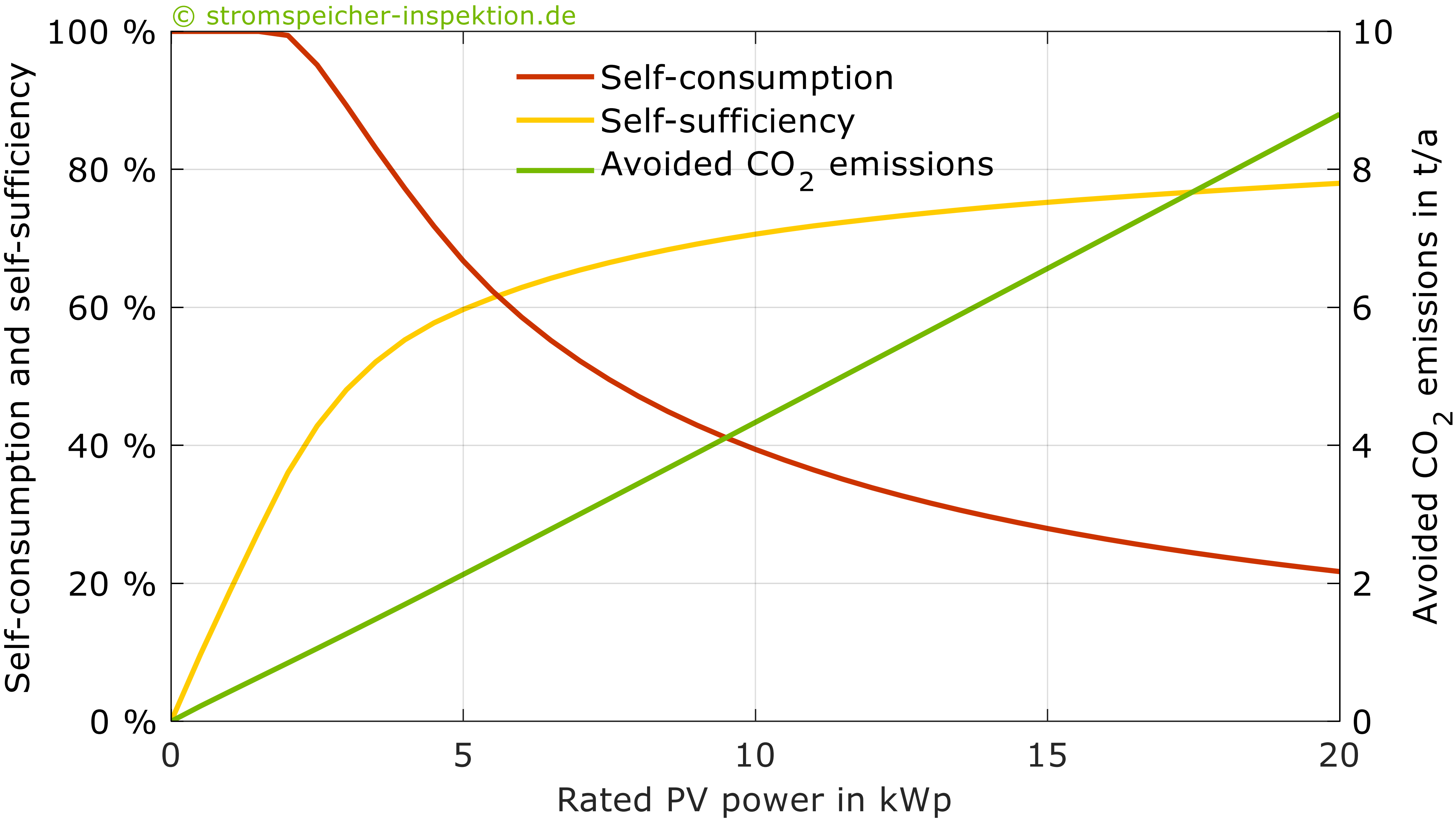


3. Simulation-based assessment of the PV-battery systems with the System Performance Index (SPI)



4. **FAQ: Answers to questions concerning the sizing of PV-battery systems**

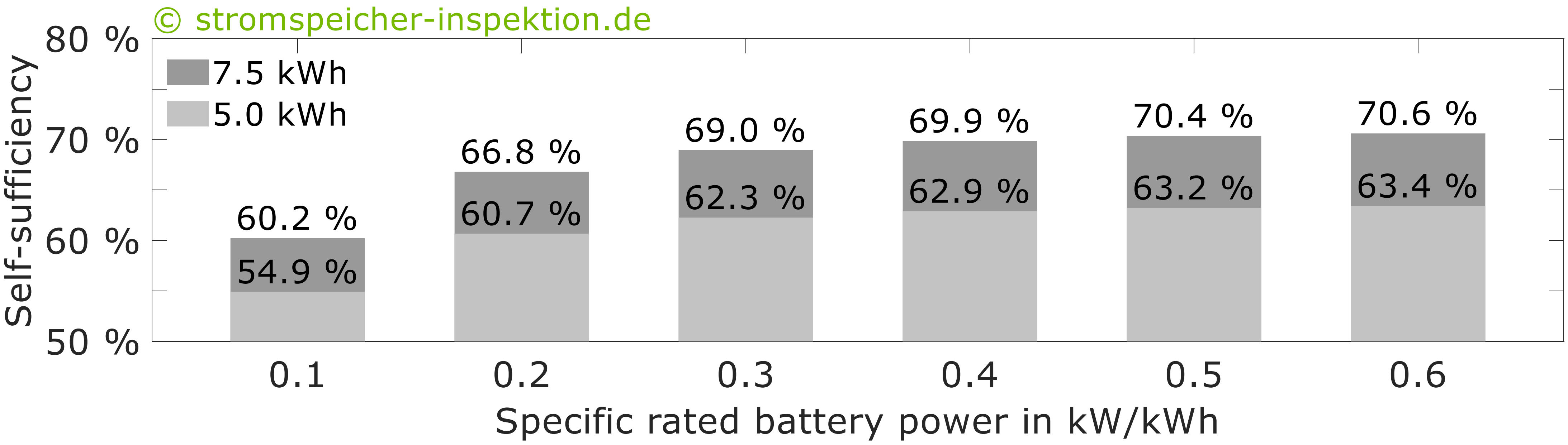
# How does the system size affect the $CO_2$ savings?



Assumptions of the simulation study: electrical energy consumption 5010 kWh/a, usable battery capacity 7.5 kWh.

# Which nominal power of the battery should be selected?

- The **max. power of the battery** influences the charging and discharging behavior of the battery system and therefore the degree of self-sufficiency.
- In residential buildings without large consumers such as electric vehicles or instantaneous water heaters a **battery power of 0.5 kW per kWh** of usable battery capacity is usually enough.



Assumptions of the simulation study: electrical energy consumption 5010 kWh/a, PV generator output 10 kWp.

# Summary

- The Energy Storage Inspection 2021 analyzed and compared the energy efficiency of **20 battery systems**.
- Many manufacturers have significantly improved the **standby consumption** and **settling time** of their systems in the past few years.
- With an average conversion efficiency in discharge mode of 97.6 % and a settling time of 0.3 s **new records** were achieved.
- System H2 scores an **SPI (10 kWp)** of **95.1 %**, which is the highest system efficiency measured in the Energy Storage Inspections so far.
- The majority of the 20 analyzed PV-battery systems achieved efficiency classes A and B and scored with a **very good system efficiency**.
- The next issue of the Energy Storage Inspection will be released in the spring of 2022.

htw

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