energie waechter

Fraunhofer ISE

renewables Made in Germany

Dr. Matthias Vetter
Fraunhofer Institute for
Solar Energy Systems ISE

Energy Storage – Key for large scale grid integration of renewable energies

www.renewables-made-in-germany.com

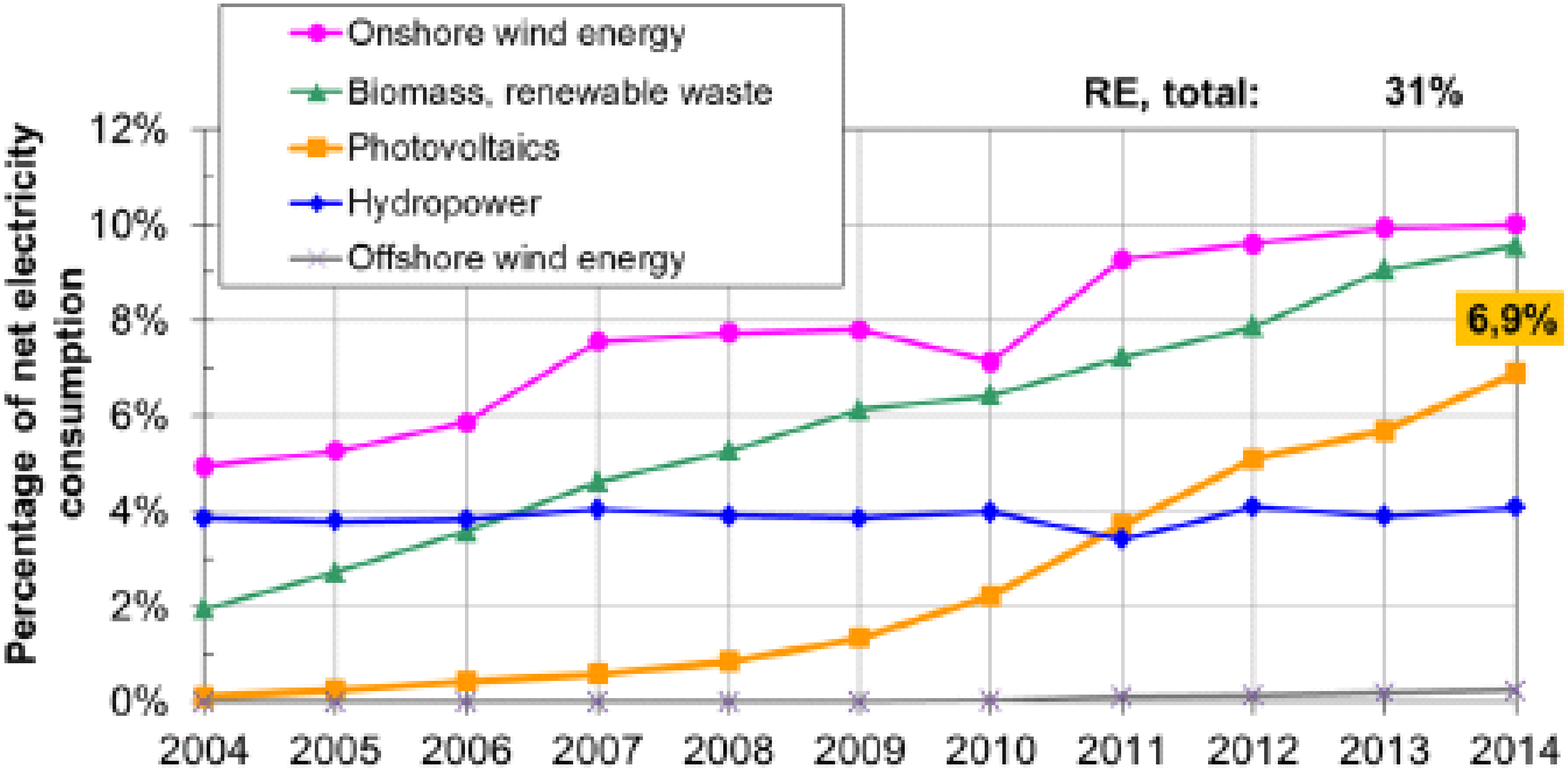
AHK Dansk-Tysk Handelskammer
Deutsch-Dänische Handelskammer

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Agenda

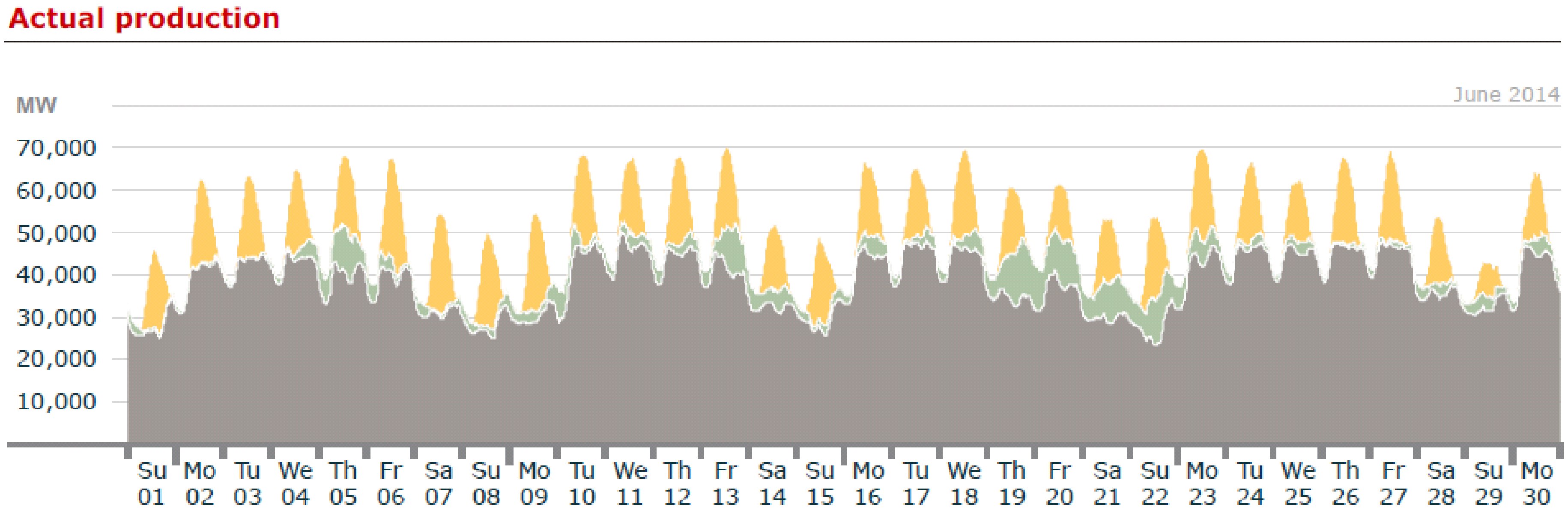
- Motivation: Germany as an example
- Stationary storage – Market and classification
- Battery technologies and cost analyses
- System design aspects – Example of a commercial PV battery system
- System integration of battery storage
- Conclusions

Motivation
Share of renewables in the German grid



Source: H. Wirth, Fraunhofer ISE: Recent Facts about Photovoltaics in Germany, http://www.ise.fraunhofer.de/en/renewable-energy-data, 19.5.2015.

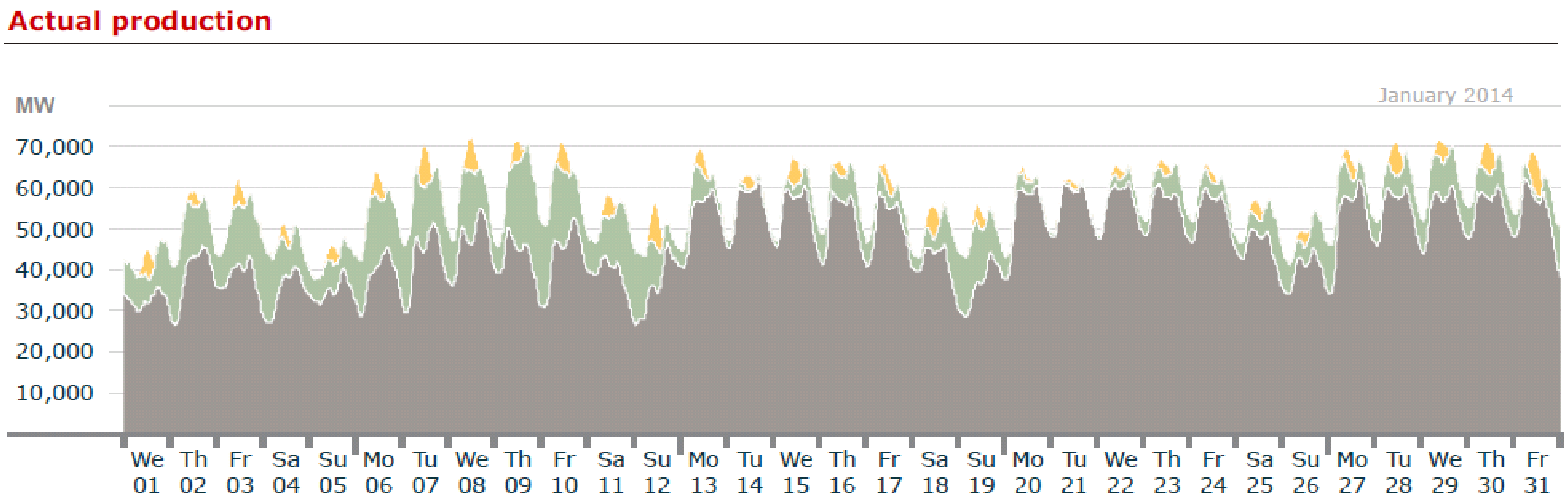
Motivation
Power production: June 2014



	max. power	date max. power	monthly energy
Solar	24.24 GW	06.06., 13:00 (+2:00)	4.84 TWh
Wind	13.7 GW	19.06., 18:45 (+2:00)	2.47 TWh
Conventional > 100 MW	50.3 GW	11.06., 08:00 (+2:00)	27.4 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform /

Motivation
Power production: January 2014



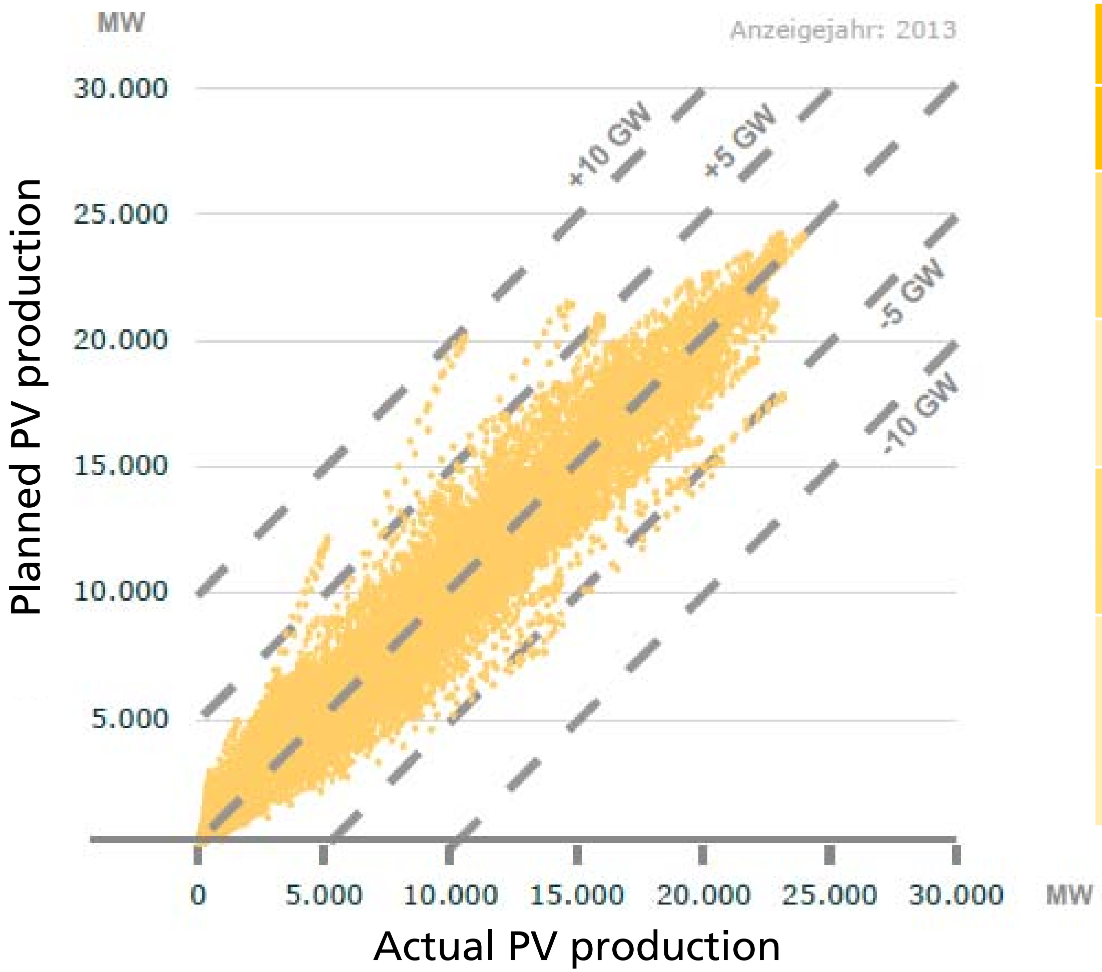
	max. power	date max. power	monthly energy
Solar	10.1 GW	07.01., 12:30 (+1:00)	0.75 TWh
Wind	25.0 GW	09.01., 18:30 (+1:00)	6.2 TWh
Conventional > 100 MW	62.2 GW	31.01., 08:00 (+1:00)	34.7 TWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform /

Motivation

PV power production: Planned versus actual

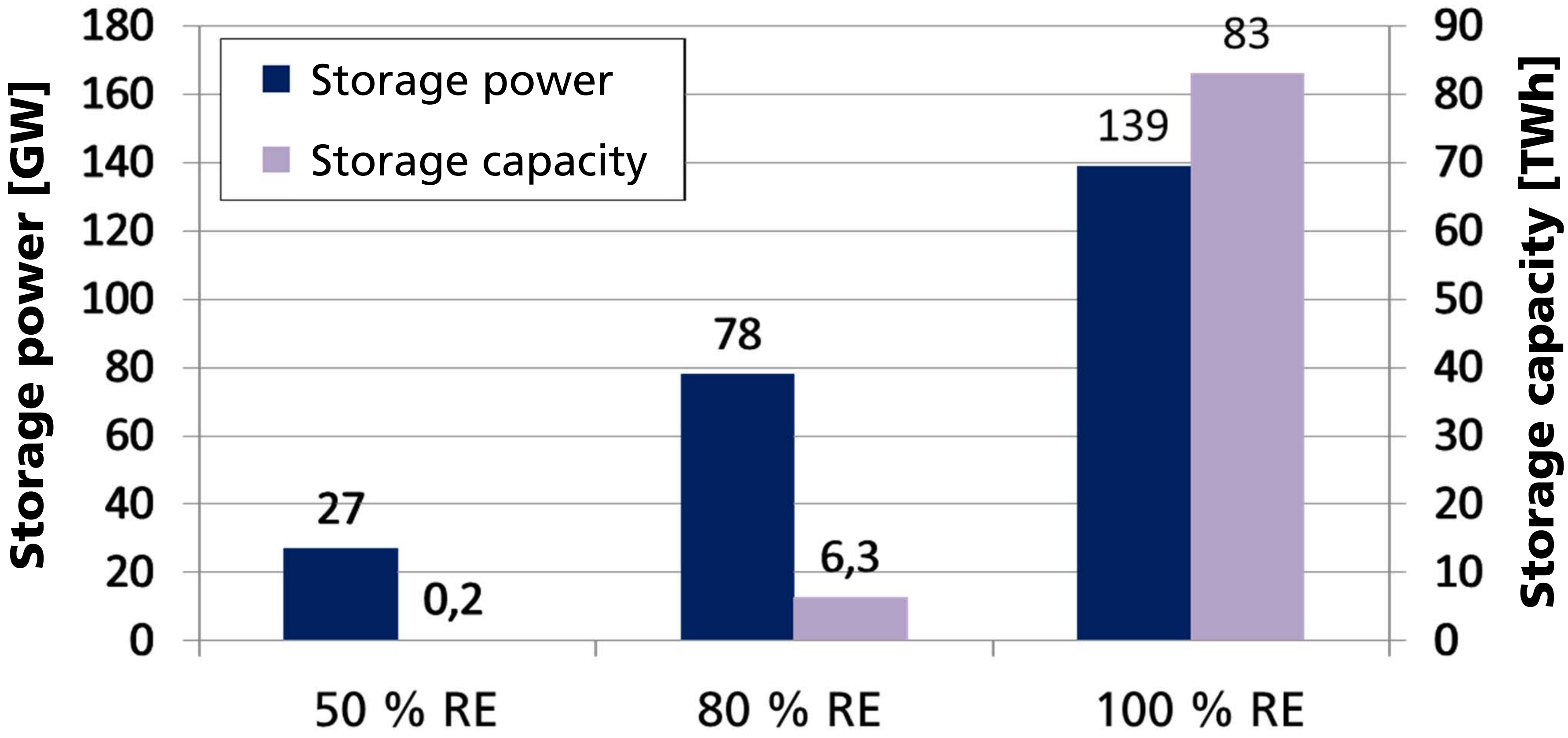
Planned versus actual PV production



Date	03.03.	03.04.
Time	13:15	12:30
GMT	+1:00	+1:00
Planned production	7.5 GW	19.7 GW
Actual production	13.7 GW	10.1 GW
Forecast error	-6.1 GW	+9.6 GW
Relative forecast error	-44.7 %	+94.8 %

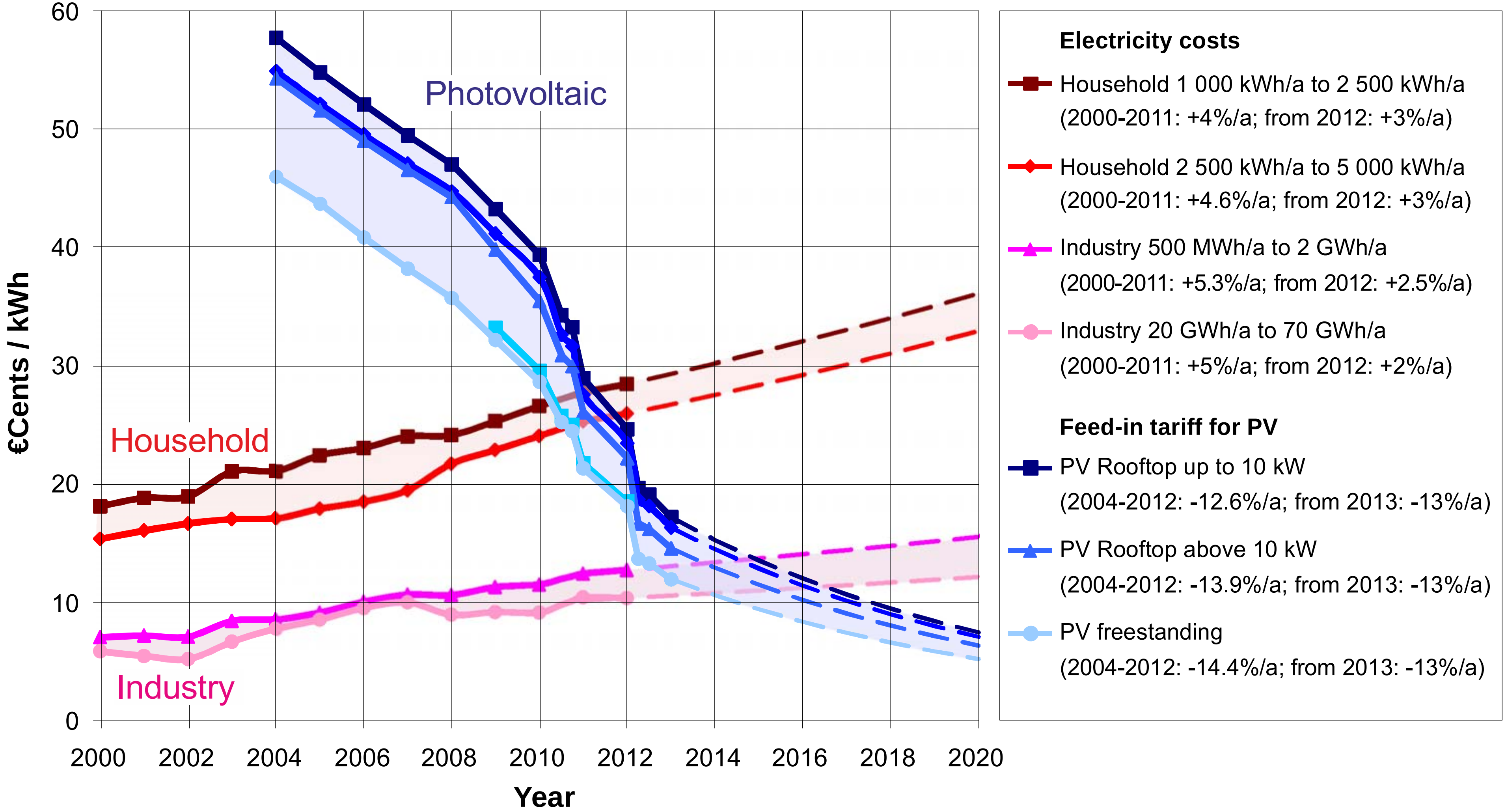
Source: B. Burger, Fraunhofer ISE; Data: EEX Transparency Platform

Motivation
Storage demand in Germany



Source: N. Hartmann, University of Stuttgart, Dissertation, 2013

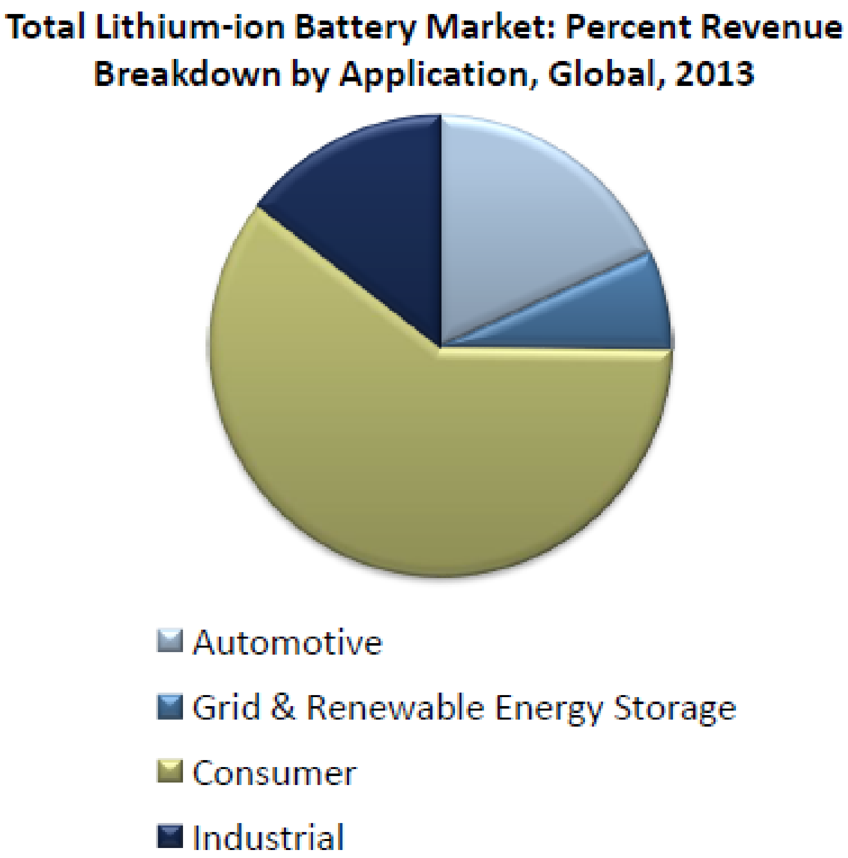
Motivation
Electricity cost and feed-in tariffs in Germany

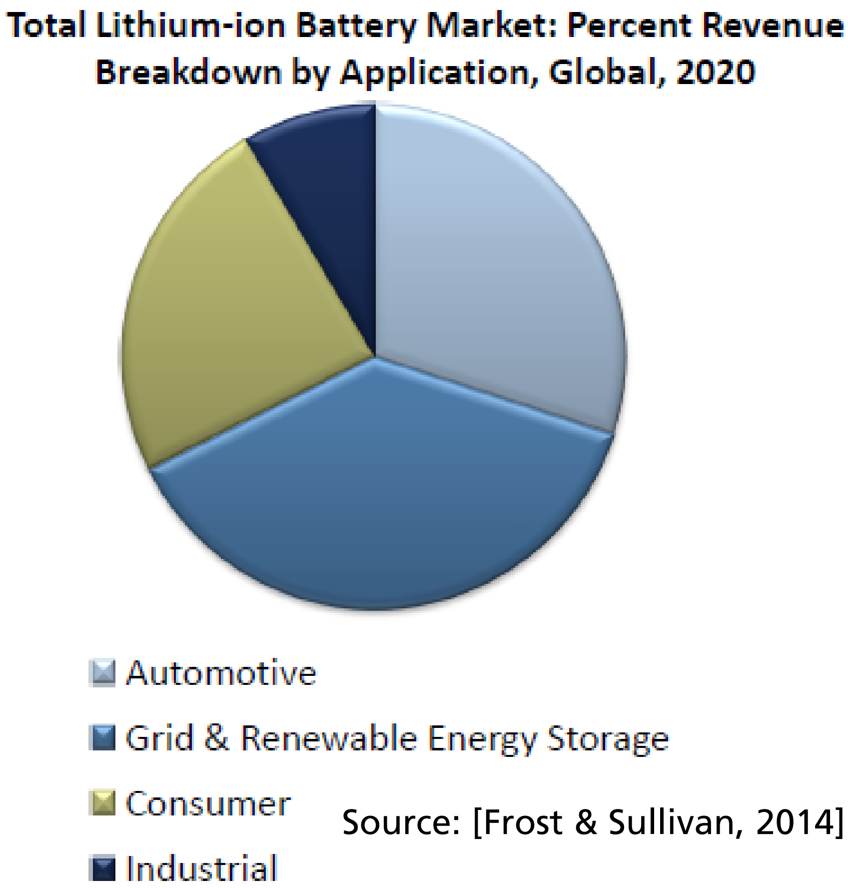


Source: B. Burger, “Energiekonzept 2050”, June 2010, FVEE, www.fvee.de, Update of 14.11.2012

Market for stationary storages
Forecast for lithium-ion batteries

Turnover 2013: 17.58 Bill. US$ → Forecast: More than four times until 2020

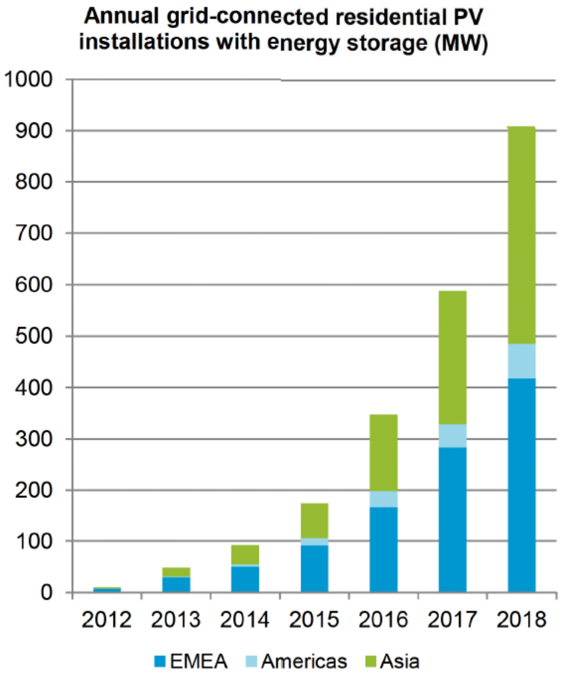


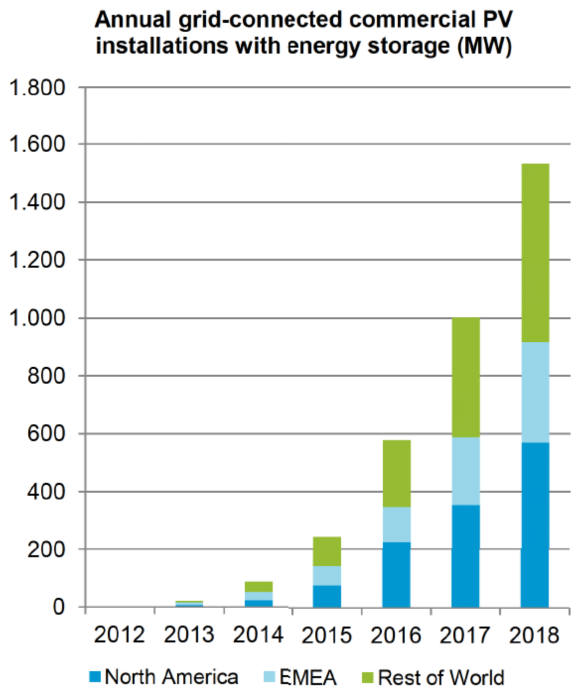


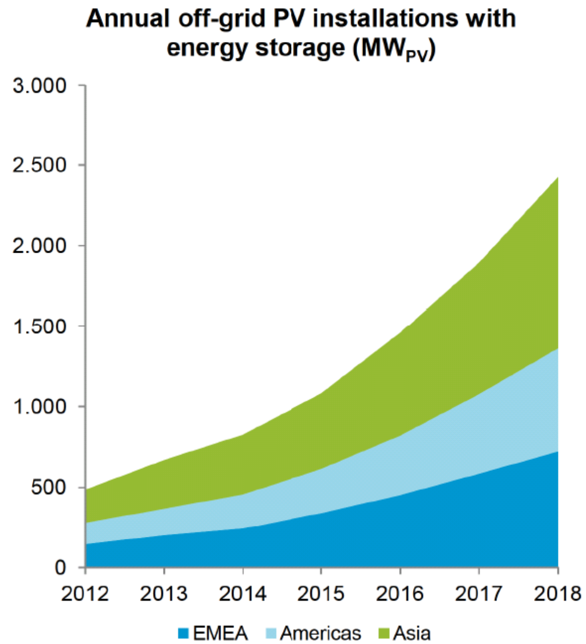
Source: [Frost & Sullivan, 2014]

Electrical energy storage

International markets for PV storage systems



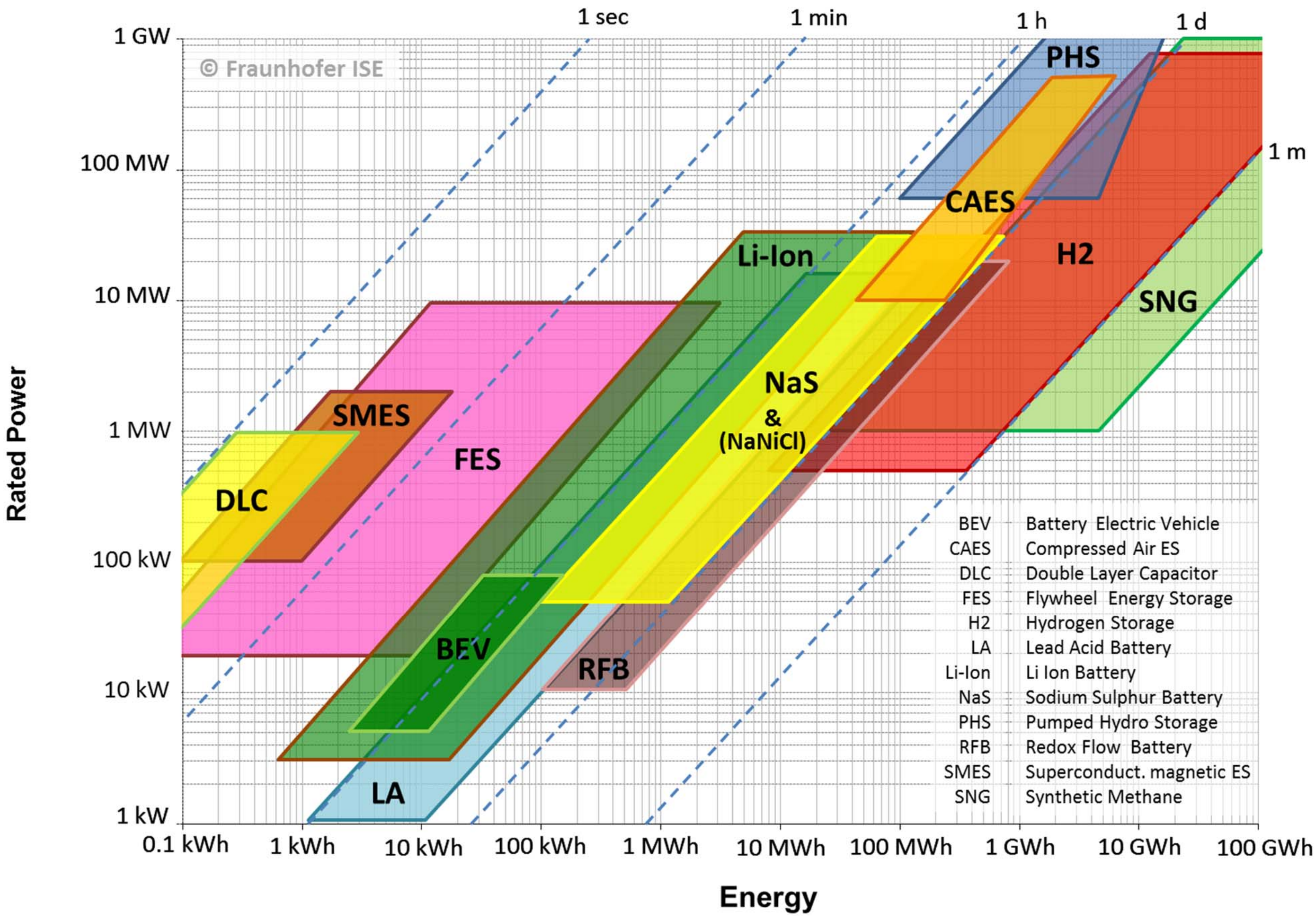




Source: S. Wilkinson, IHS: Opportunities and Challenges for Energy Storage in PV – On and Off the Grid. Energy Storage – VDE Financial Dialogue, 10.03.2015.

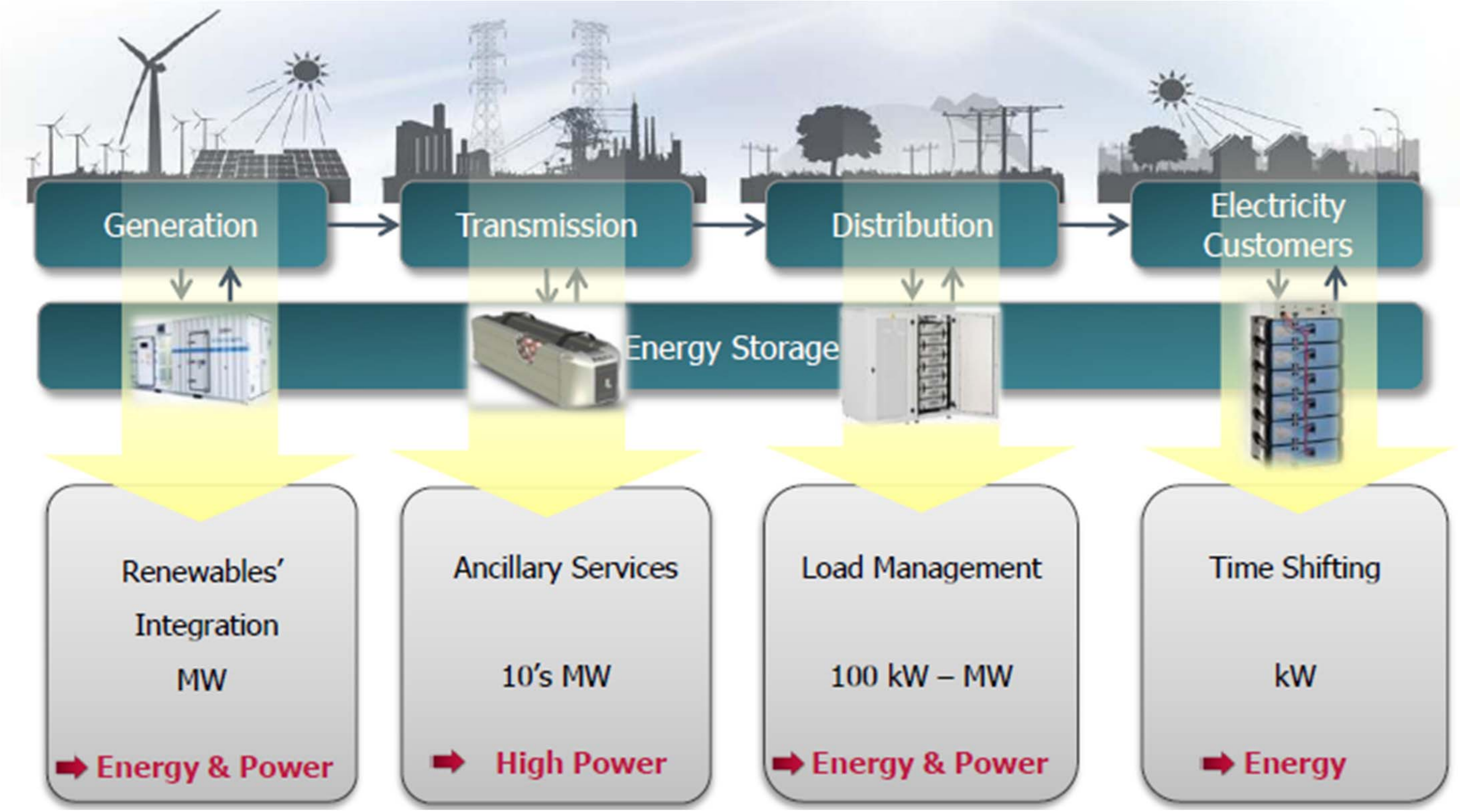
renewables Made in Germany energie waechter Fraunhofer ISE

Classification of storages



Classification of storages

Grid connected systems along the electricity value chain



Source: Michael Lippert, Li-ion battery storage and renewables, Intersolar Munich, 2014

Battery technologies

Redox-flow

NiMh

Source: www.saftbatteries.com

Lithium-ion

NaS / NaNiCl

Source: www.ngk.co.jp

Lead-acid

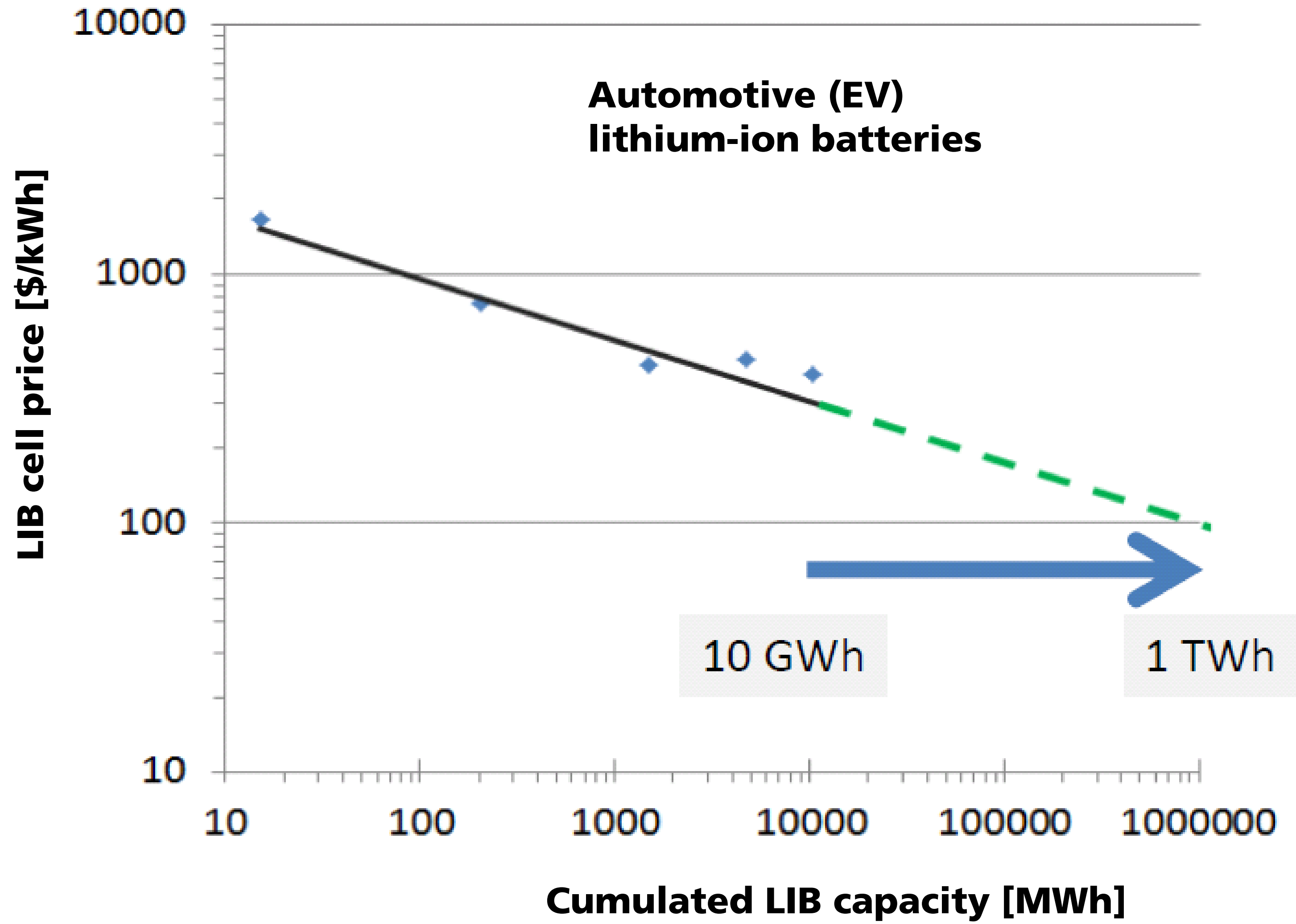
Sodium-ion

Source: www.aquionenergy.com

Battery technologies - Parameters

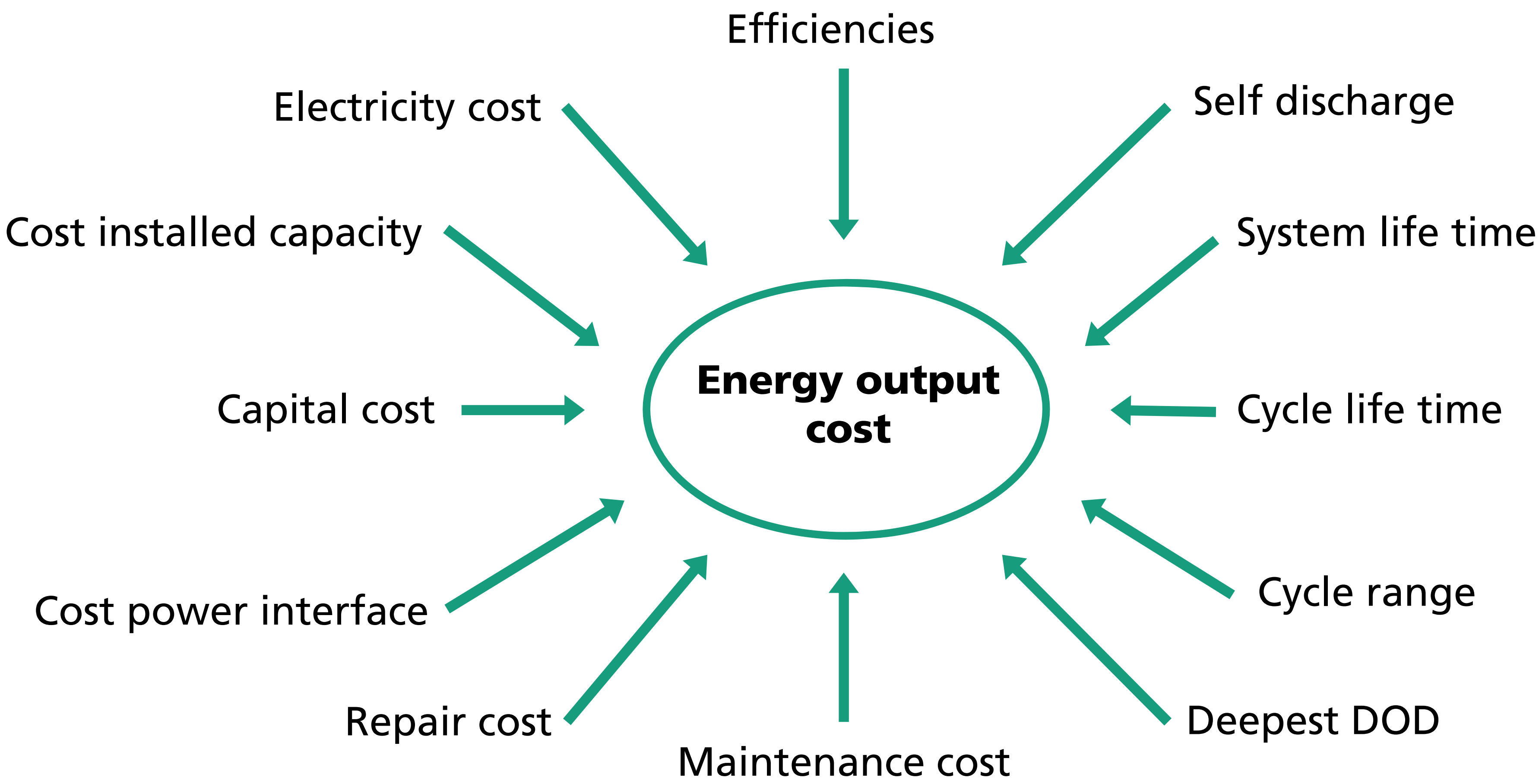
	Lead acid	NiMH	Li NMC / Graphite	LiFePO4 / Graphite	LMO / Graphite	LMO / Titanat	Vanadium-Redox-Flow	NaNiCl	NaS
Energy density (Wh / kg)	40	75	160	110	130	75	45	100	110
Power density (W / kg)	350	600	1300	4000	1500	4000	120	120	100
Cycle life time	600	900	2500	5000	3000	8000	12000	2500	4500
Calendar life time (years)	7	5	7	14	8	12	15	12	11
Efficiency (%)	85	75	93	94	94	94	80	85	80
Self discharge (% / month)	8	20	3	3	2	2	5	10 pro Tag	12 pro Tag

Battery technologies – Investment cost
Price experience curve for automotive applications



Source: Winfried Hoffmann, Importance and Evidence for Cost Effective Electricity Storage, PVSEC, 2014

Cost analyses – Levelized cost of electricity storage



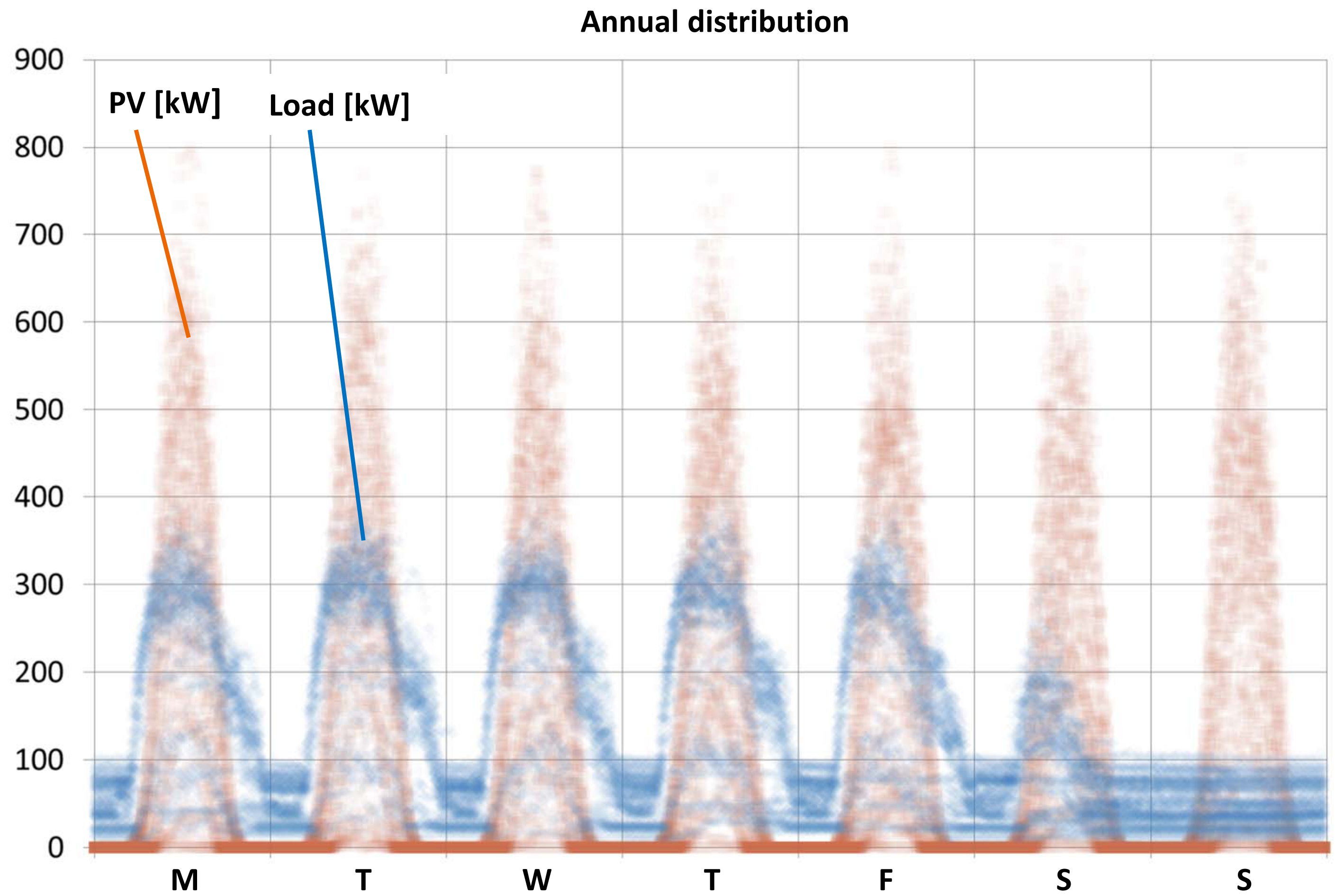
Example: Commercial PV battery system
Analyses of load profile and PV generation profile

Load:

- Consumption: 1120 MWh/a
- Max. power: 422 kW

PV system (1 MWp):

- Production: 990 MWh/a
- Max. power: 800 kWp



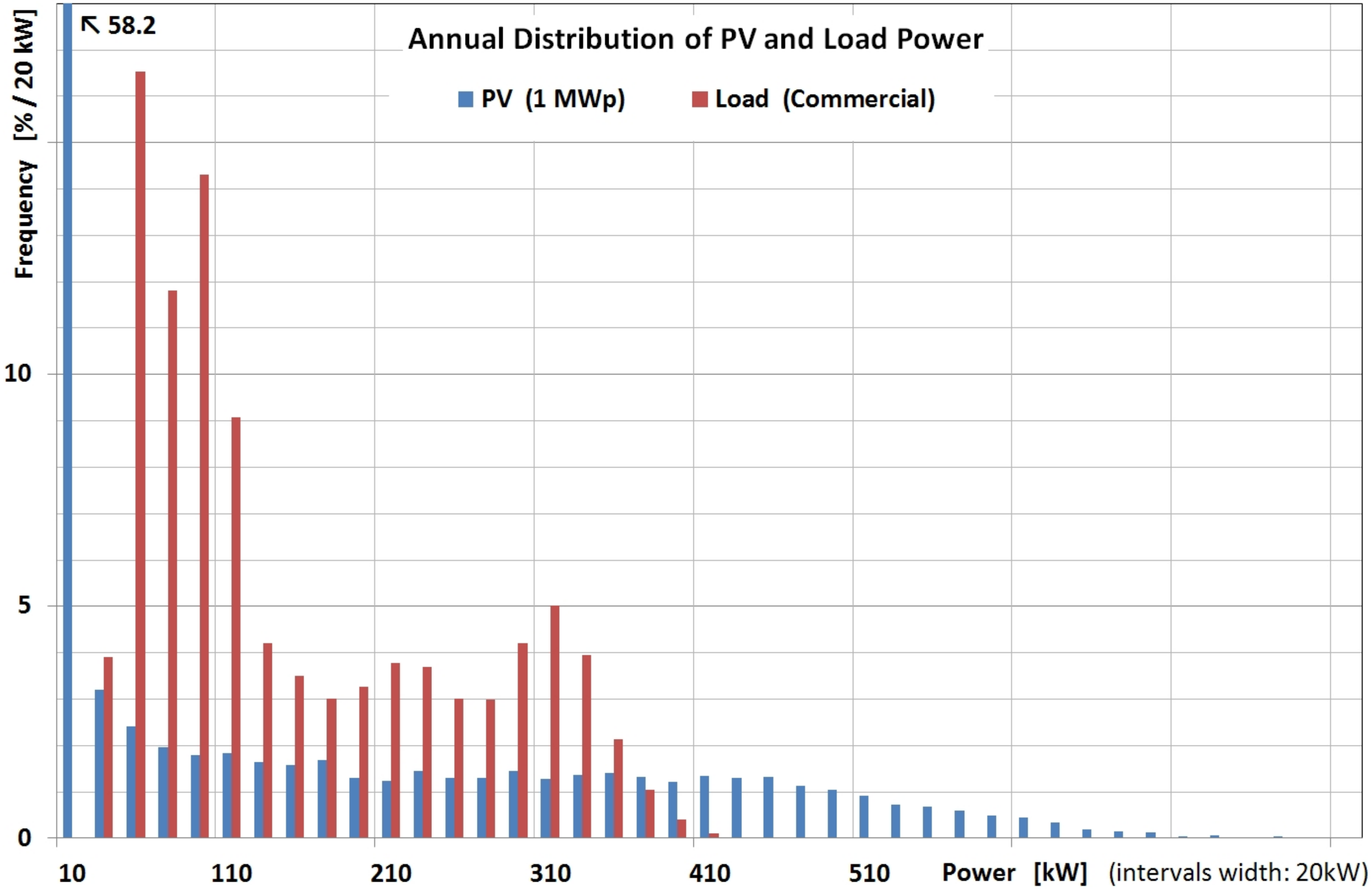
Example: Commercial PV battery system
Analyses of load profile and PV generation profile

Load:

- Consumption: 1120 MWh/a
- Max. power: 422 kW

PV system (1 MWp):

- Production: 990 MWh/a
- Max. power: 800 kWp



Example: Commercial PV battery system
Simulation based system analyses and dimensioning

Load:

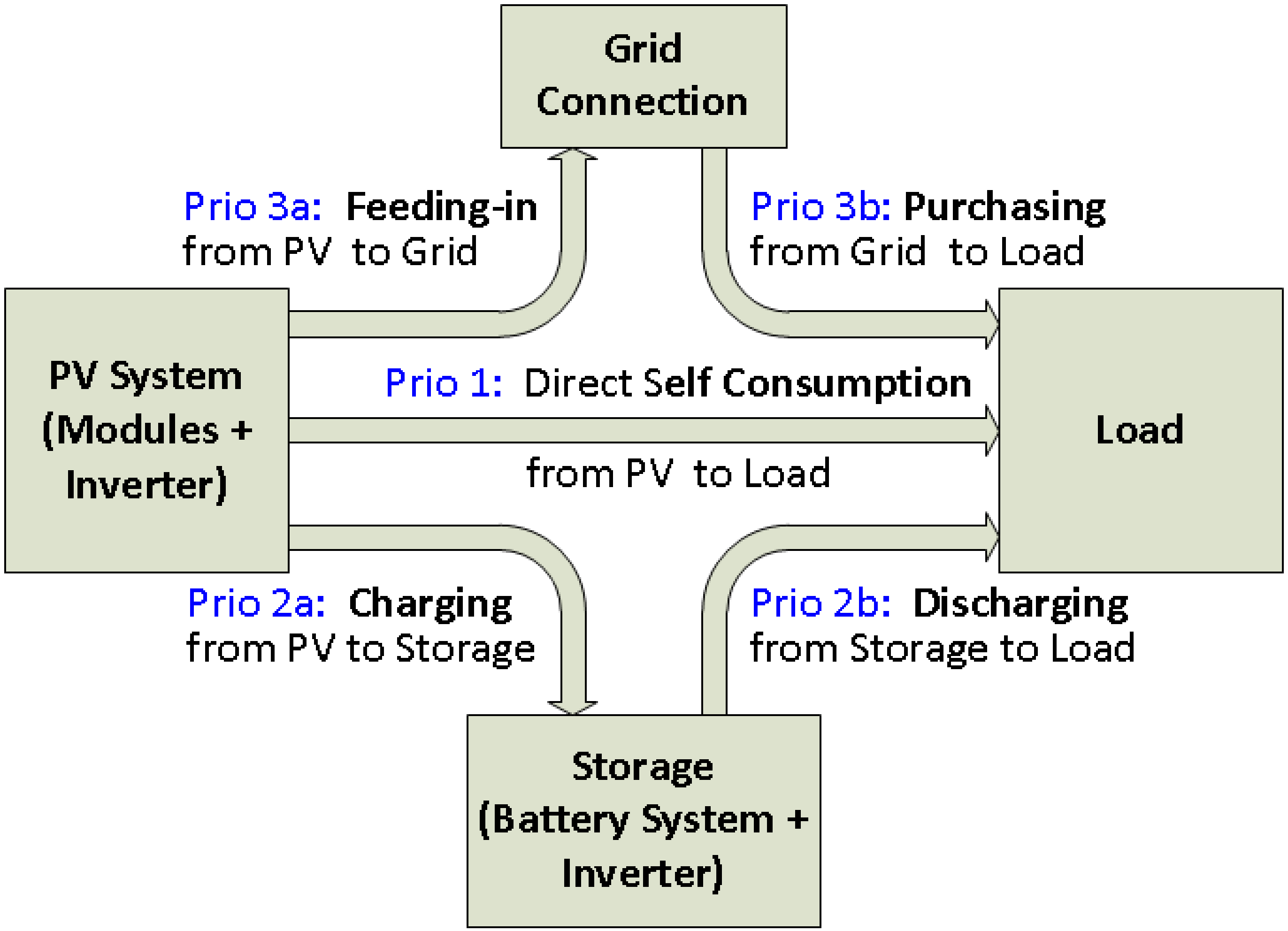
- Consumption: 1120 MWh/a
- Max. power: 422 kW

PV system (1 MWp):

- Production: 990 MWh/a
- Max. power: 800 kWp

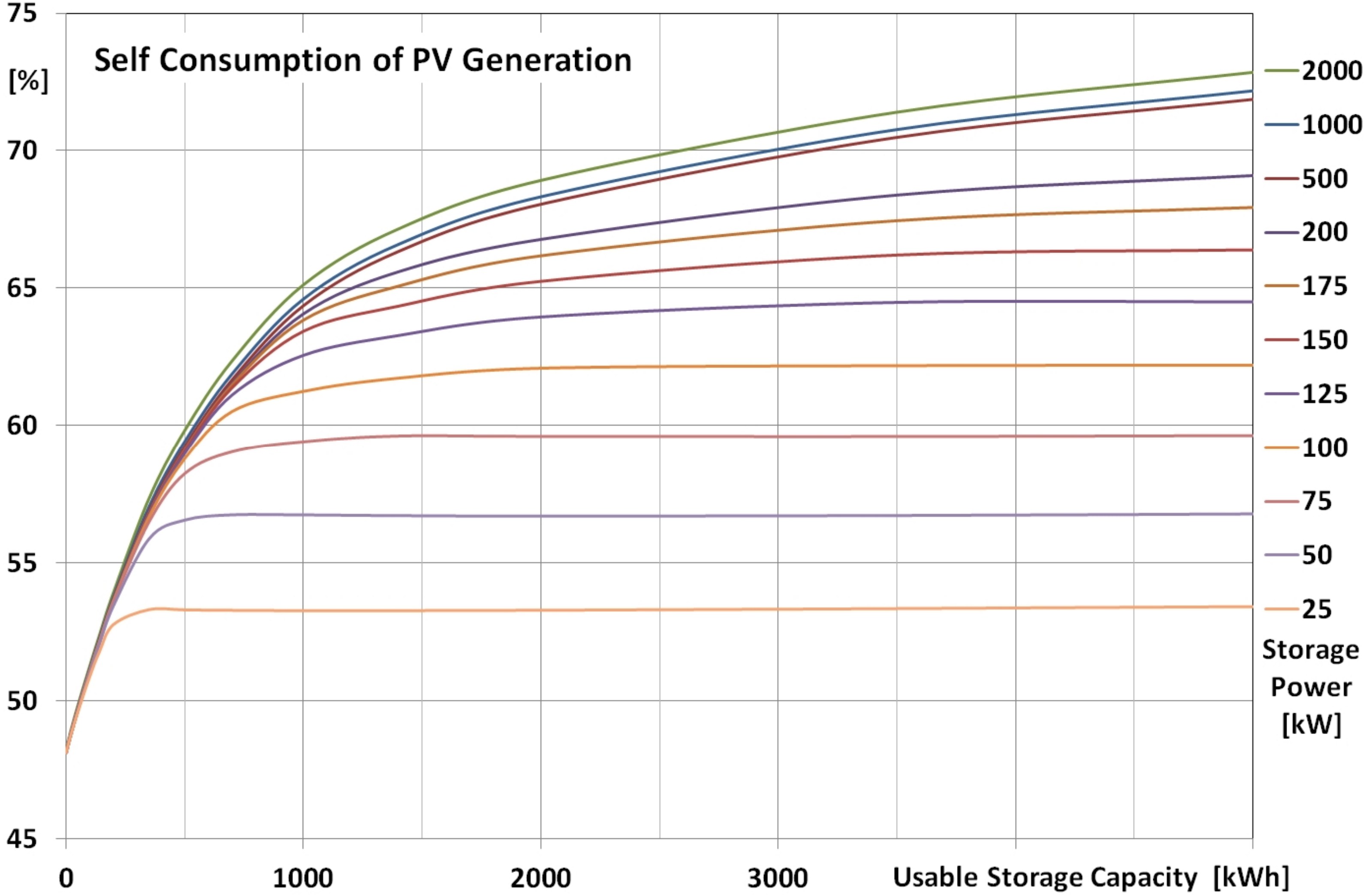
Integration of a lithium-ion battery storage

- Variation of capacity
- Variation of power



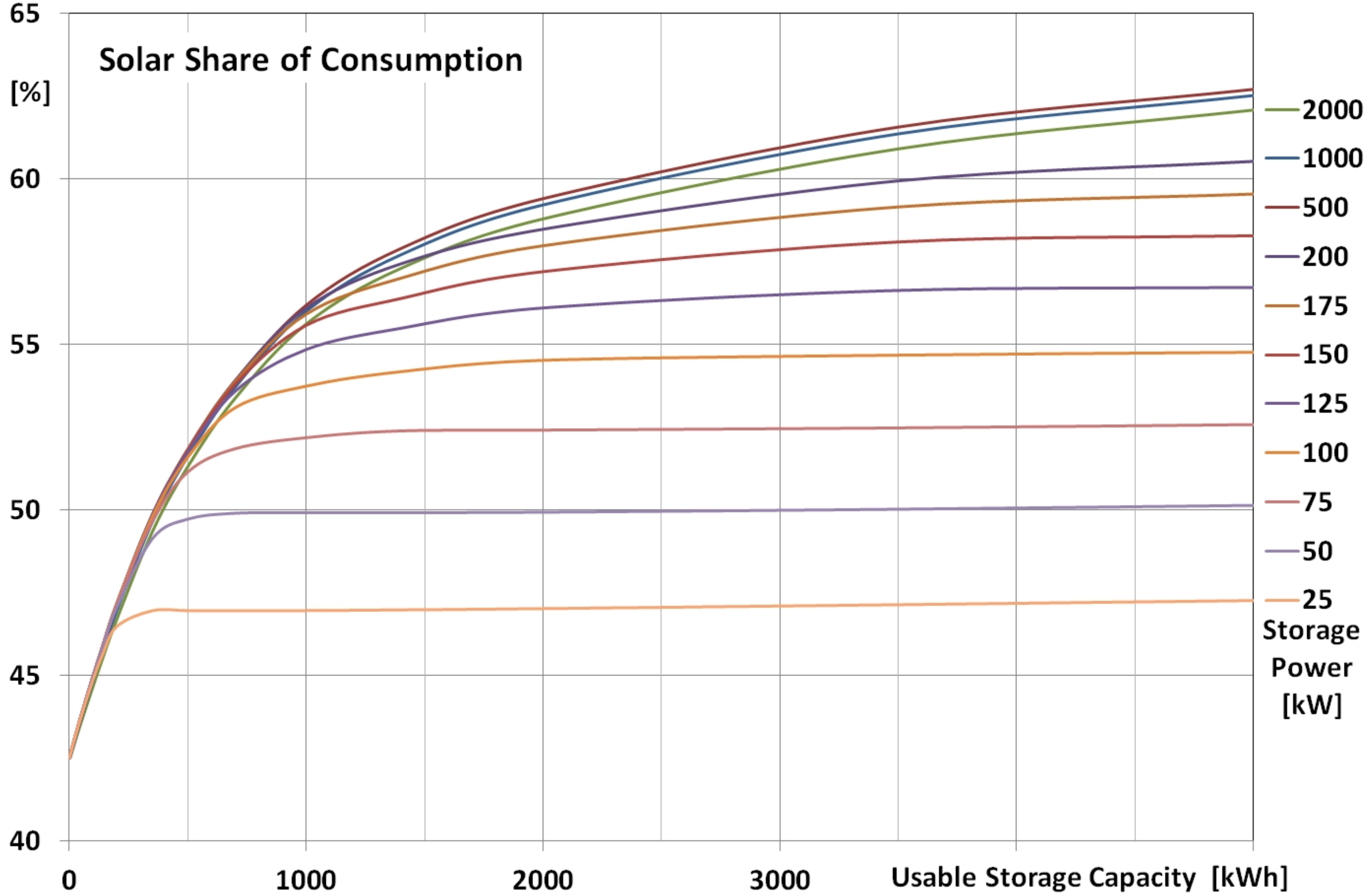
Example: Commercial PV battery system
Simulation based system analyses and dimensioning

Self consumption as a function of usable storage capacity and storage power



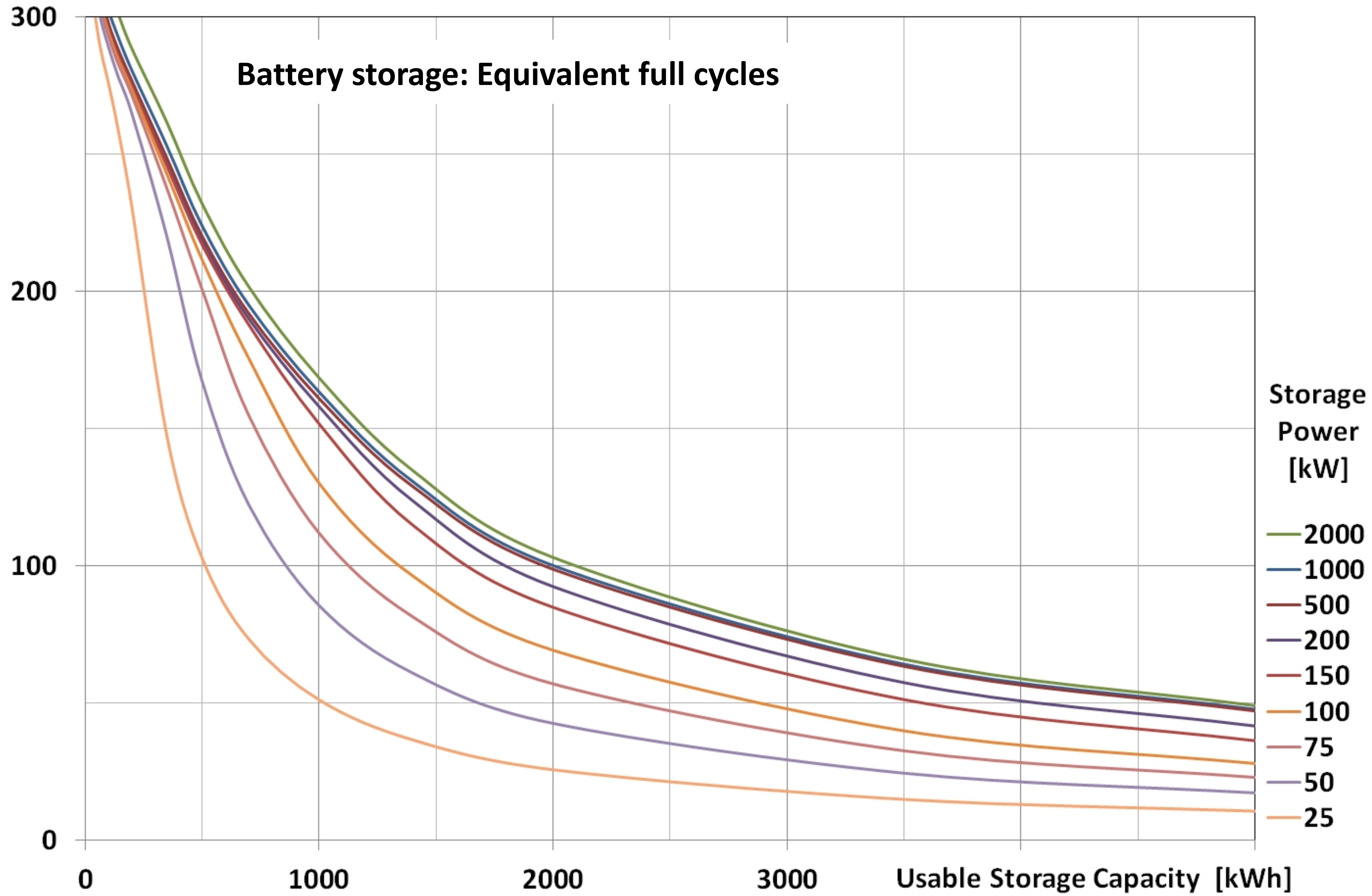
Example: Commercial PV battery system
Simulation based system analyses and dimensioning

Solar share as a function of usable storage capacity and storage power



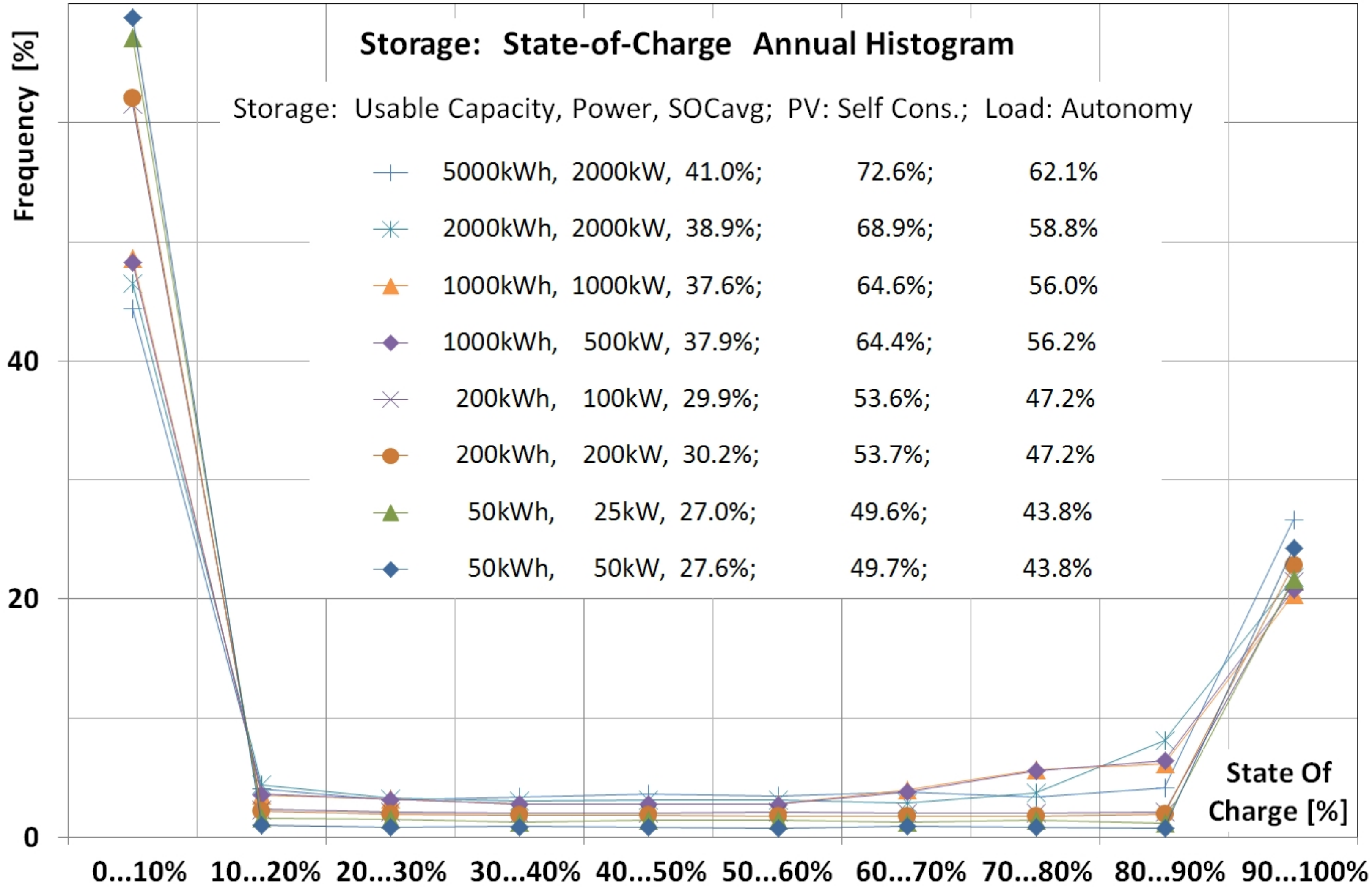
Example: Commercial PV battery system
Simulation based system analyses and dimensioning

Battery storage: Equivalent full cycles as a function of usable capacity and power



Example: Commercial PV battery system
Simulation based system analyses and dimensioning

Battery storage: Annual frequency distribution of the state of charge values



Example: Commercial PV battery system

Simulation based system analyses and dimensioning

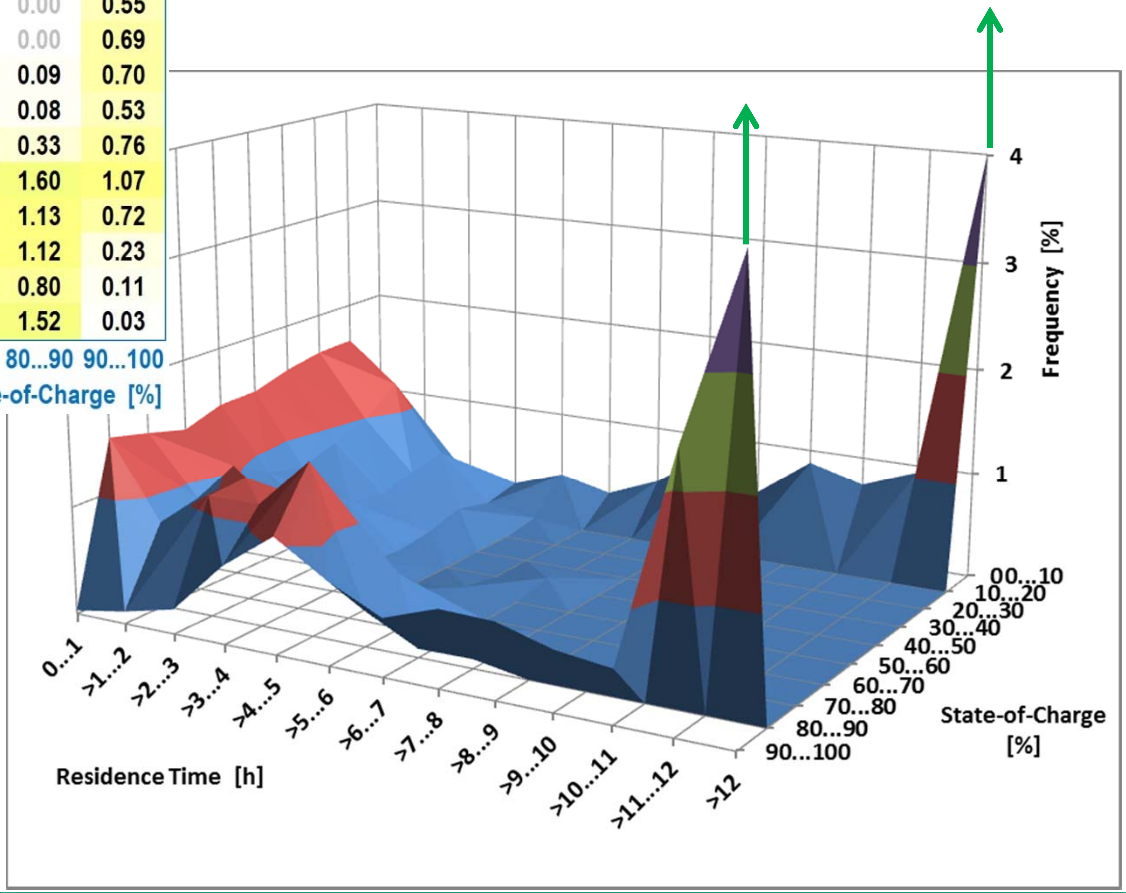
Storage: Usable Capacity 1000 kWh, Power 200 kW (dimensioning candidate 297)

Residence Time [h] / Frequency Distribution [%] / State-of-Charge [%]

Residence Time [h]	0...10	10...20	20...30	30...40	40...50	50...60	60...70	70...80	80...90	90...100
>12	42.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.51
>11...12	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40
>10...11	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
>9...10	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55
>8...9	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.69
>7...8	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.70
>6...7	0.46	0.00	0.00	0.00	0.08	0.00	0.00	0.07	0.08	0.53
>5...6	0.25	0.00	0.00	0.00	0.00	0.06	0.06	0.50	0.33	0.76
>4...5	0.37	0.05	0.00	0.00	0.00	0.00	0.10	0.66	1.60	1.07
>3...4	0.20	0.13	0.21	0.12	0.08	0.12	0.58	1.07	1.13	0.72
>2...3	0.16	0.58	0.51	0.43	0.49	0.44	0.70	1.16	1.12	0.23
>1...2	0.10	1.24	0.99	0.88	0.76	0.85	1.05	0.88	0.80	0.11
0...1	0.05	1.63	1.62	1.56	1.46	1.45	1.33	1.43	1.52	0.03

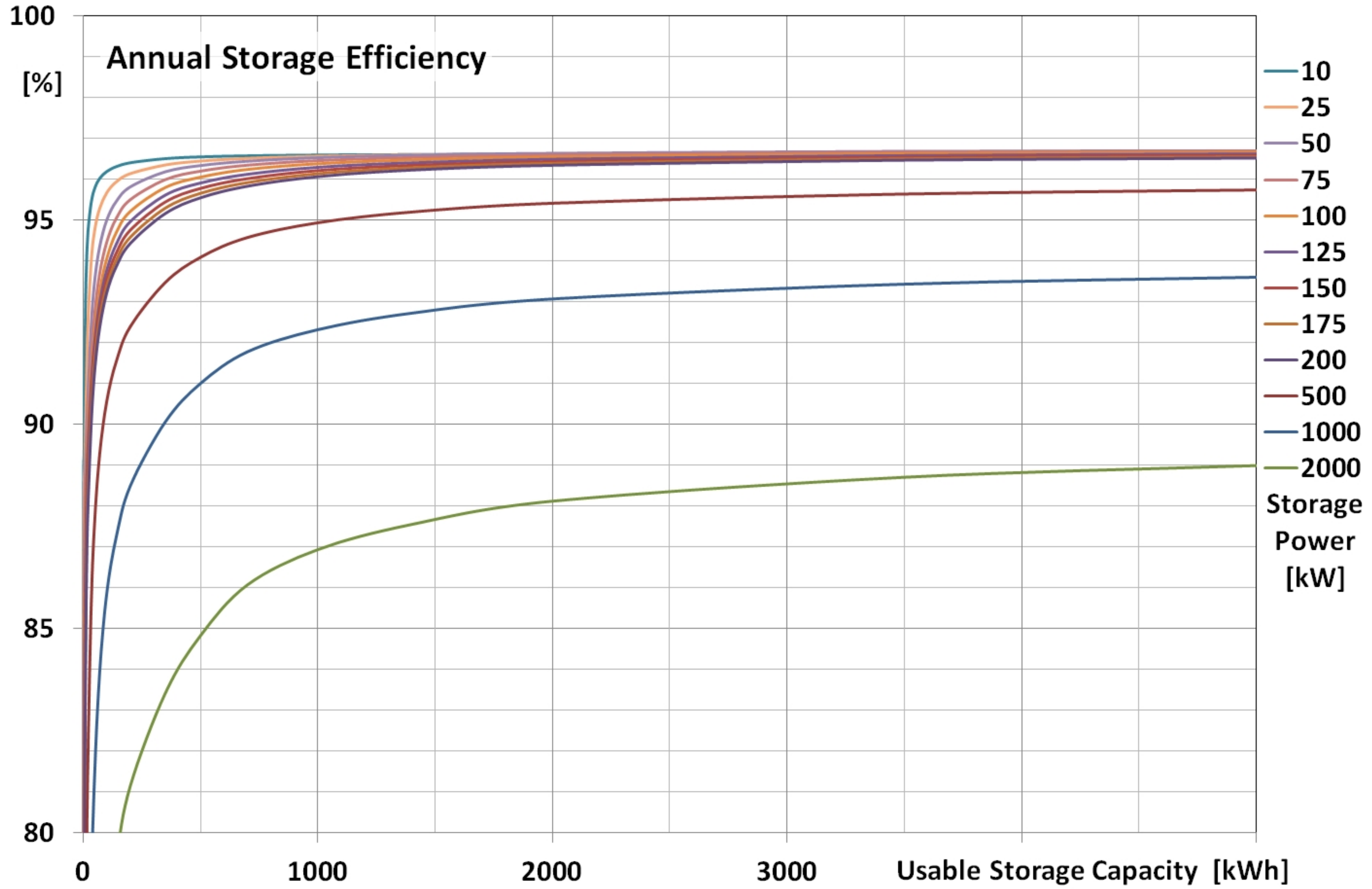
Battery storage, case 1000 kWh / 200 kW:

Annual frequency distribution for the single residence times and state of charge values



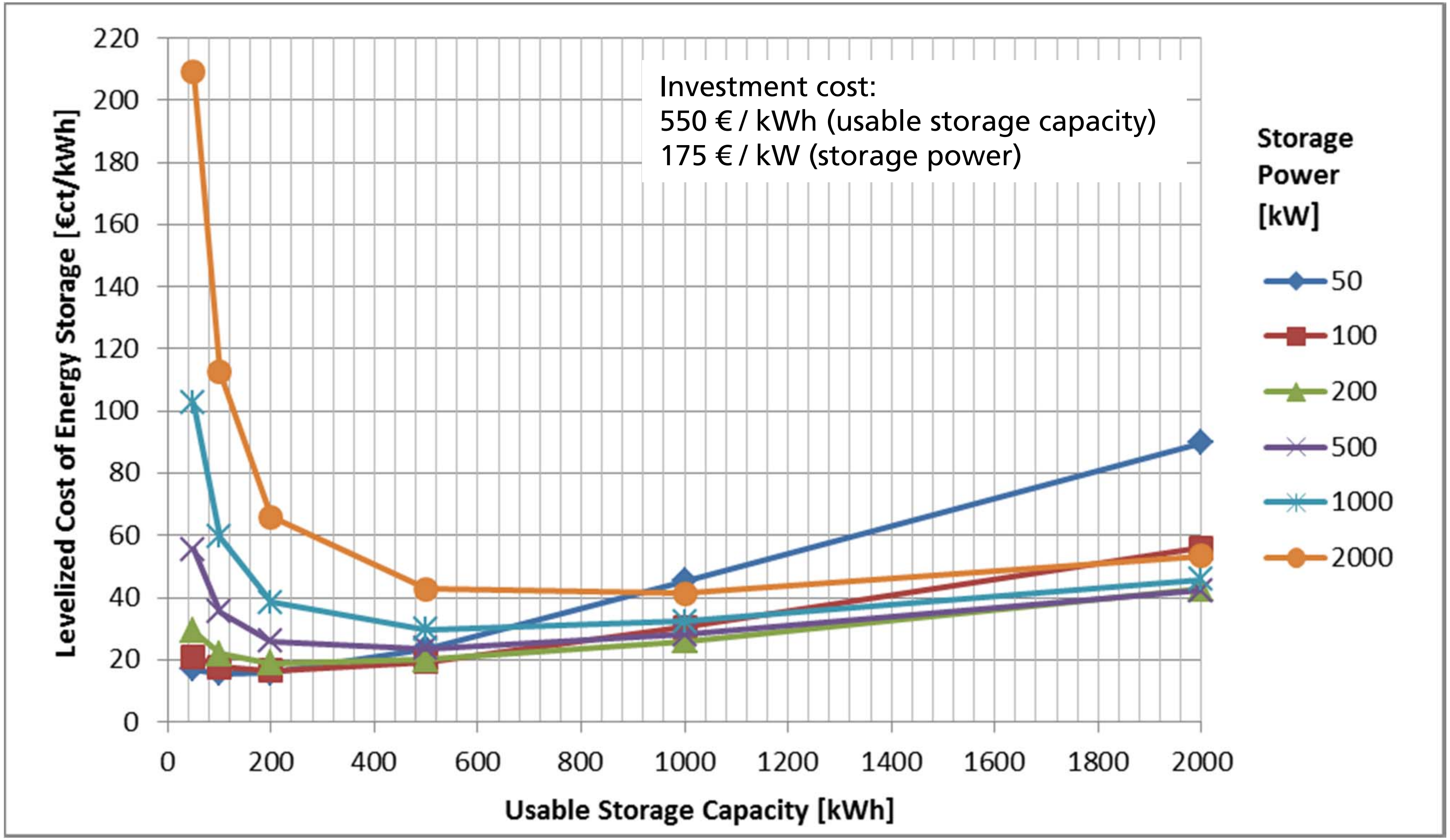
Example: Commercial PV battery system
Simulation based system analyses and dimensioning

Battery storage: Annual storage efficiencies as a function of usable capacity and power



Example: Commercial PV battery system
Simulation based system analyses and dimensioning

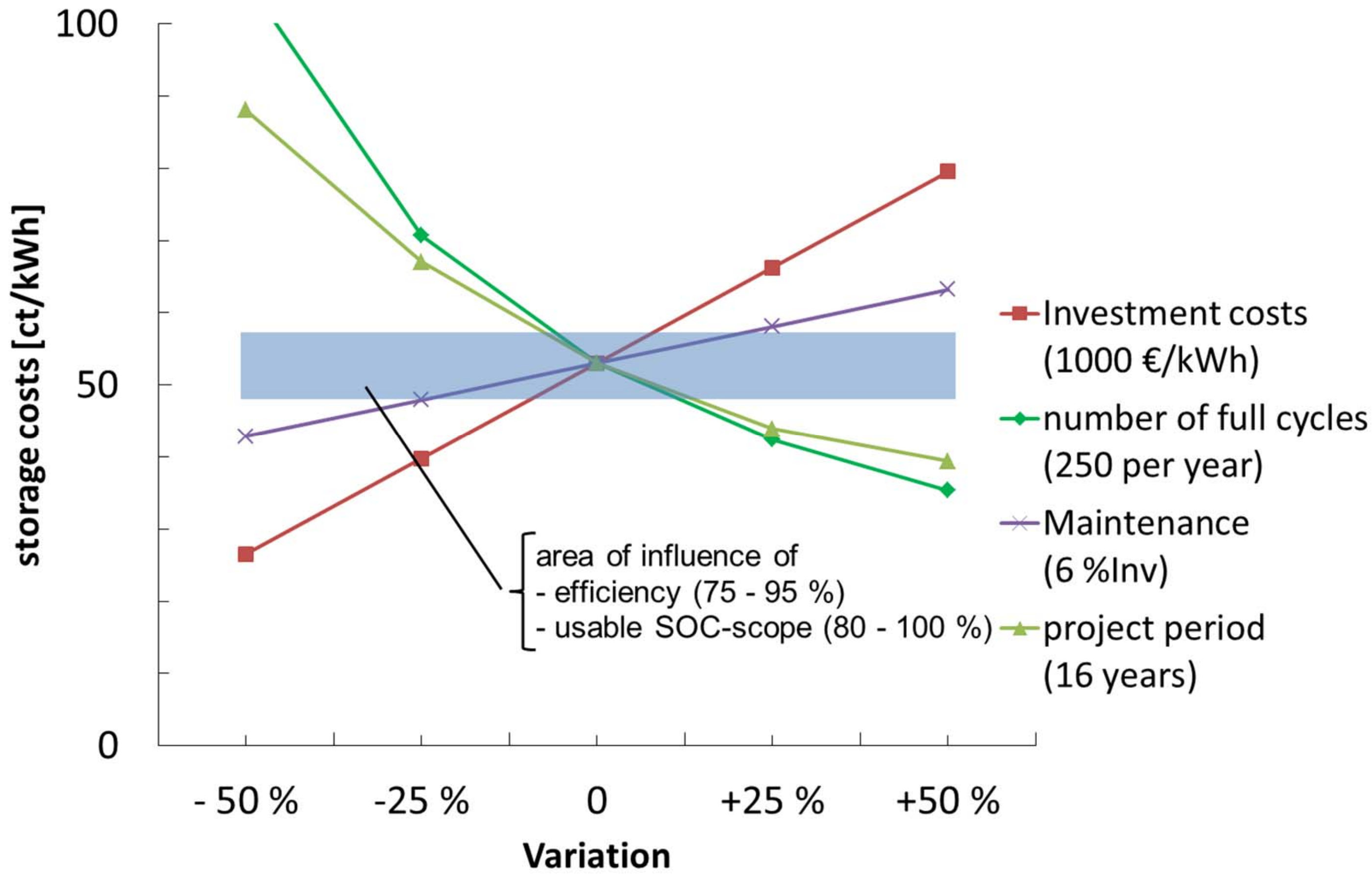
Battery storage: Levelized cost of energy storage as a function of usable capacity and power



Cost analyses
Lithium-ion battery system

Cost drivers

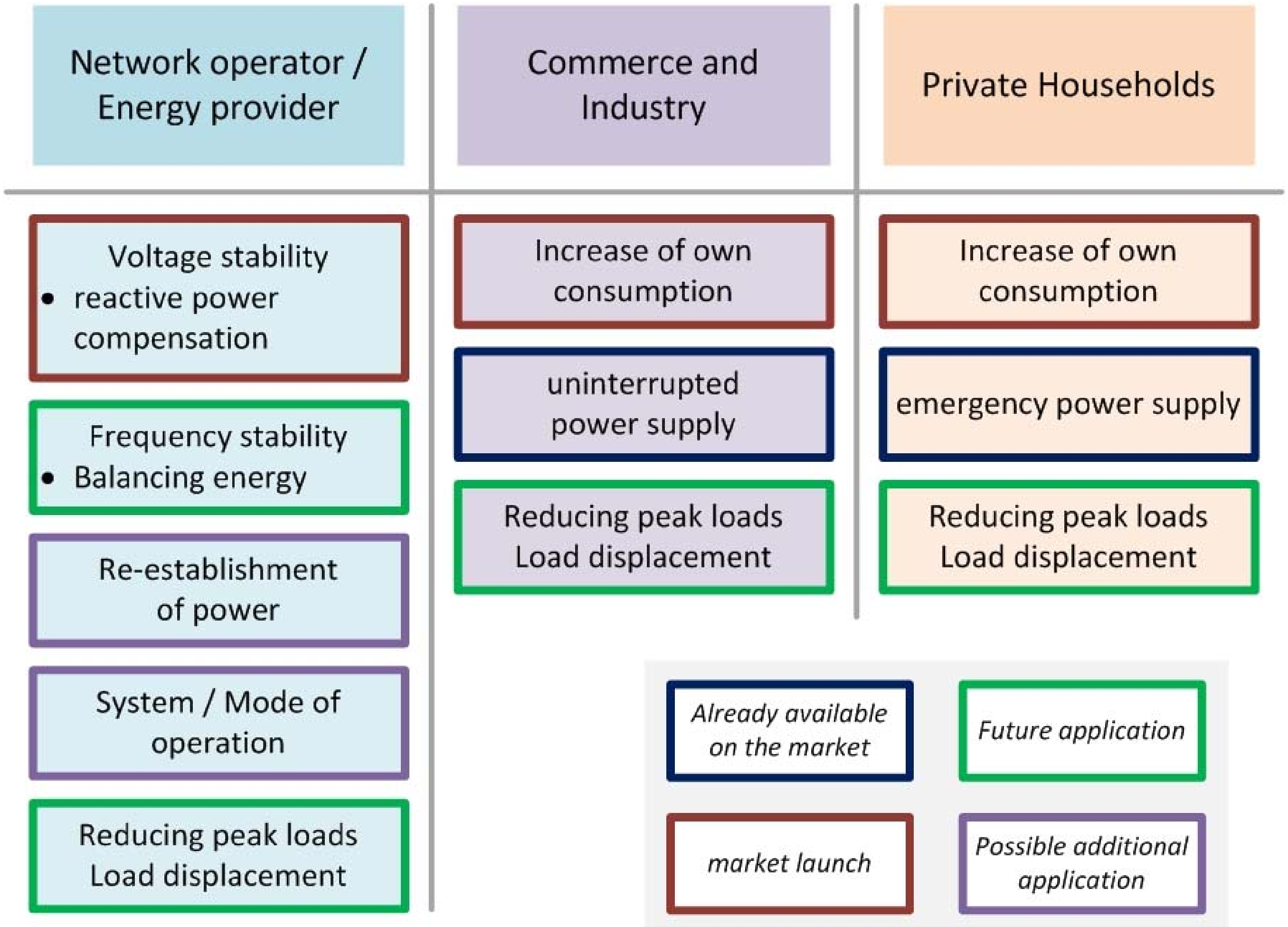
- Investment cost
- Cycle number
- Operation and maintenance
- Project period



Stationary battery systems

Additional business cases beyond PV self-consumption

- Multiple use of storage device
  - → Additional services, e.g. grid support
  - → Additional revenues



Future distribution grids with various flexibility options
Classification

Additive generation

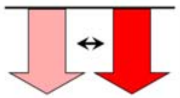
- Application: rare short-term peak loads
- Technology: e.g. emergency power units (hospitals)

Dispatchable generation

- Application: frequent and high short-term peak loads
- Technology: CHP units

Electric power storage

- Application: daily balancing of power demand and generation
- Technology: e.g. battery systems, decentralized and "centralized"



Dispatchable load

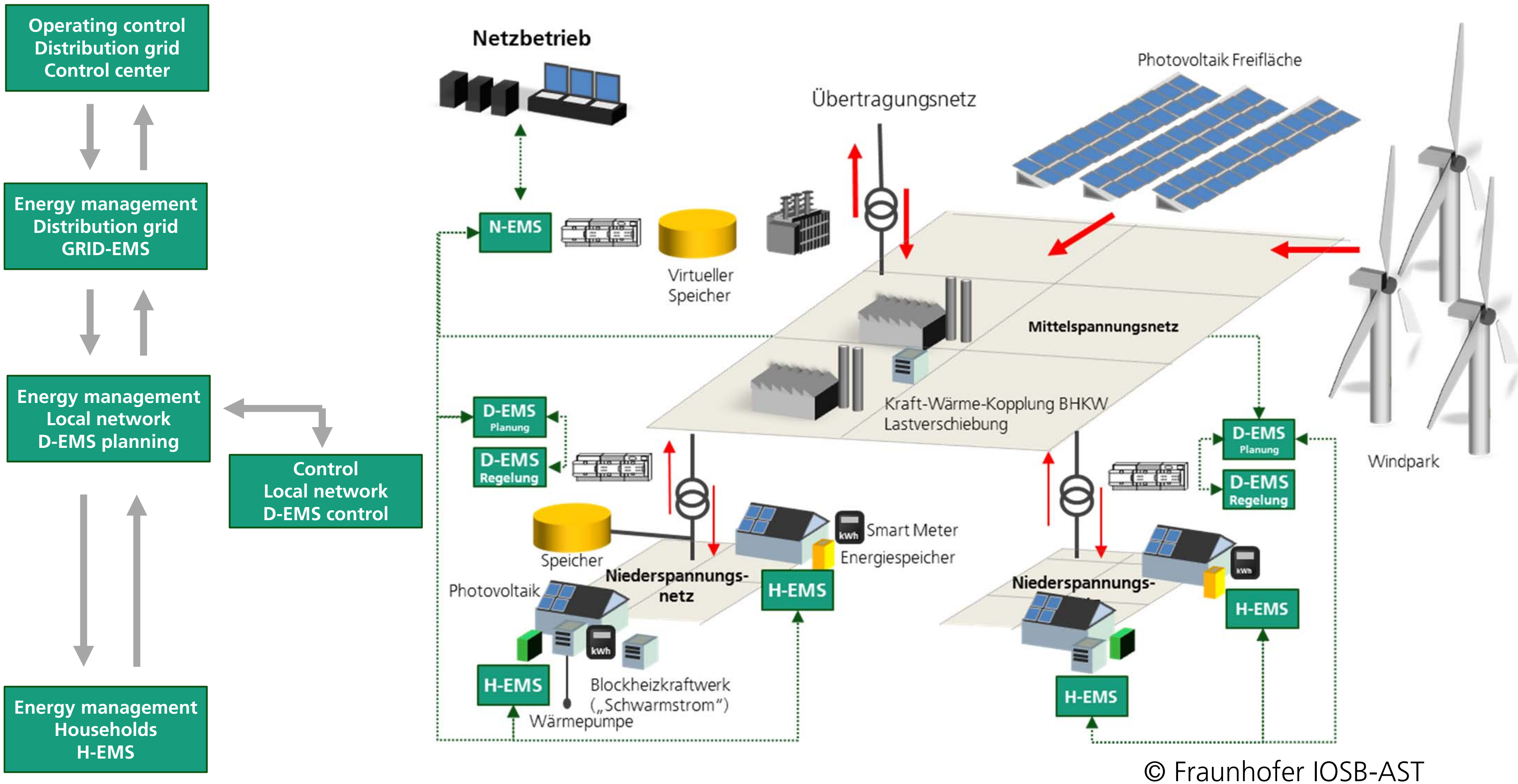
- Application: frequent and high short-term generation peaks
- Technology: e.g. heat pumps with thermal storages, *electric cars (!)*

Additive load

- Application: rare generation peaks
- Technology: e.g. electrical heating (domestic hot water, district heating)

Future distribution grids with various flexibility options

Example of an energy management structure



© Fraunhofer IOSB-AST

renewables Made in Germany
energie waechter
Fraunhofer ISE

Conclusions

- Energy storage crucial for **large scale integration** of fluctuating renewables
- Market forecasts for **stationary battery storage** very promising
- Especially **lithium-ion** battery systems very interesting for the use in grid-connected PV applications as short-term storage
- Lithium-ion batteries on the way to be **profitable**, dependent on the specific application and the boundary conditions
  - ➢ Detailed simulation based system analyses enable an **optimized design**
  - ➢ Cost still have to be decreased → Detailed **cost analyses** important
  - ➢ **Multiple use** of storage systems may improve the economics
- But: There are more **flexibility options** in the (distribution) grid, which also have to be considered
  - ➢ Smart integrated **system solutions** necessary

Thank you very much for your attention!

Contact: matthias.vetter@ise.fraunhofer.de

Dansk-Tysk Handelskammer
Deutsch-Dänische Handelskammer

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag