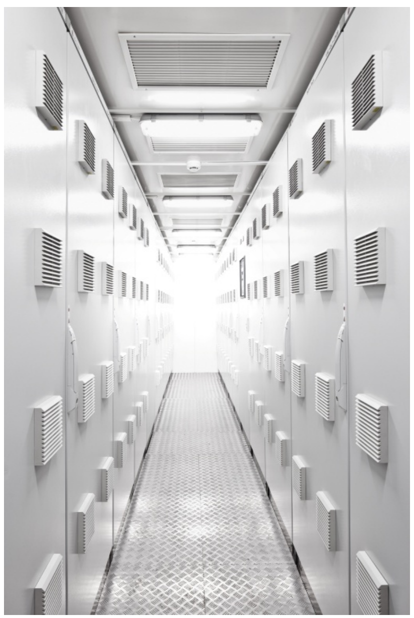
Results from energy technology innovation projects - the perspective of a Swiss utility

Michael Koller, Chief Technology Officer

May 15th 2018, Seminar talk Lawrence Berkeley National Lab

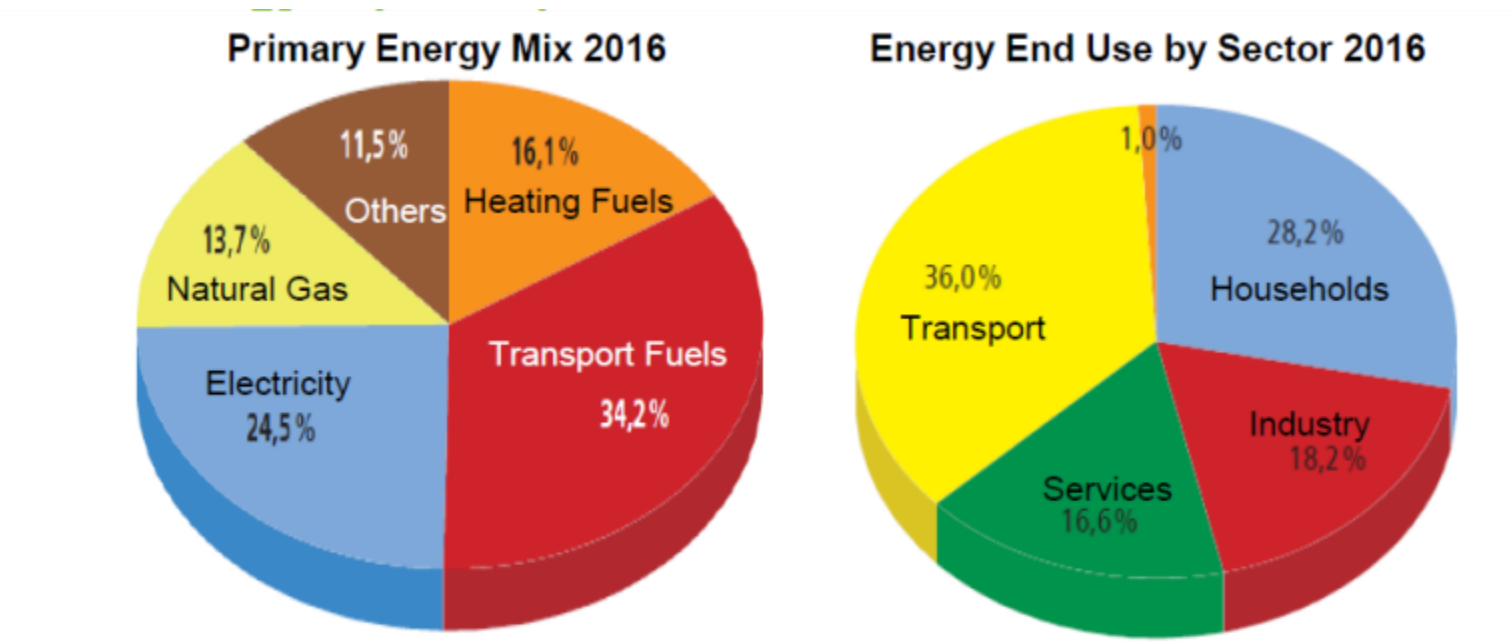


Outline

- Introduction to Swiss energy transition strategy
- Introduction to EKZ
- Photovoltaic activities
- Self-consumption communities
- Flexibility from industrial loads
- Flexibility from batteries
- Flexibility from residential loads

Swiss energy landscape

- 80% import dependance

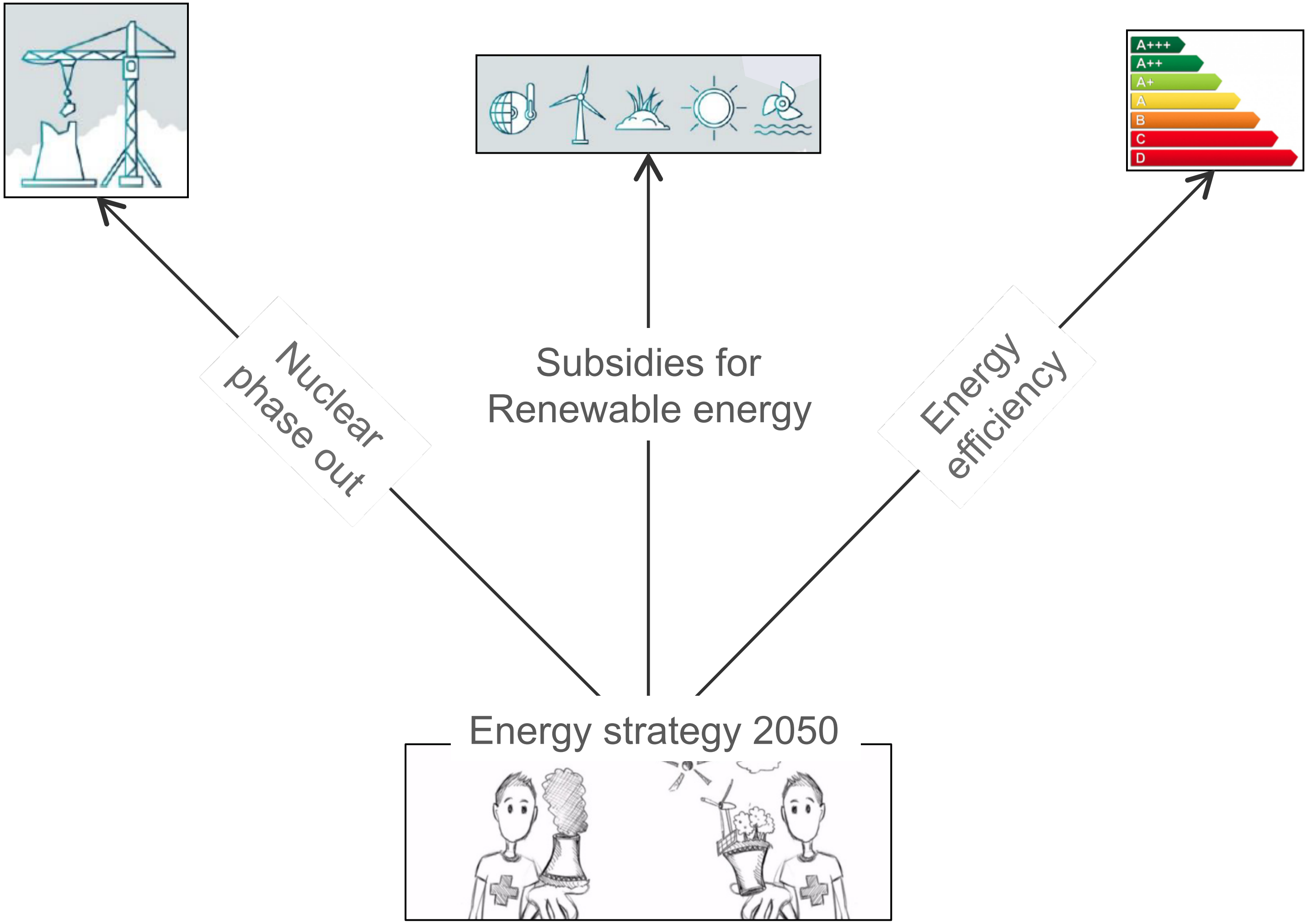


Swiss energy strategy 2050

11.3.2011	Fukushima
25.5.2011	Government opts for nuclear phase out
28.9.2012 - 31.1.2013	Discussion on first measurement package
04.9.2013	Start of parlamentary discussion
Parlamentary discussion	
30.9.2016	Final vote
31.1.2017	SVP (right wing party) calls for referendum
01.2.2017 - 08.5.2017	Preparation of enactment
21.5.2017	Public vote on Swiss energy strategy 2050
01.1.2018	**Enactment**

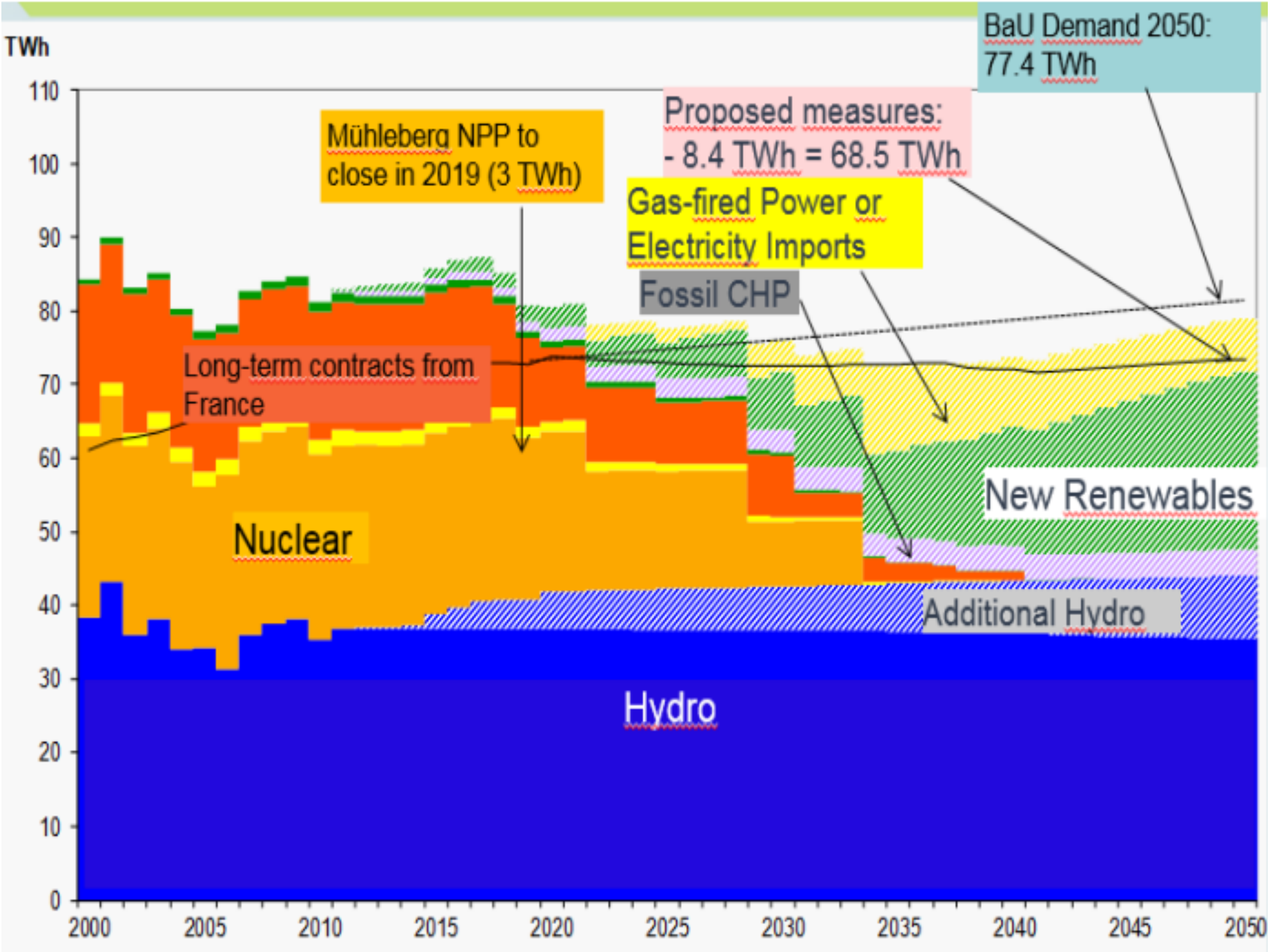
EKZ

Swiss energy strategy 2050



EKZ

Swiss energy strategy 2050



EKZ

Swiss electricity sector

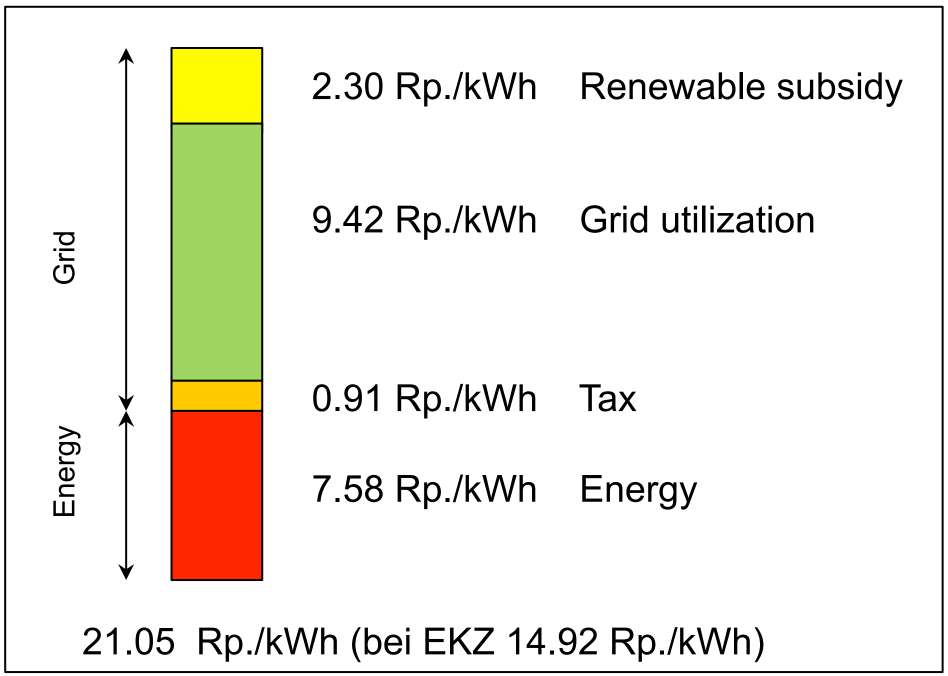
- Approx. 650 DSOs (partially unbundled)
- Swissgrid as the only national TSO (unbundled)
- Deregulated market for customers with 100 MWh and above
- Regulated market for residential customers (DSOs)

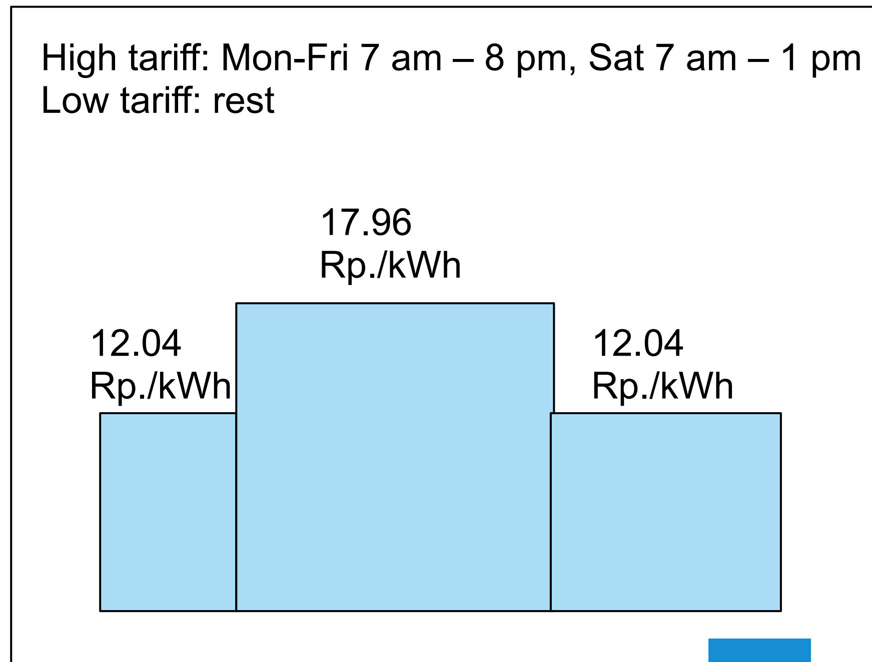
EKZ

Swiss electricity tariff structures

- Grid fees are charged exclusively to consumers – no connection or utilization charge for generators
- All tariffs are time of use – tariffs for industrial customers include demand charges (4 – 12 CHF/kW for maximum 15 minute peak in a month)
- No grid charges for on-site generation (self consumption)

Residential customers

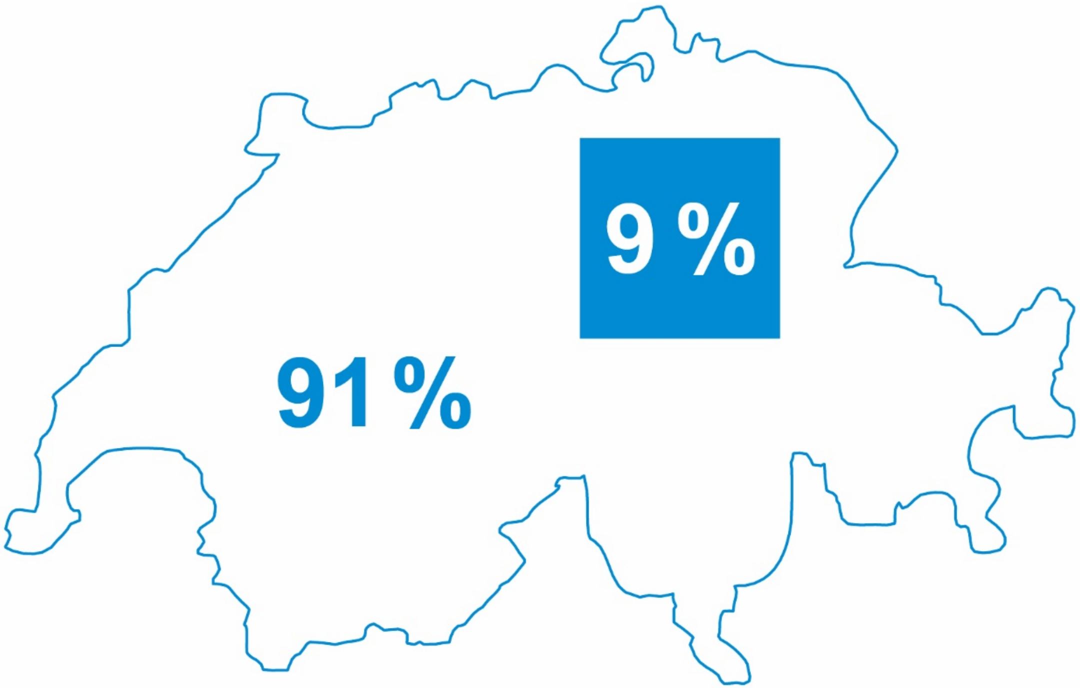




One of Switzerland's largest power companies

5492

Gigawatt hours



EKZ

Our contribution to the energy transition

- **We invest 600 million Swiss Francs in renewables**
- **We believe in Swiss Hydropower**
- **We develop smart solutions for the future of energy**
- **We promote energy efficiency**

EKZ

Energy for the Canton of Zurich

The EKZ distribution grid supplies electricity to a large part of the Canton of Zurich

- Medium and Low Voltage grid
- All customers with three-phase connections
- 39 primary substations
- 2'500 secondary substations
- 14'300 km cables
- 700 km overhead lines
- 375'000 electricity meters

Reliable performance: maximum grid availability

99.997 %

Availability of our grid

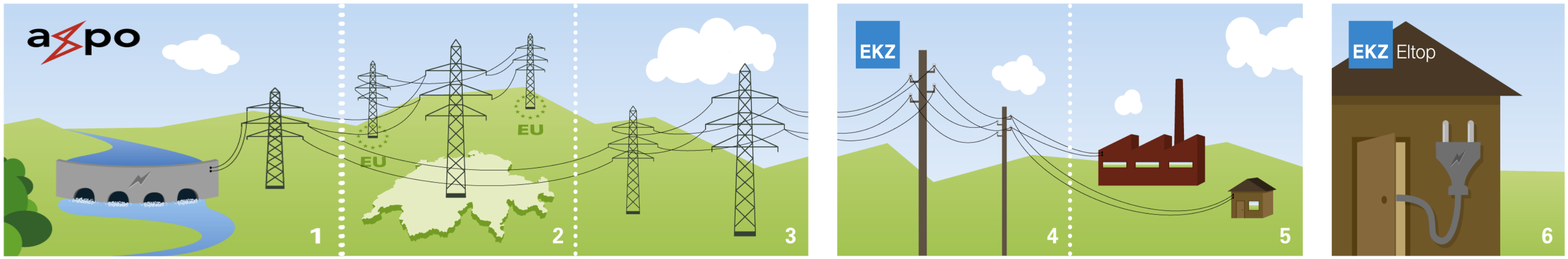
- **EKZ customers are on average 14 minutes a year without electricity**
- **The Swiss average stays at 19 minutes – considerably higher**
- **We invest more than 50 million Swiss Francs a year in security of supply**
- **EKZ's grid utilization fees are significantly below the Swiss average**

Our key figures

	2016/17	2015/16
Electricity supplied by the distribution grid in GWh	5492	5463
Sales in CHF million	740.7	771.1
EBIT in CHF million	81.6	70.5
Profit for the year in CHF million	58.6	70.5
Cash flow from operating activities in CHF million	129.9	2245.2
Employees	1370	1353
Trainees	126	139

EKZ

EKZ‘s value chain and business units



Produktion | Handel & Verkauf | Übertragung | Verteilung | Vertrieb & Beratung | Anwendung & Installation

1  **Grid**

2  **Energy**

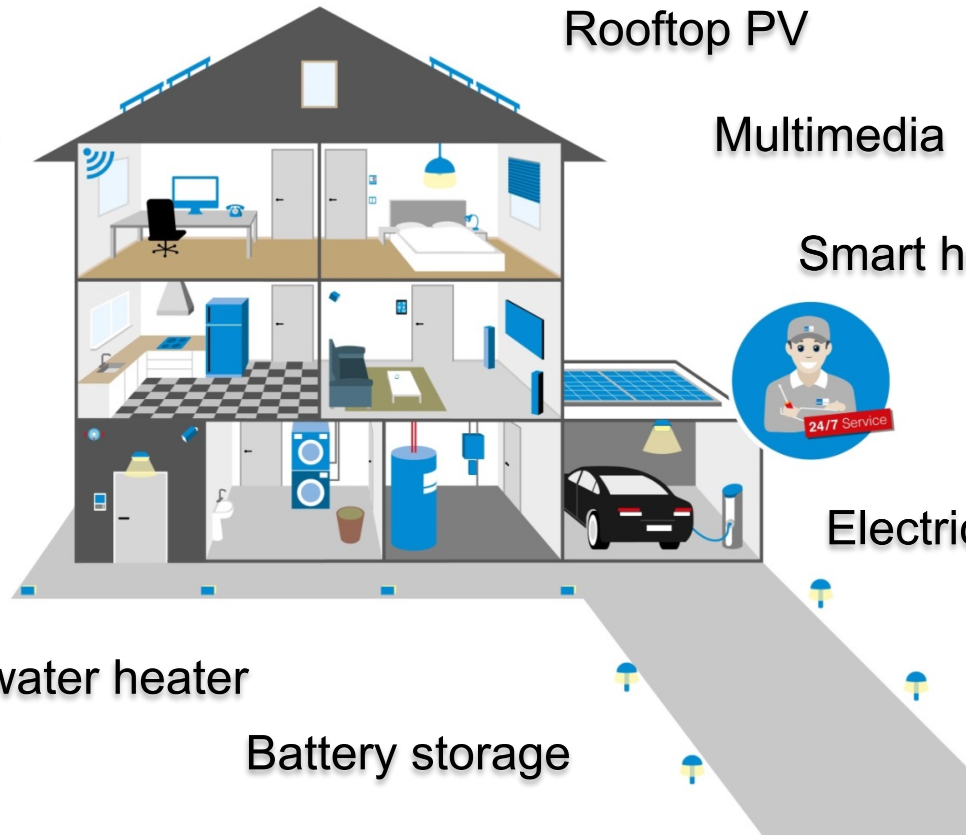
3  **Elect. Installations**

4  **Renewable Energy**

5  **HVAC Contracting**

6  **Grid Services**

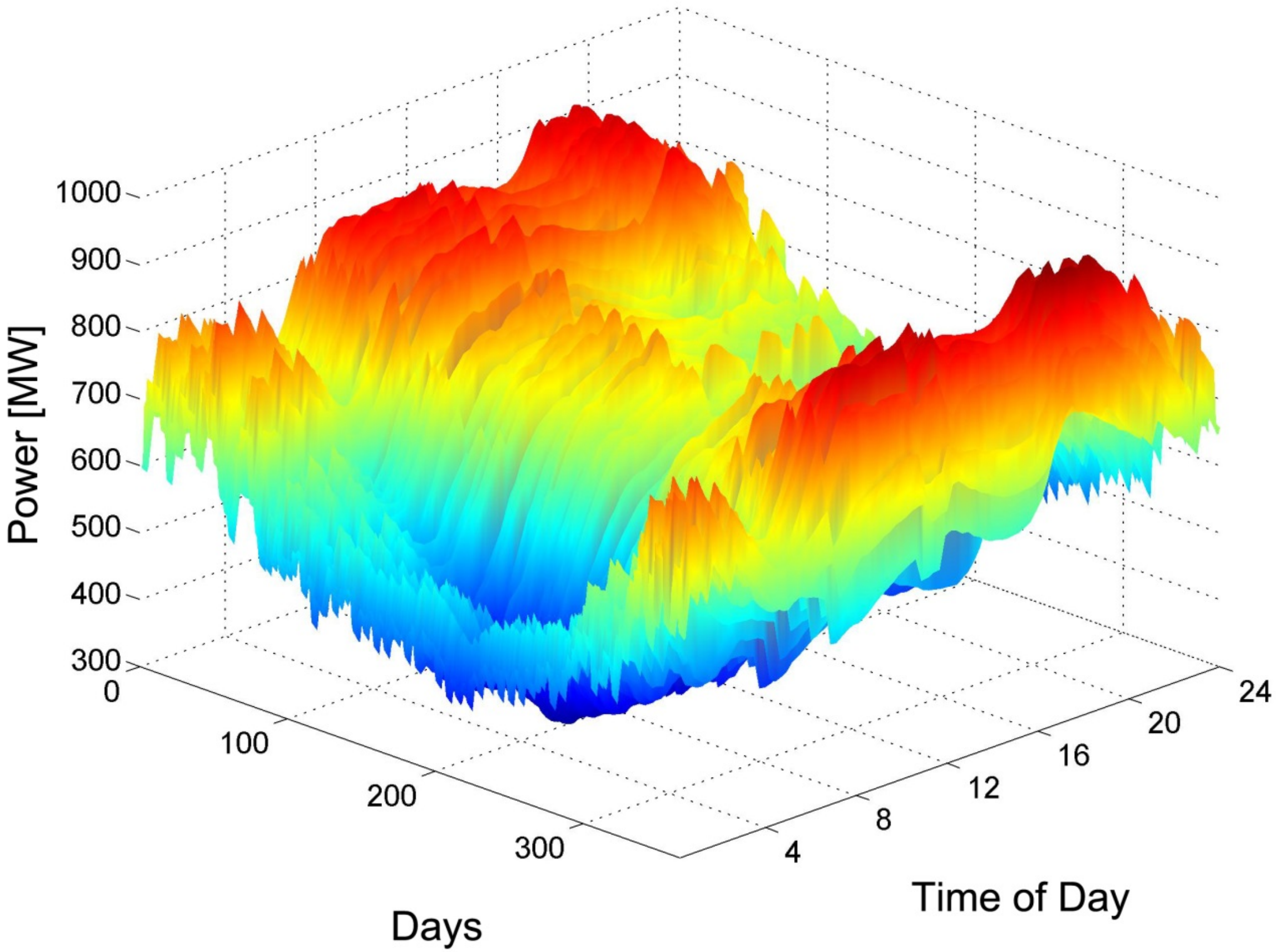
EKZ’s electrical installation offering (residential)



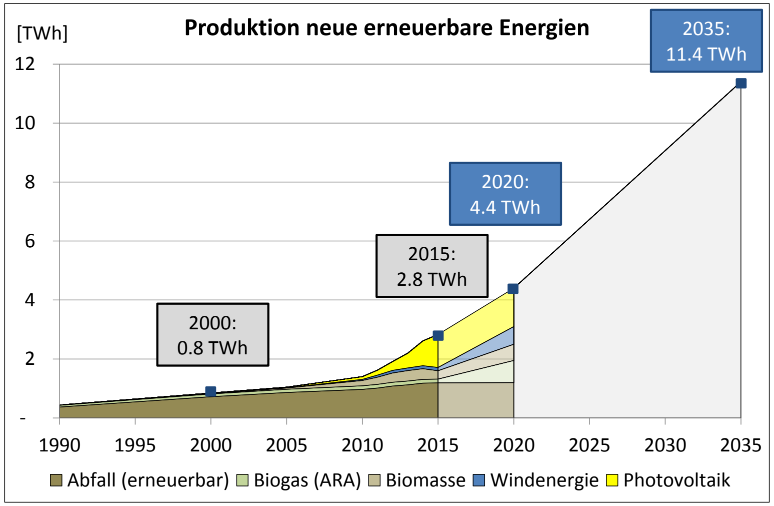
- 24/7 Hotline
- 400 electricians
- More than 30 locations in the canton of Zurich

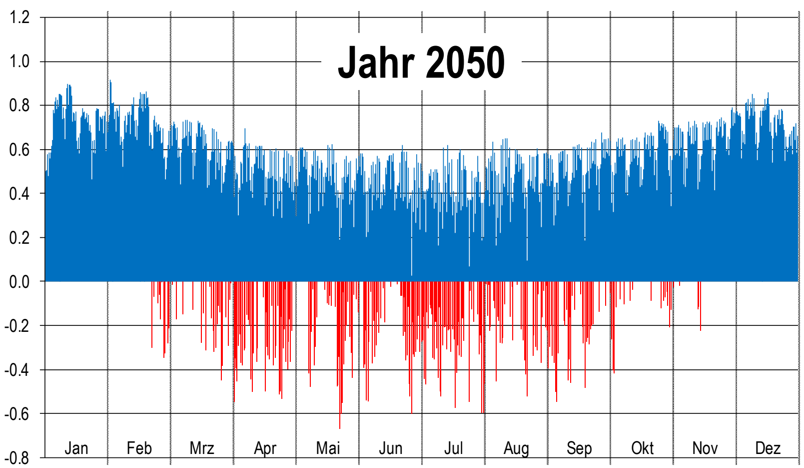
EKZ

EKZ aggregated distribution grid residual load



Expected PV development





Swiss energy strategy 2050

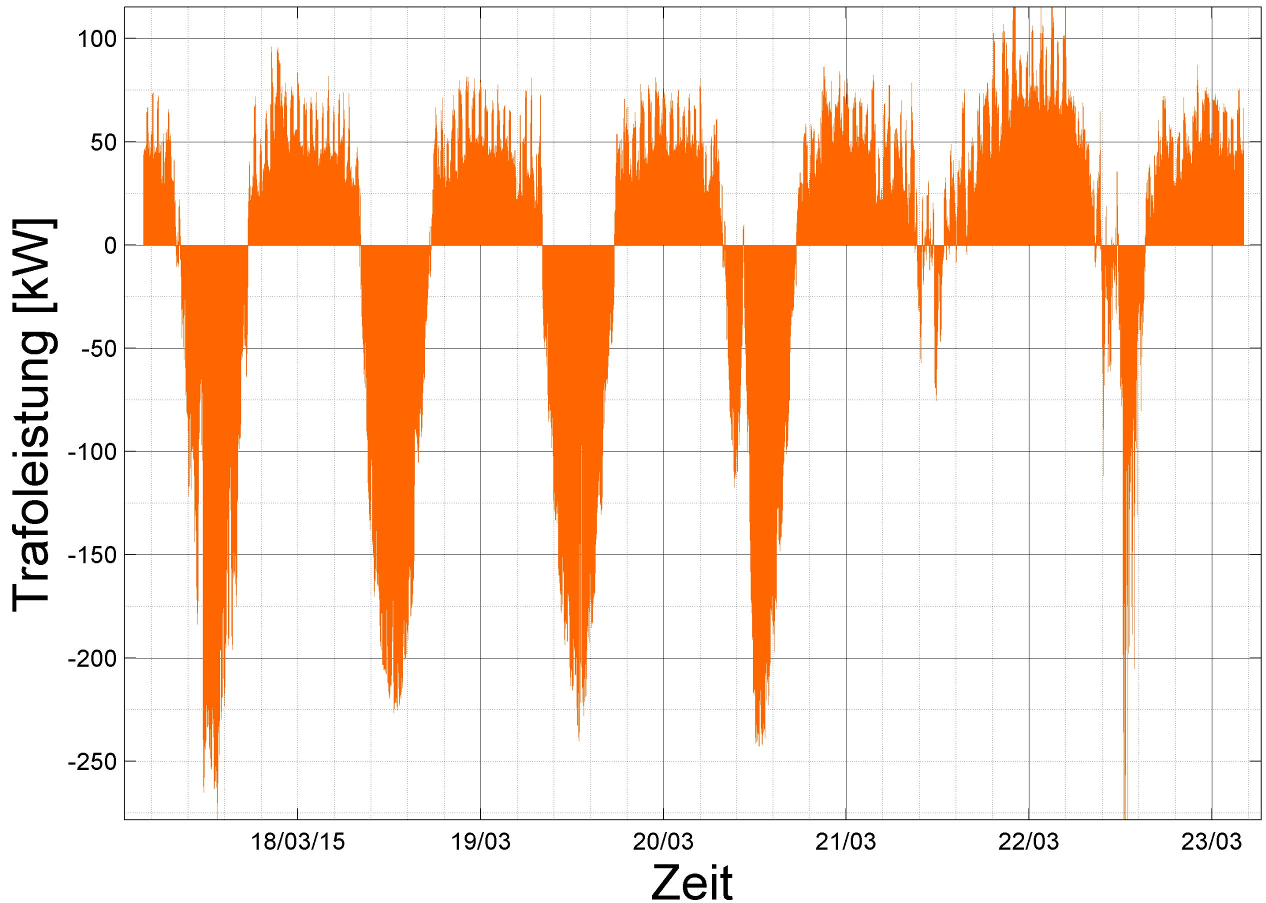
- 11 TWh PV until 2050

EKZ

- Today ~4000 grid connected PV plants (~80 MW, ~0.08 TWh)
- ~7000 plans expected until 2020
- ~1.4 TWh PV until 2050 (1.4 GW) in EKZ distribution grid

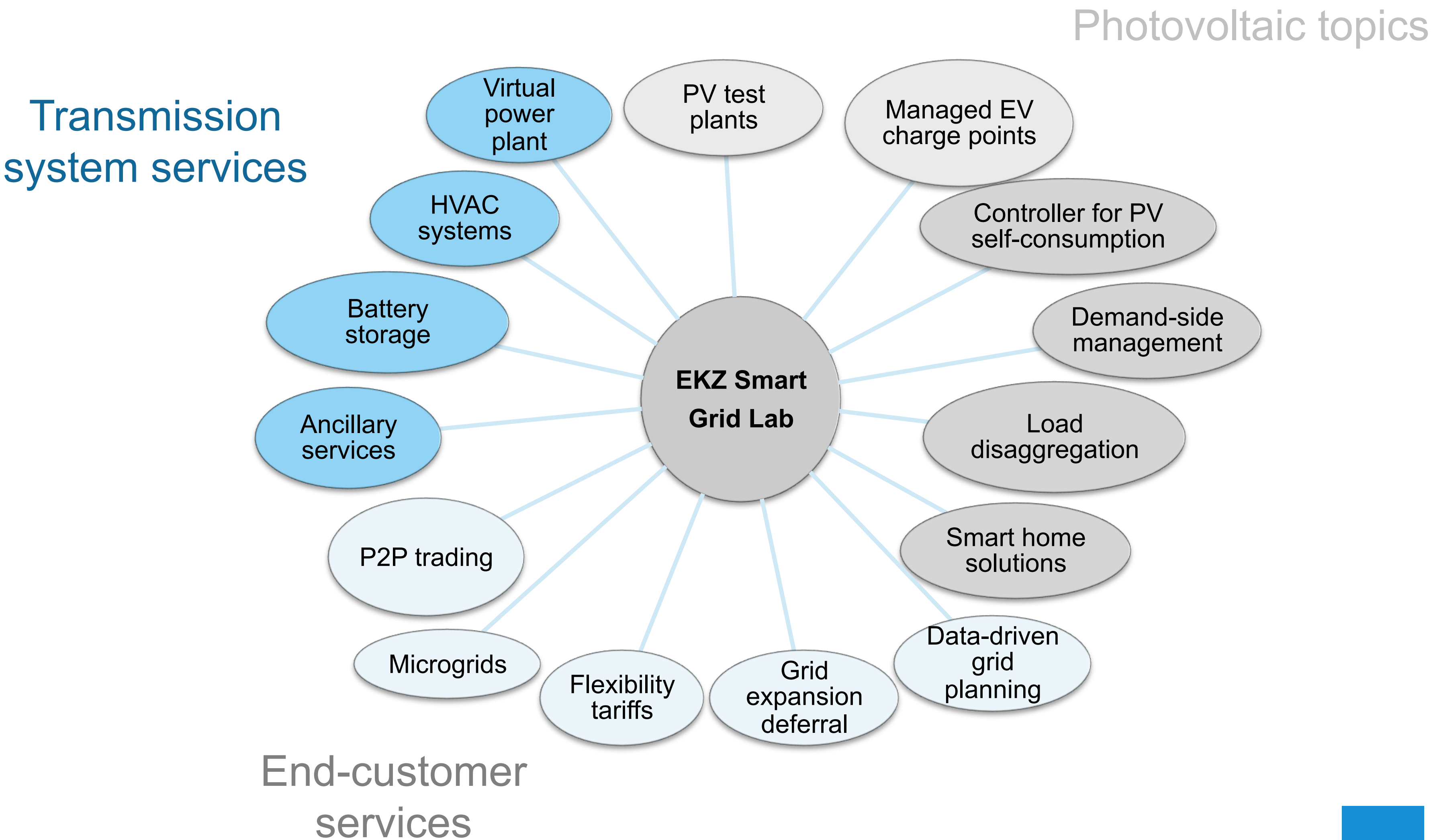
Grid integration challenges

Measurement of load flow situation at EKZ secondary substation



EKZ

Projects EKZ Smart Grid Lab



Partners EKZ Smart Grid Lab

ETH Zürich

ABB

KIWIGRID

Zürcher Hochschule für Angewandte Wissenschaften
zh aw School of Engineering

steadysun

embotech
Doing more with less

n|w Fachhochschule Nordwestschweiz

LG Chem

SOLARWATT
Systemintelligenz

VIRTUAL GLOBAL SYSTEMS AG

ADAPTRICITY

Landis+Gyr
manage energy better

EKZ

EKZ PV test infrastructure

PV-Modules | EKZ Meteo | Self consumption | Ancillary services

Measurement bus

EKZ Meteo

Swiss business environment for residential photovoltaic + battery systems

Photovoltaic systems

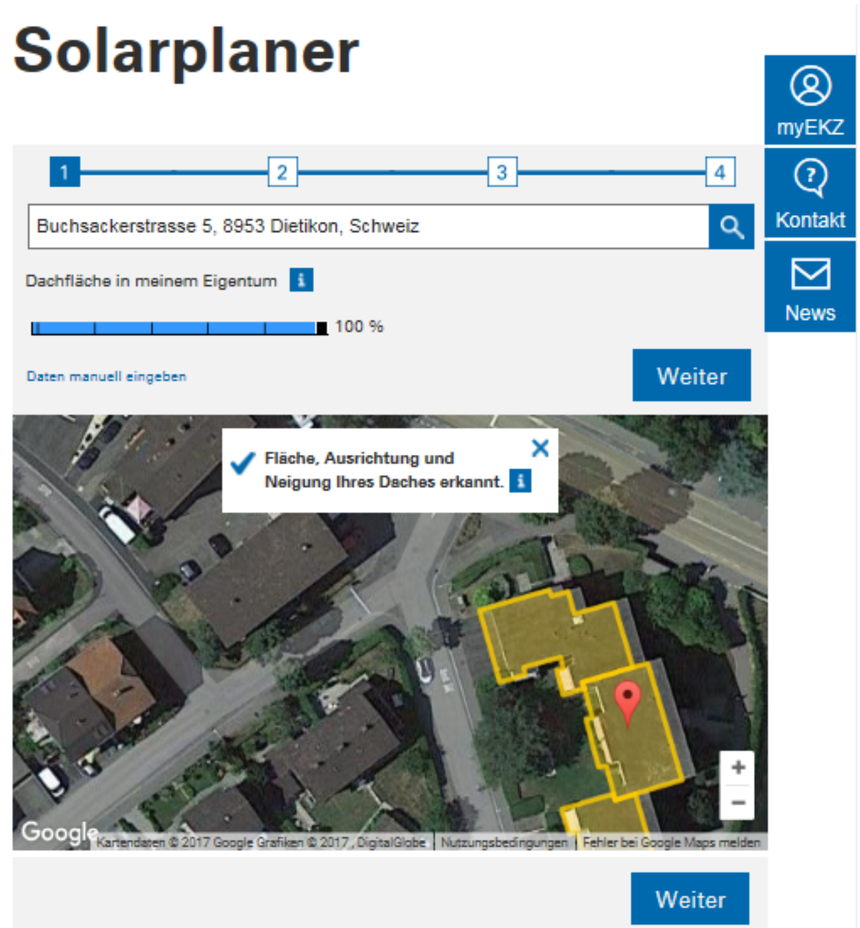
- Investment grants for PV-systems <30 kWp
- Feed-in tariff of currently **4 – 10 Rp./kWh** for new built systems (decreasing trend)
- LCOE 5 – 30 kWp PV-systems
  14 – 18 Rp./kWh (incl. investment grants)

Distribution system

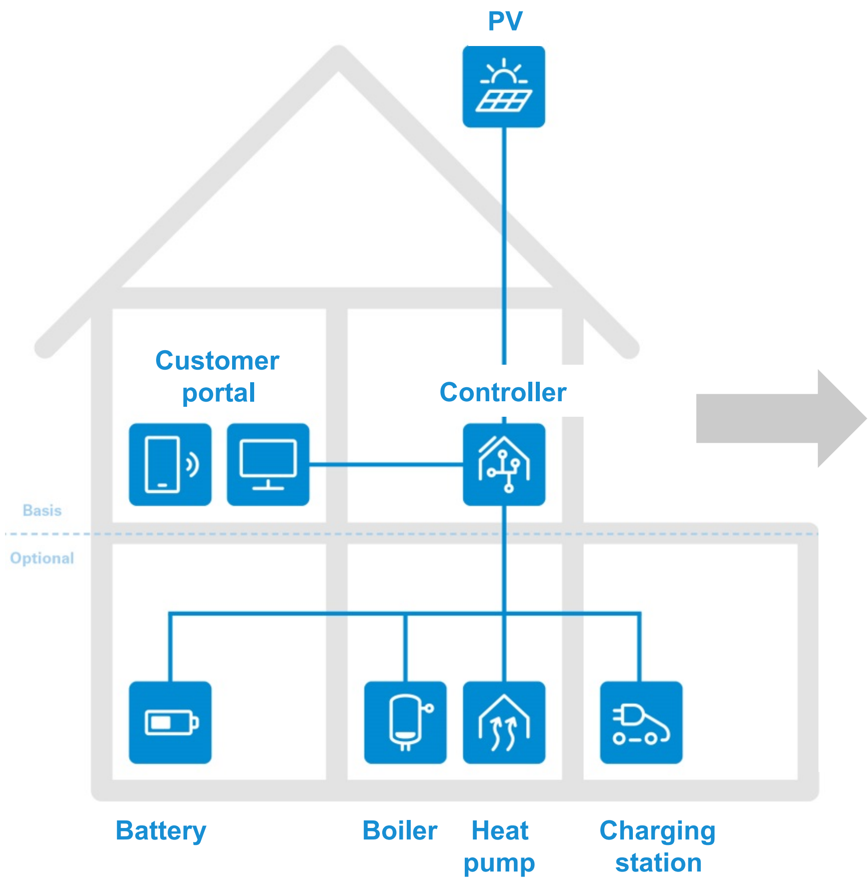
- Peak tariffs for residential customers
  16 – 25 Rp./kWh (no choice of supplier)
- No grid utilization fees for self-consumed PV
- Three-phase connection required for PV-systems >3.6 kVA and all sizes[1] of battery storage systems

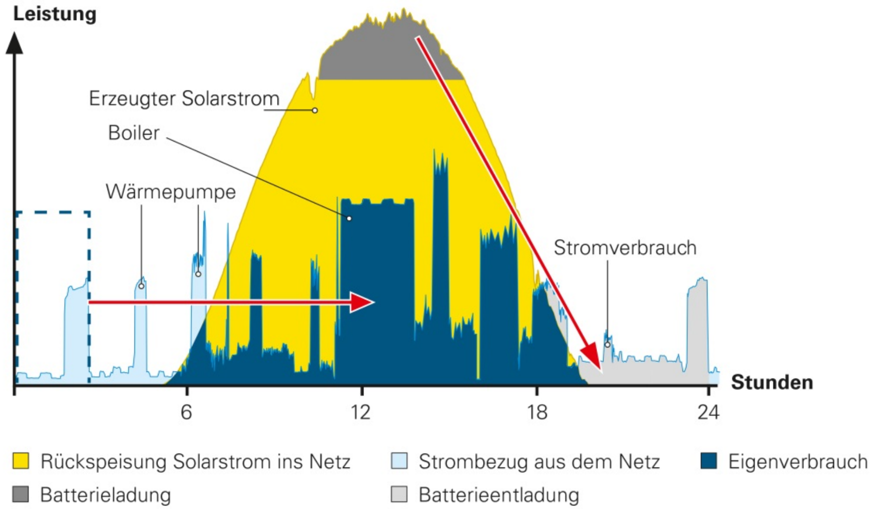
[1] upcoming changes in 2018

einfachSolar.ch – EKZ prosumer offering



Self-consumption with EKZ einfachSolar controller





- Increased self-consumption through targeted control of main appliances

Sizing guidelines for residential battery systems

Different approaches to determine optimal values for battery power [kW] and capacity [kWh] (most with a negative net present value):

Technical	Financial	Emotional
Use desired target values for:	Maximize KPIs for residential battery investment:	Avoid certain events:
self-sufficiency [%] self-consumption [%] Islanding capability [h]	IRR [%] NPV [%]	Battery not empty during breakfast following a sunny day Battery not full before noon during summer
Large batteries	**Small batteries**	**Medium batteries**

EKZ

einfachSolar Battery
myReserve vs. MATRIX

Until October 2017: myReserve

8.8 kWh / 4 Packs à 2.2 kWh
Volume: ~ 450 Liter

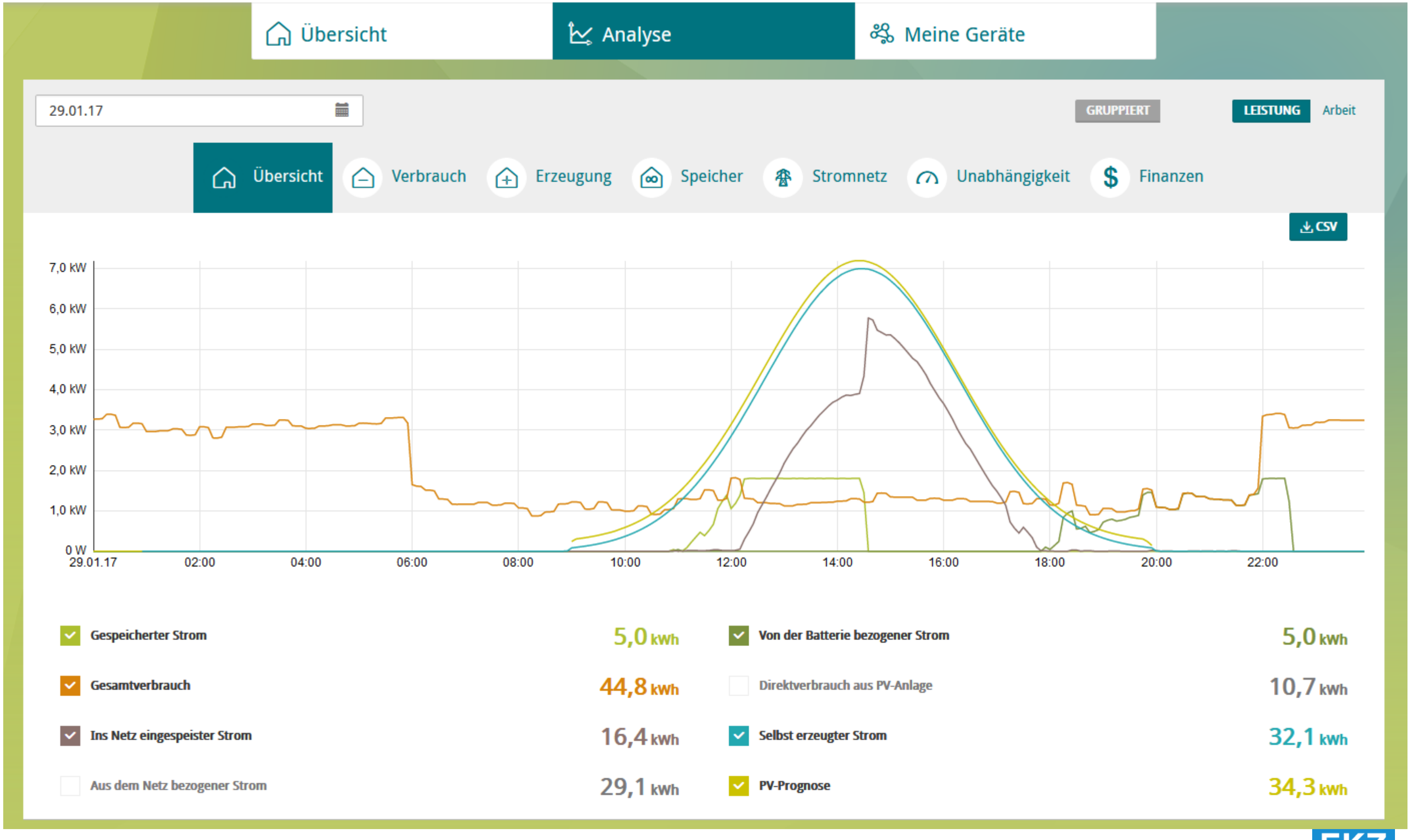
- **Energy density: ~20 kWh/m³**
- **Power density: ~ 6 kW/m³**

Since November 2017: Matrix

9.6 kWh / 4 Packs à 2.4 kWh
Volume: ~ 125 Liter

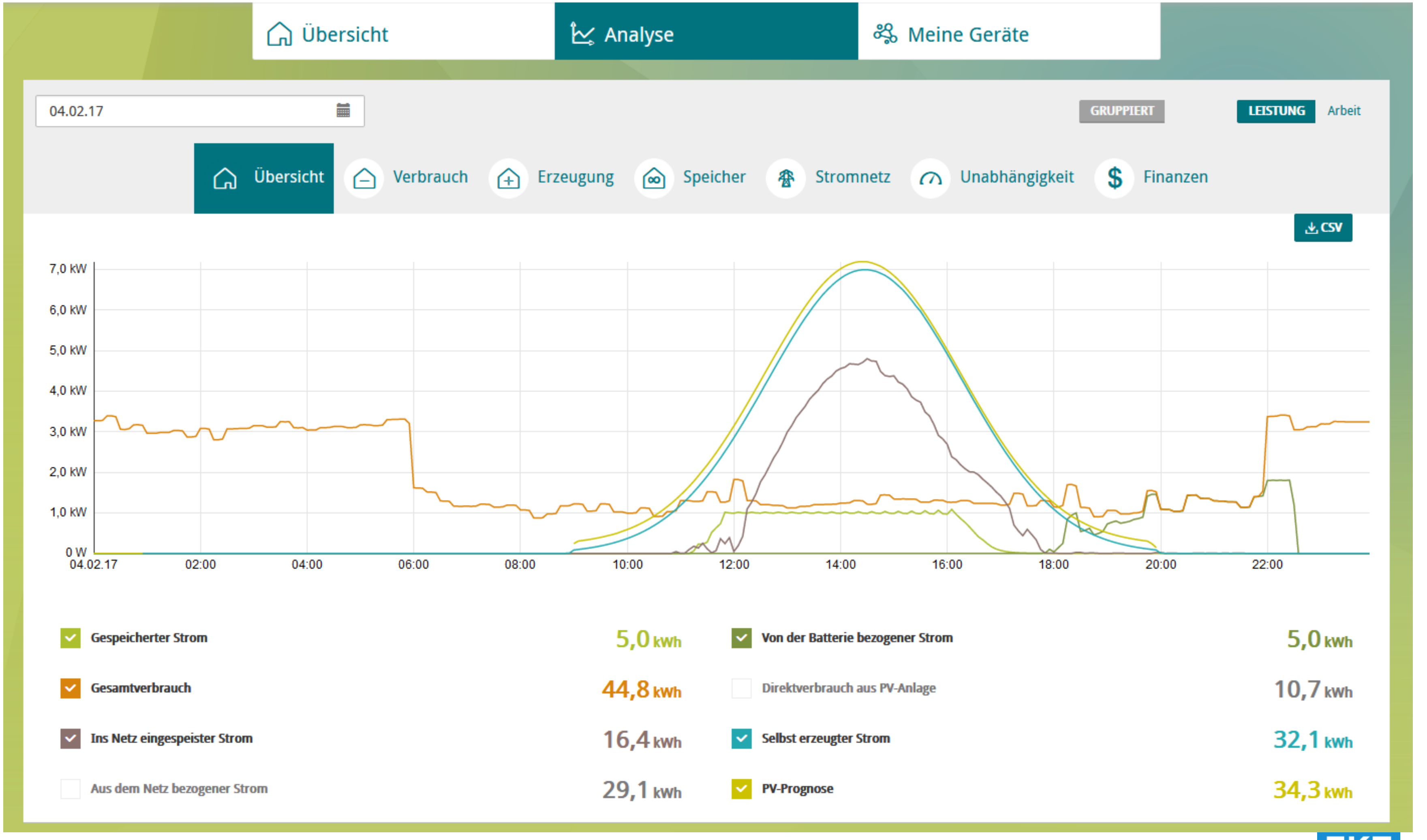
- **Energy density: ~ 76 kWh/m³**
- **Power density: ~ 25 kW/m³**

Battery storage to maximize self-consumptions
Maximum grid load unchanged (but less grid fees)



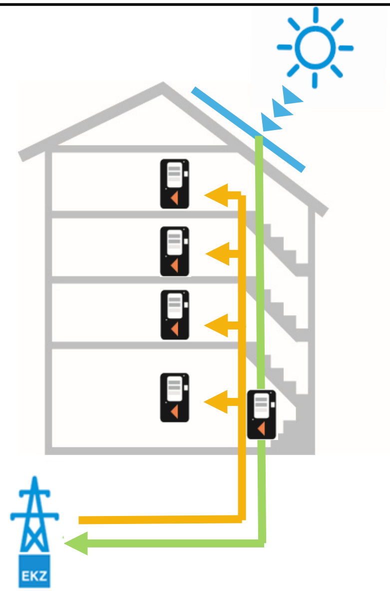
Battery storage to maximize self-consumptions

Grid friendly – einfachSolar controller starting Q3/2018



Self-consumption consorium in multi-family homes

Before

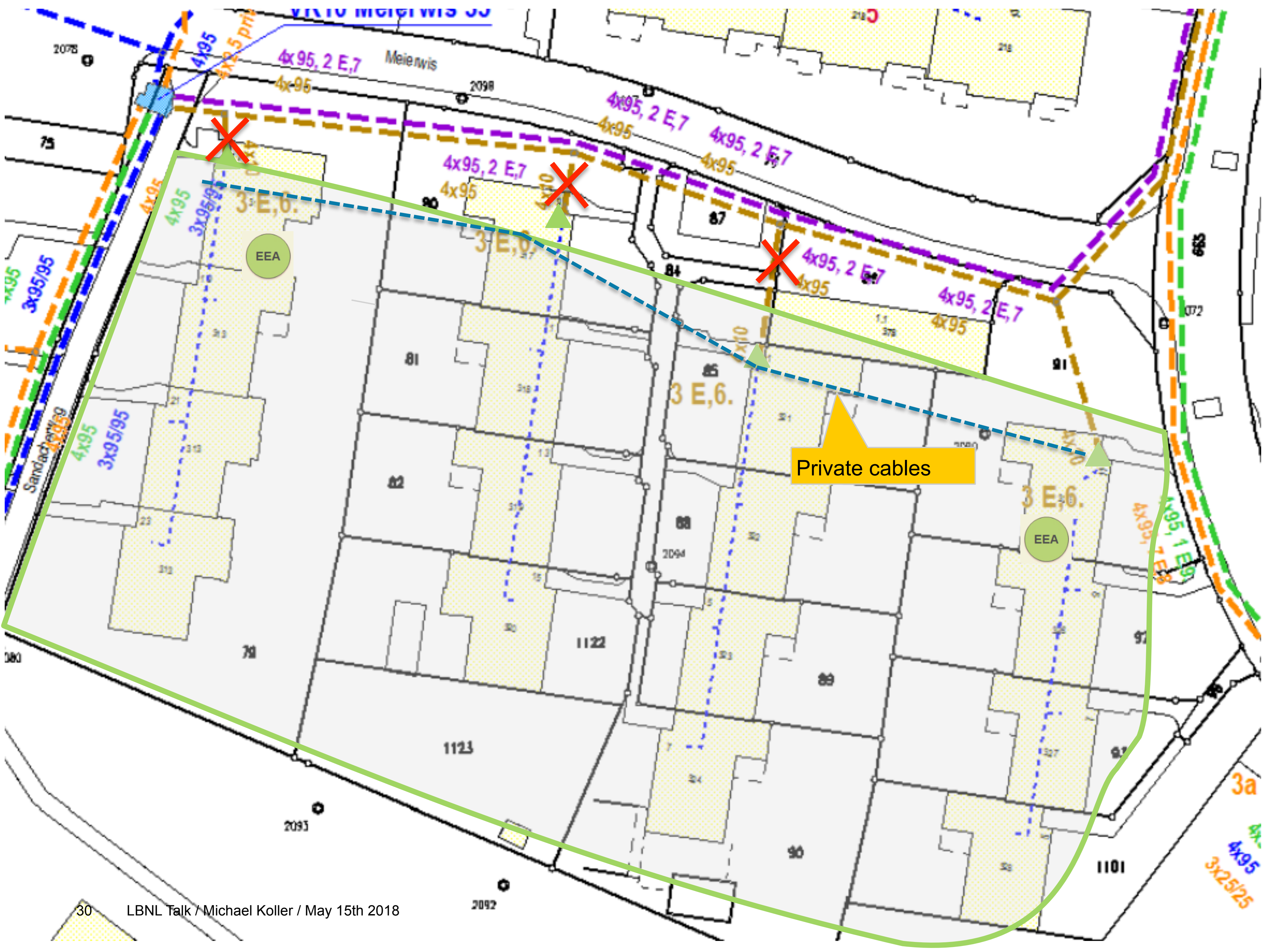


- Every apartment is one customer
- PV generation metered seperately

Since 01.01.2018

- Consortium is customer
- Metering inside consoritum deregulated
- Market access if consortium >100 MWh
- **Loss of customers** for DSO and utility

EKZ



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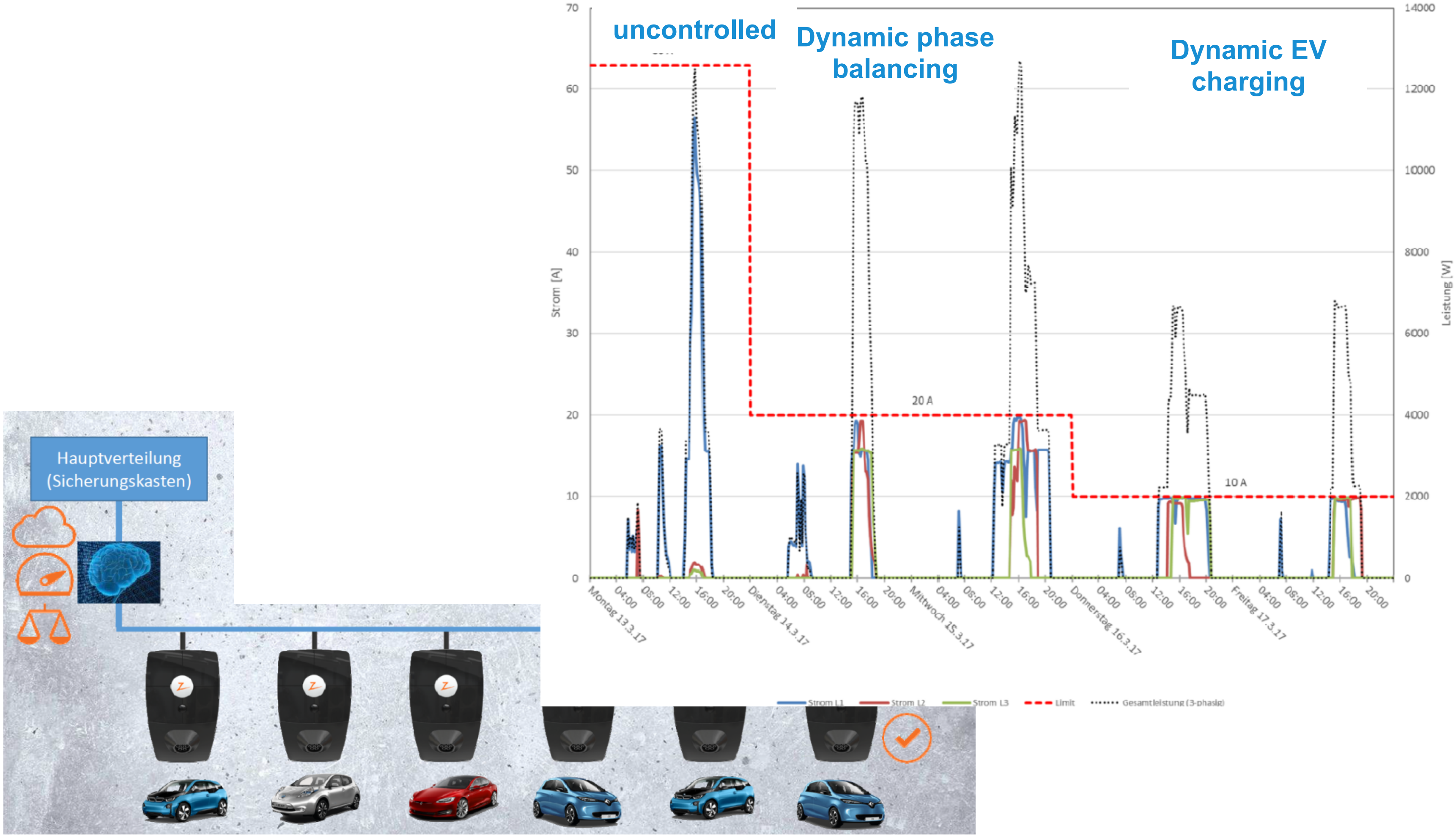
4x95, 2 E,7
4x95
EEA
EEA
3 E,6.
Private cables

EKZ's answer to self consumption cosortiums

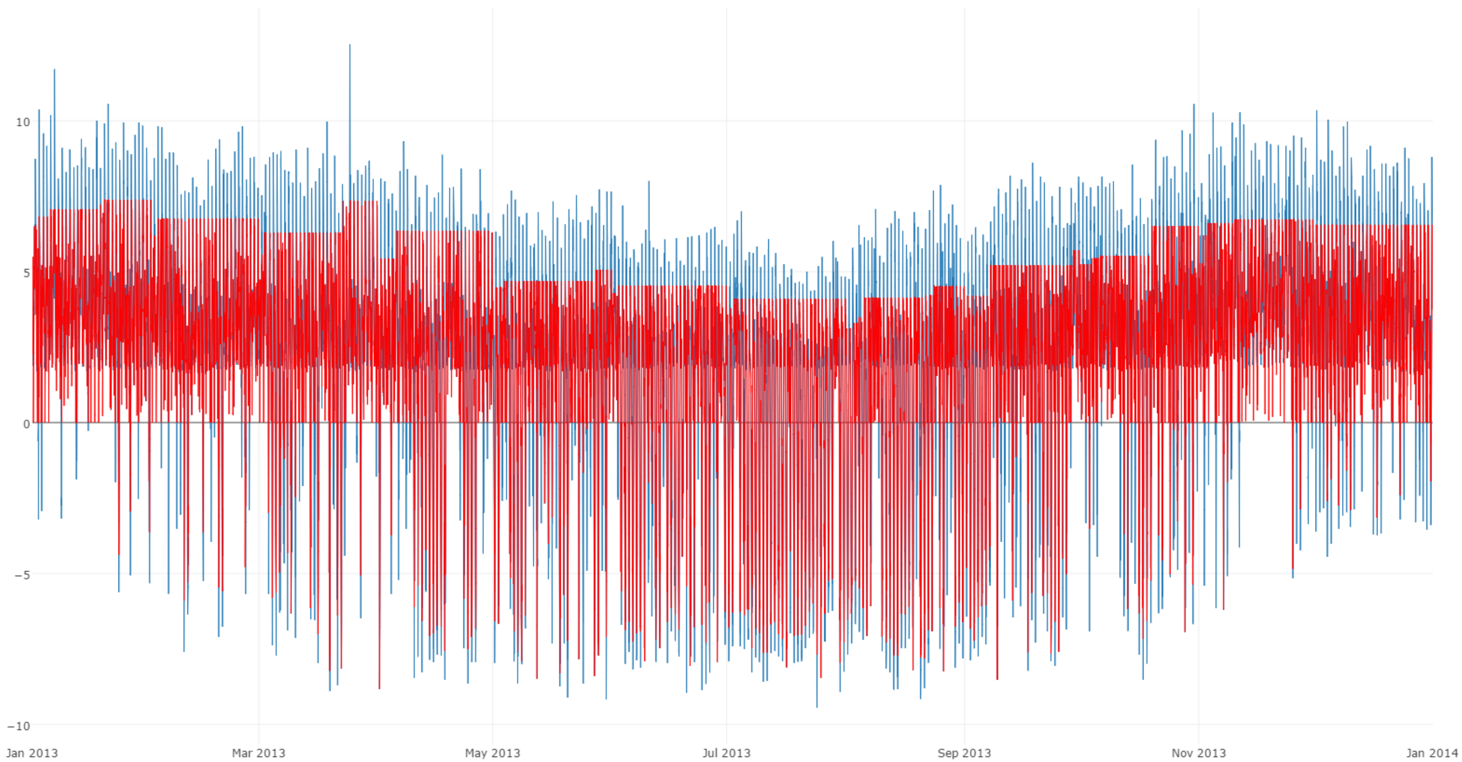
- **Metering as a service**
- **Photovoltaic installations**
- **Integrated energy solutions (PV, heat pumps and EV charging)**
- **Microgrid services (grid connected)**

Managed charging points



Commercial or utility with PV and storage

Tariff ewz business customers



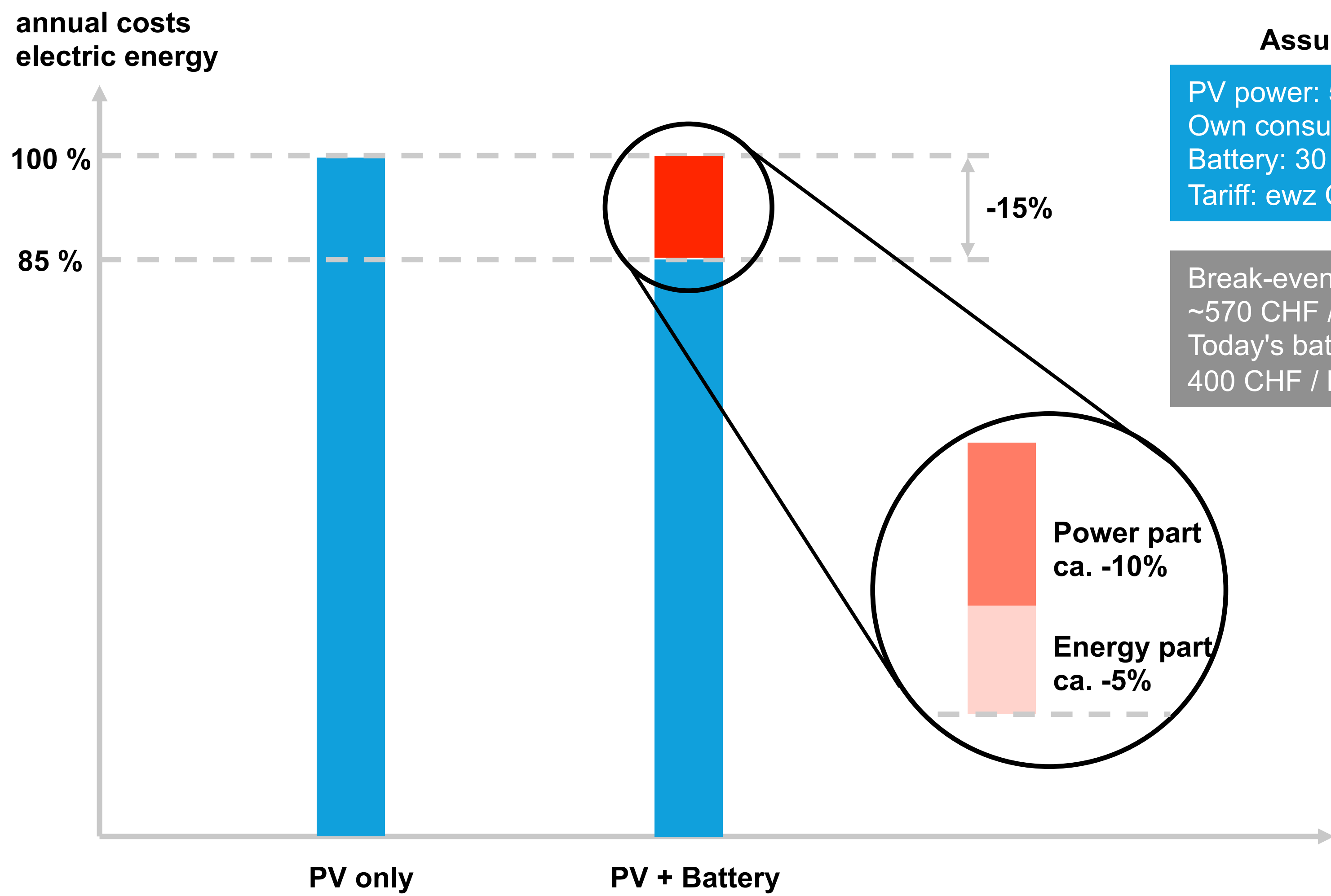
HT: 20.60 Rp./kWh
NT: 11.15 Rp./kWh
LT: 10 CHF/kW/Mt.

Average 33% reduction in peak performance

Conclusion:
Reduction of peak load by BESS when demand charges are present

EKZ

Battery and PV for MFH or commercial (study)



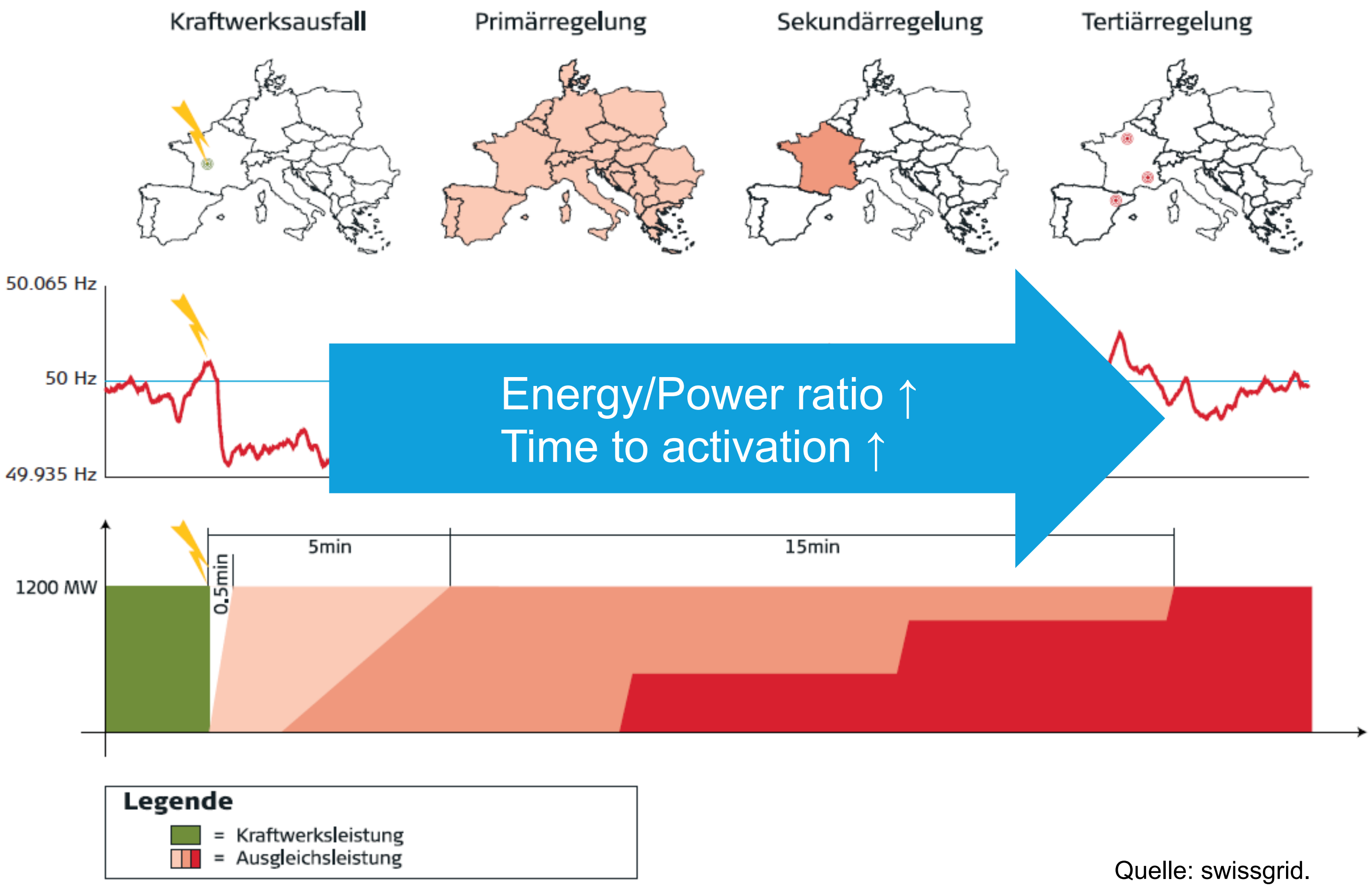
Assumptions system

PV power: 51.6 kW
Own consumption level PV: 70%
Battery: 30 kWh / 30 kW
Tariff: ewz C&I customers

Break-even price battery 10 yrs .:
~570 CHF / kWh
Today's battery price:
400 CHF / kWh (without install.)

EKZ

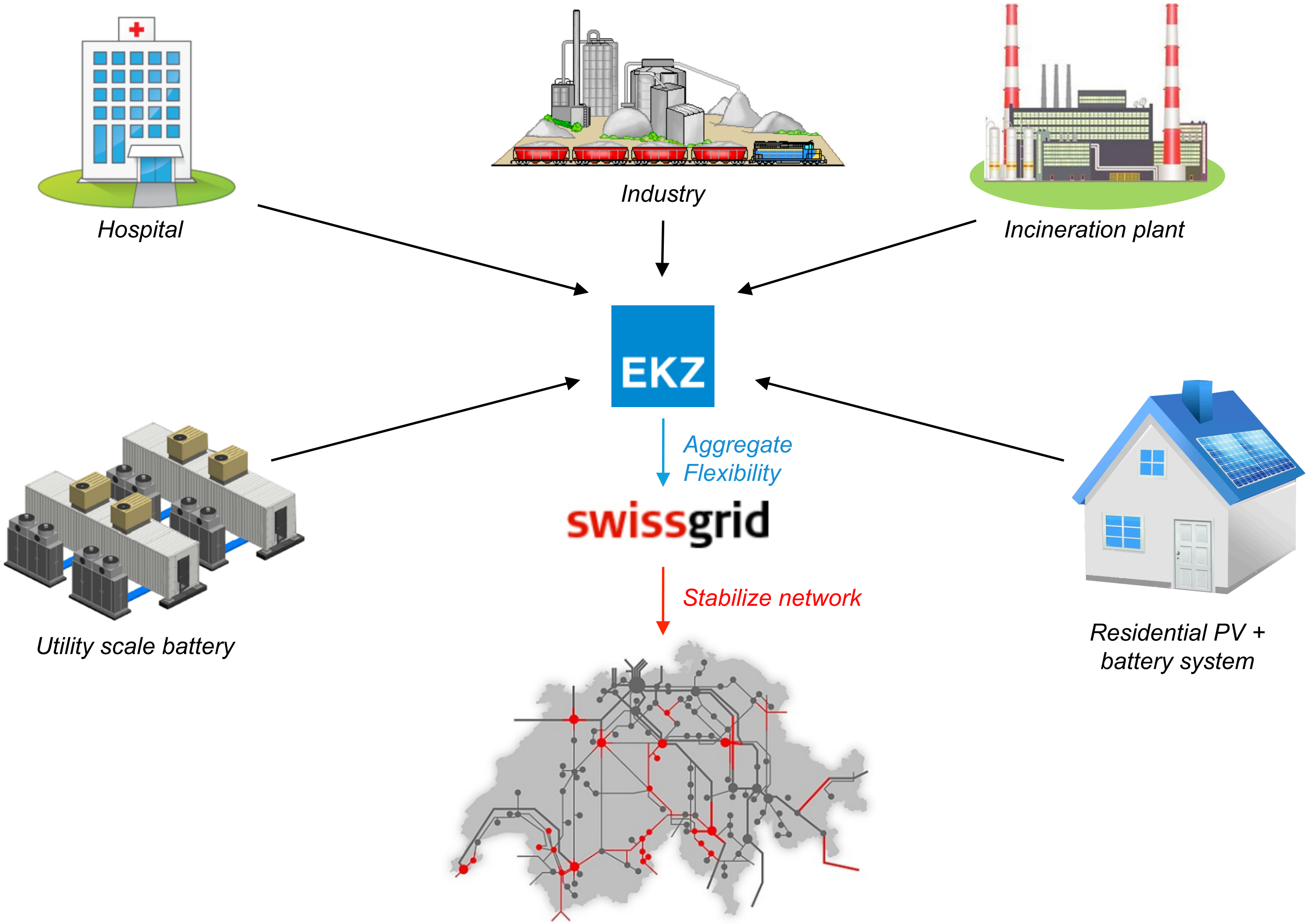
Frequency control in ENTSO-E Continental Europe



Quelle: swissgrid.

EKZ's Virtual Power Plant

Flexible industrial assets >200 kW

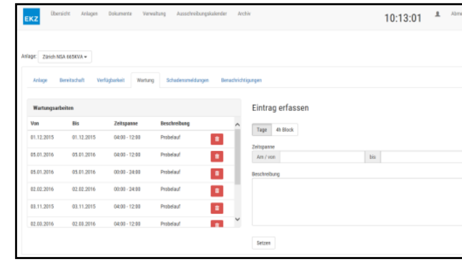


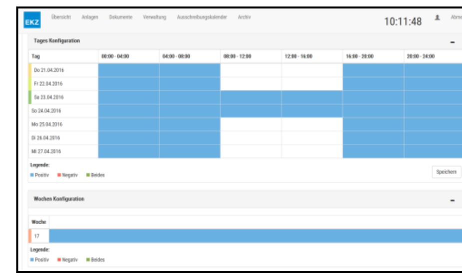
Connecting flexible units to EKZ's VPP

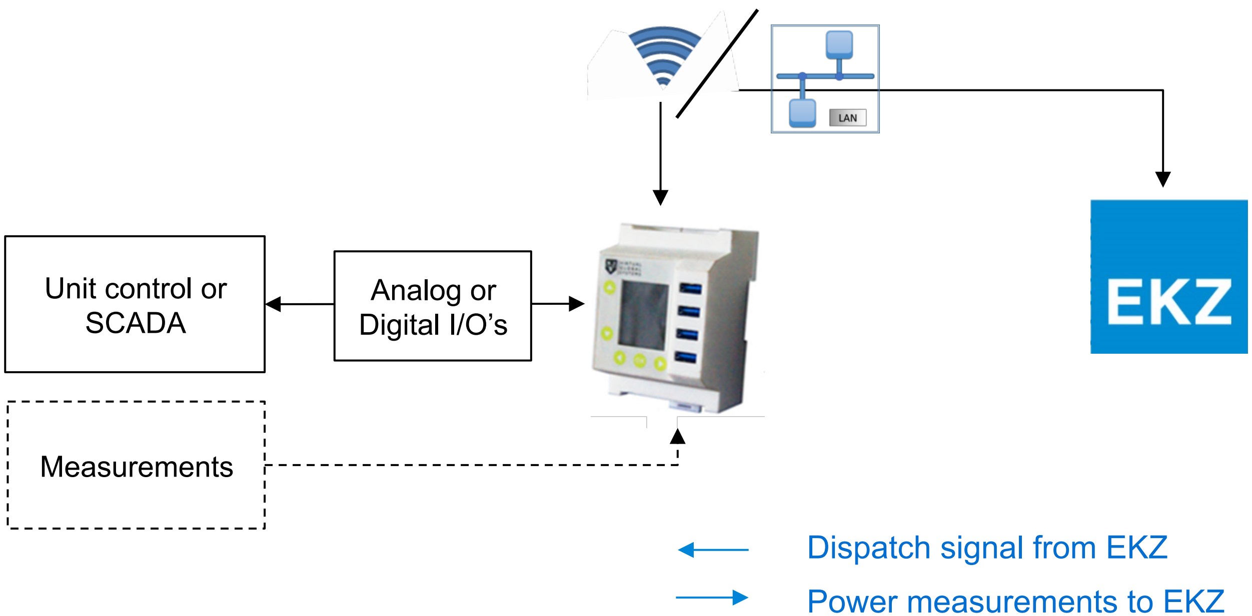
>200 kW connected with custom gateway

Key aspects of cyber security

- Point-to-point connections (outgoing connections)
- Encryption using TLS 1.2
- Closed user group on M2M mobile network

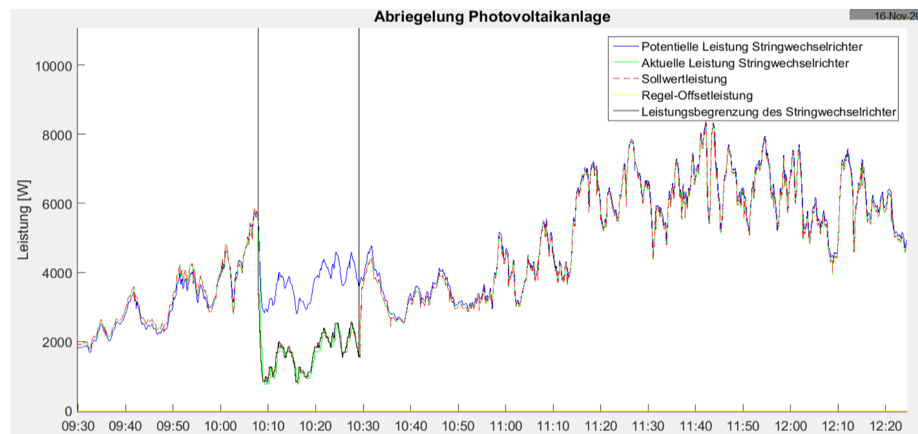






Virtual power plant pioneers
Control reserves from PV

- 1st Solar PV system in the commercial ancillary services market in CH
- Prequalification from Swissgrid obtained in January 2016
- Cooperation with Energie360° using their plant with 2.4 MWp

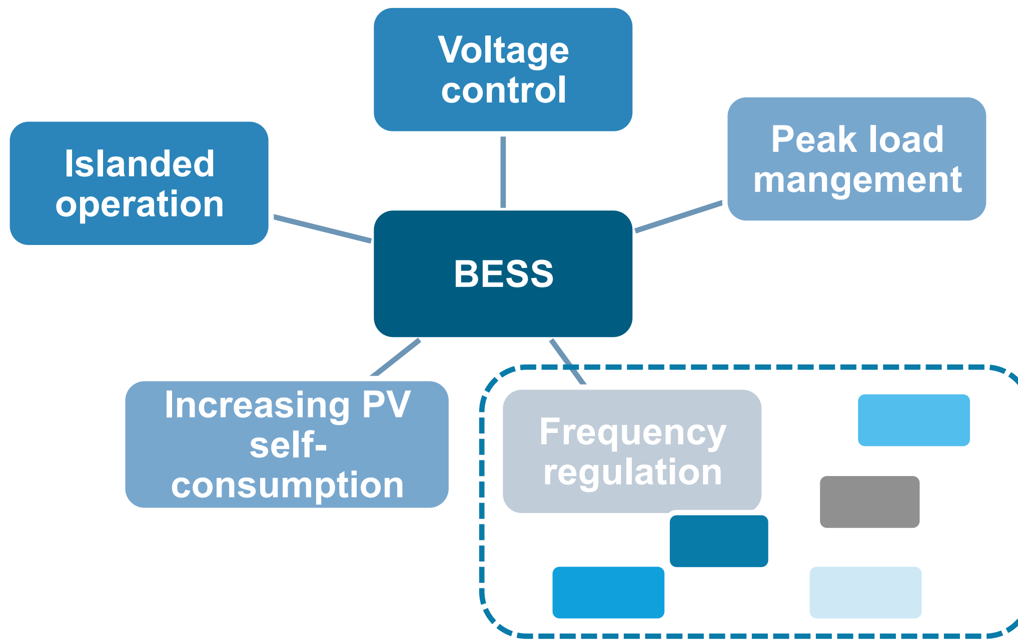


energie360°

EKZ

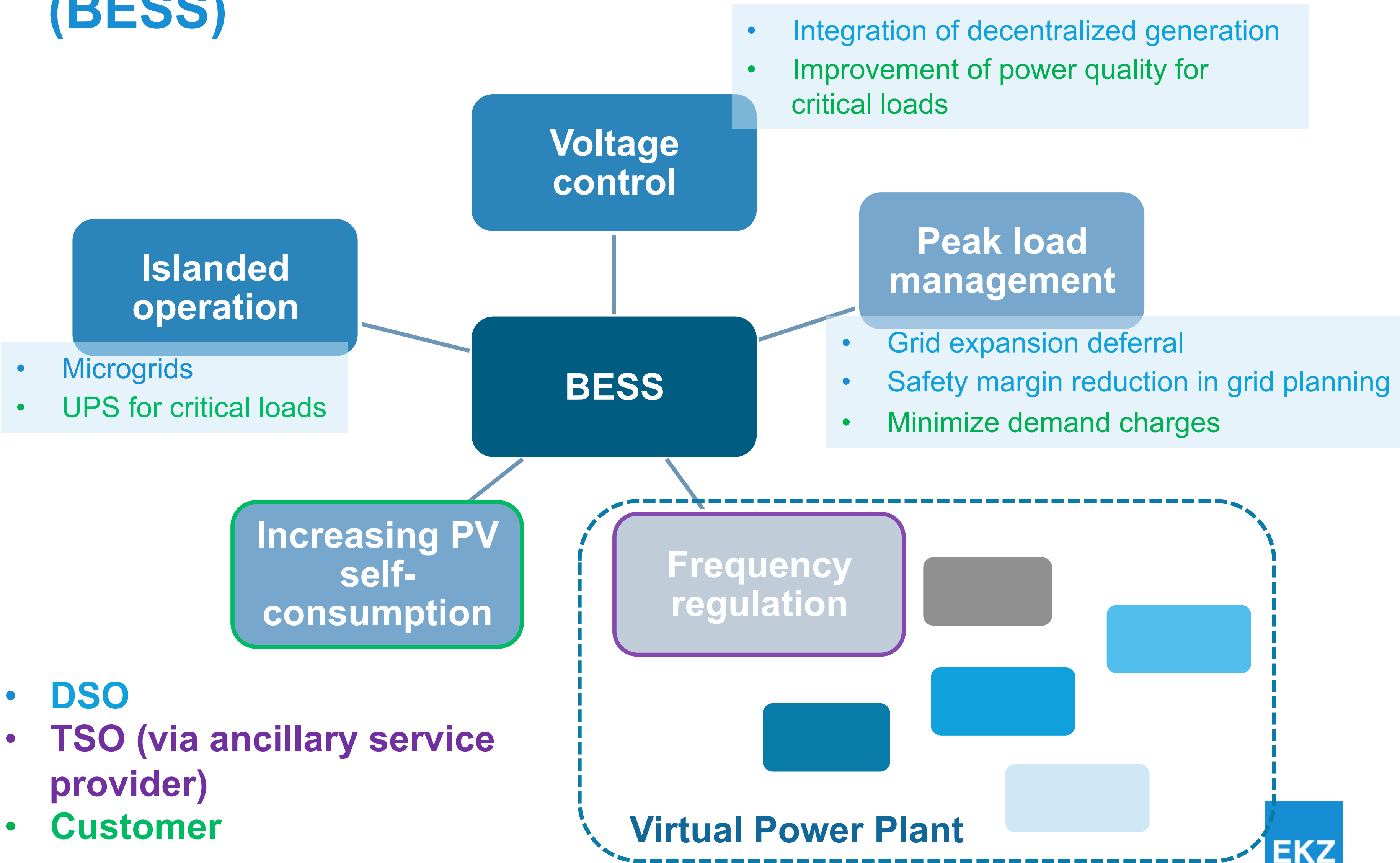
EKZ battery activities and applications

1)	Utility scale	1 – 20 MW
2)	Commercial & Industrial	20 – 1000 kW
3)	Residential	1 – 20 kW



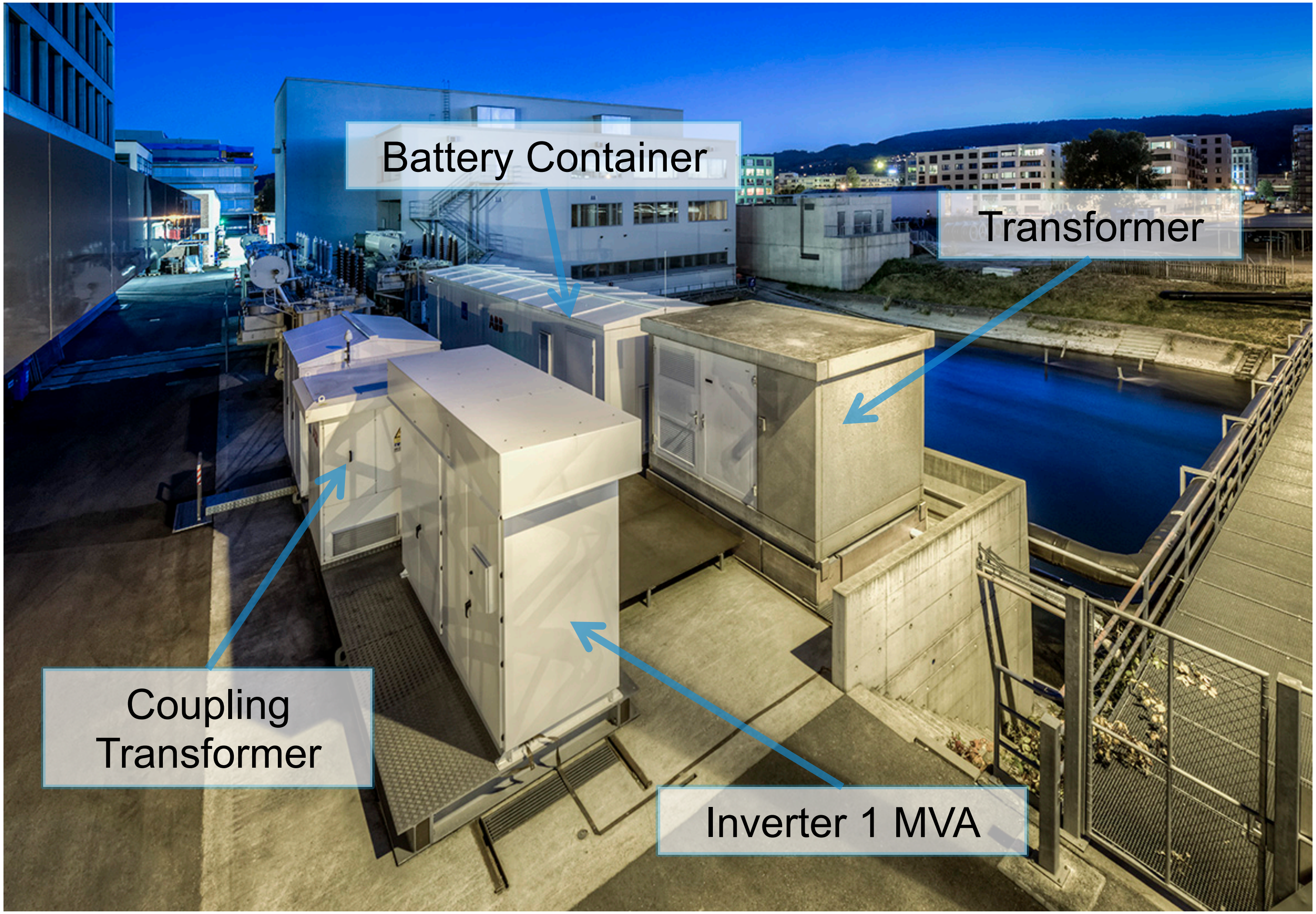
Virtual Power Plant

Applications for battery energy storage systems (BESS)



EKZ

The Zurich 1 MW BESS



EKZ

System Components

Battery modules

Battery container

Inverter

SCADA

Key properties

Property	Value	Notes
Power	1 MW	charging and discharging
- installed power	*1.1 MW*	
- Peak power 15 min	*>1.3 MW*	
Capacity	580 kWh	250 kWh @ 1 MW
System Integrator	ABB	
Battery Manufacturer	LG Chem	
Cell Type	Li-Ion	
Lifetime[1]	3500 Cycles	2 Cycles/day, 250 kWh
System Costs[2]	~2 Mio EUR	~500k Battery

[1]Warranty, real lifetime most likely higher.
[2] Reflecting costs of procurement in 2011, incl. development costs of ABB and EKZ.

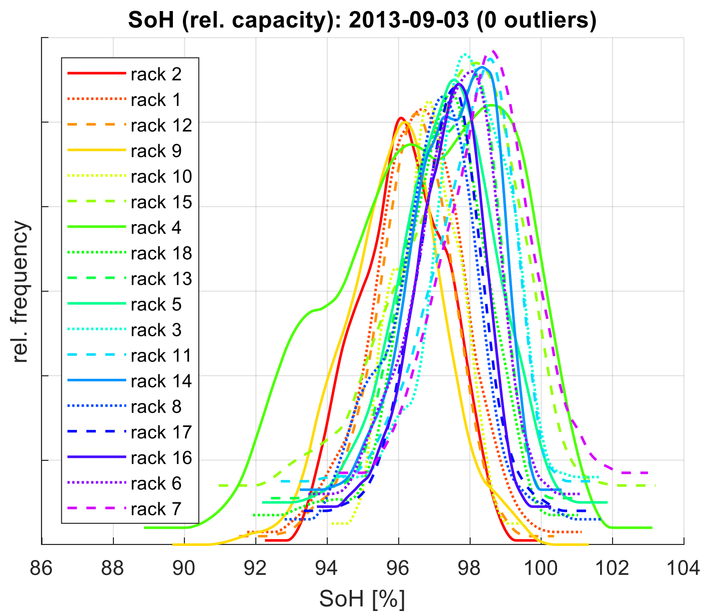
EKZ

Analysis battery ageing 1 MW BESS Dietikon

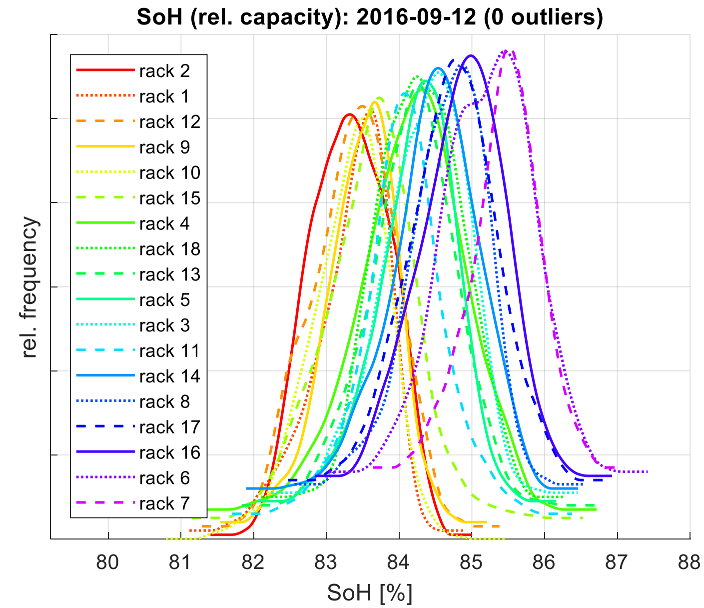
Data logging EKZ battery

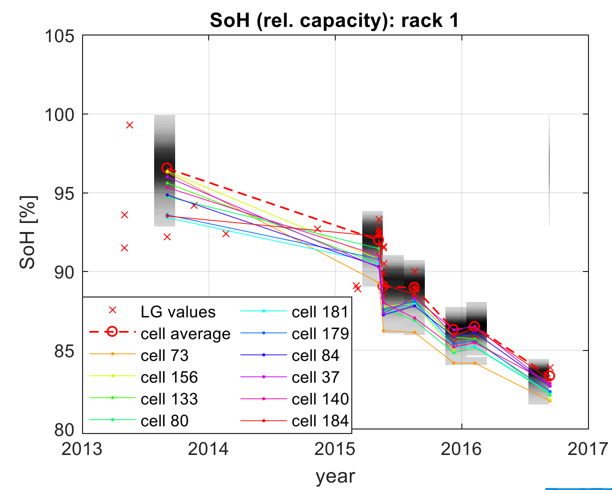
- 328 GB data, >5 years
- approx. 180 Mio. DB entries
- approx. 10^9 voltage values
- approx. $3.3 \cdot 10^9$ temperature values
- approx. $2.5 \cdot 10^9$ current values
- approx. $2.5 \cdot 10^9$ SOC values
- $>20 \cdot 10^9$ data entries

Preliminary results from ABB corporate research on EKZ battery (Dietikon)



5 years

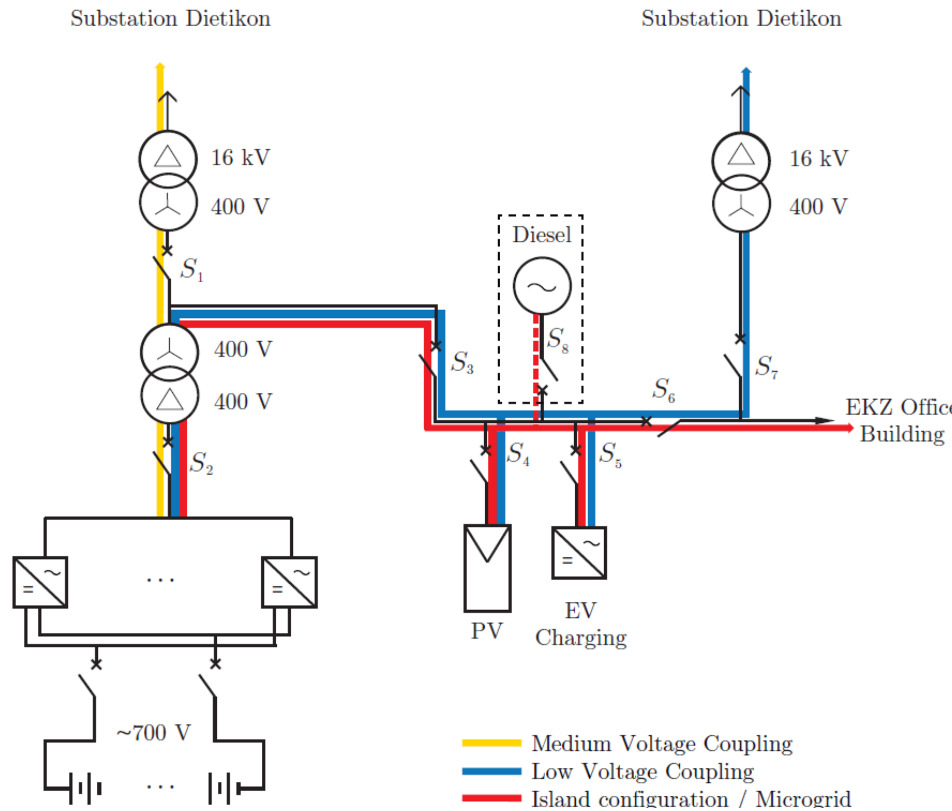




Islanded operation / Microgrid

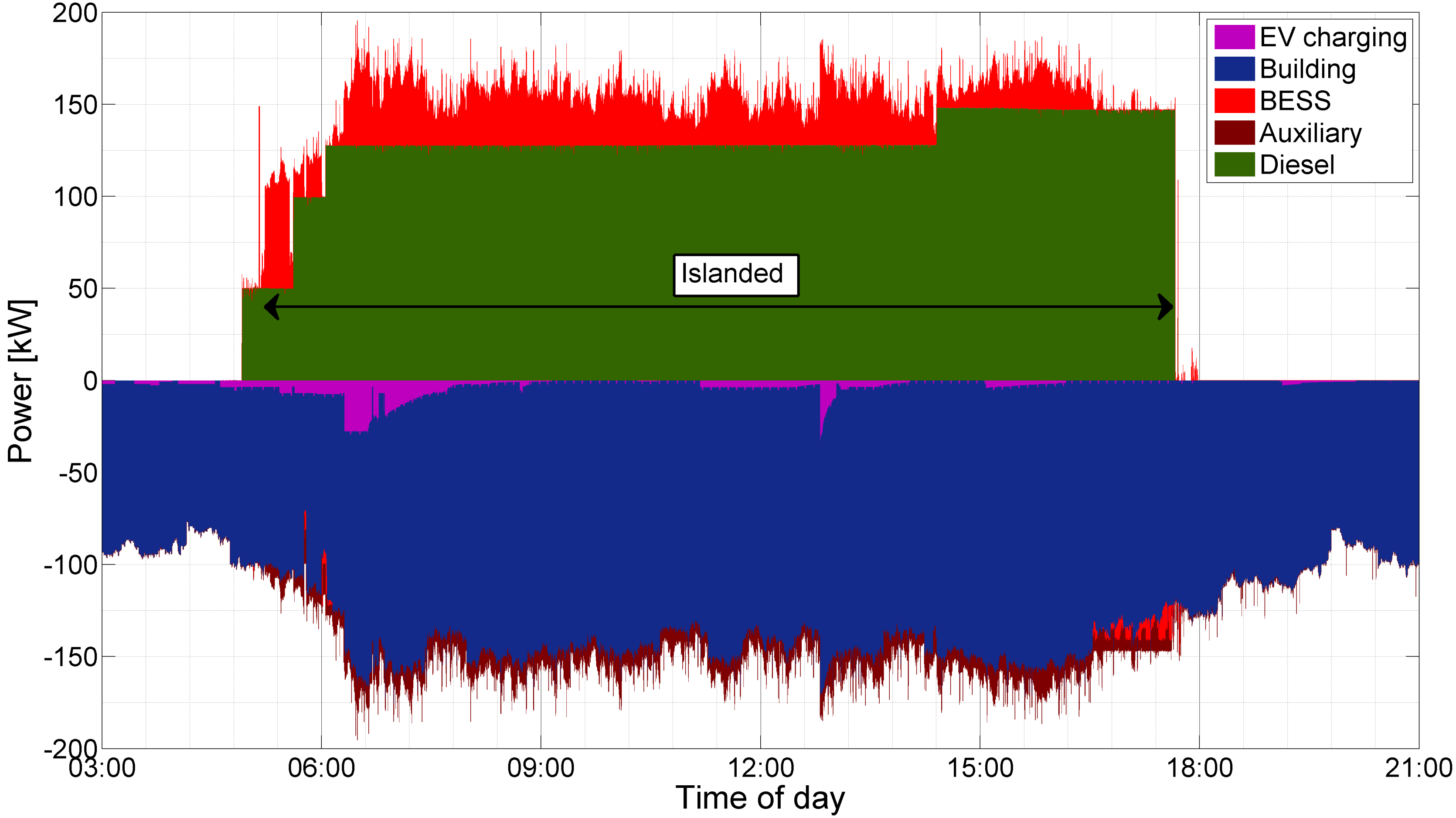
Components

- BESS
- Office building
- PV plant
- Diesel genset
- Electric vehicle charging

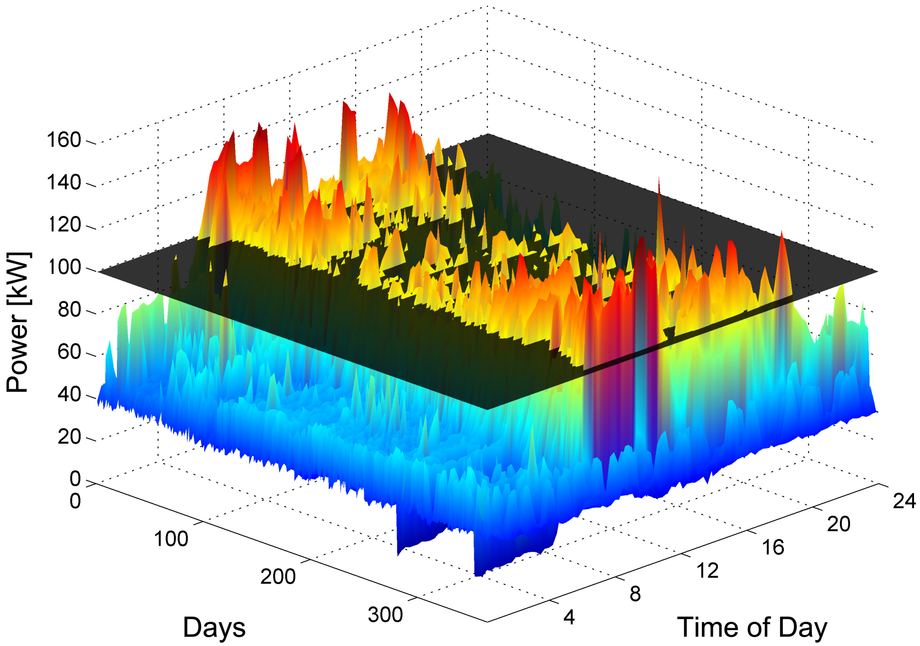


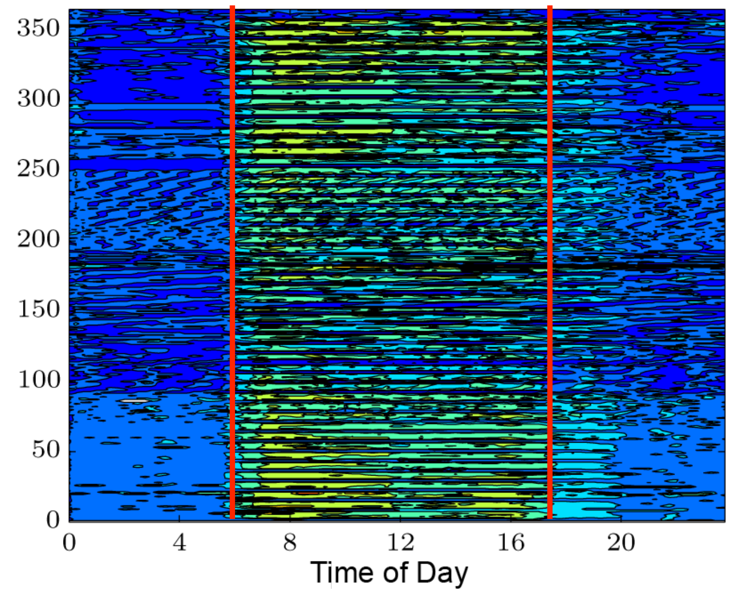
grid disconnection ►island operation ►synchronization ►grid reconnection

Measurements from islanded operation



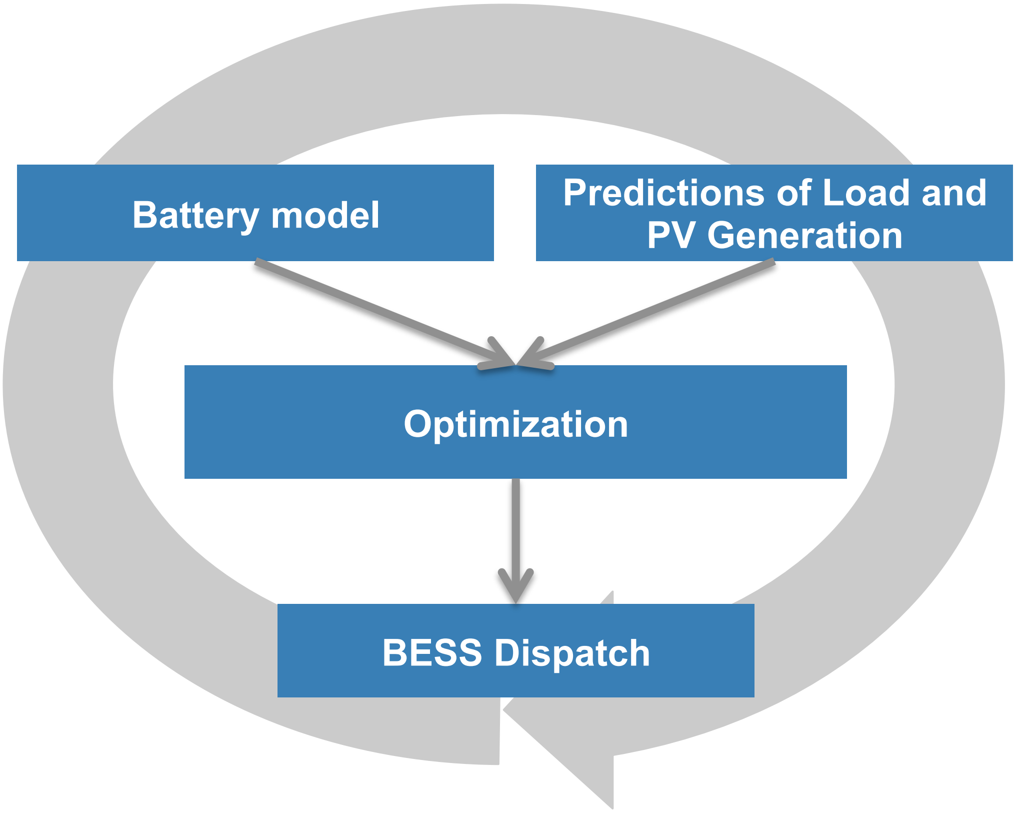
Peak Shaving EKZ office building





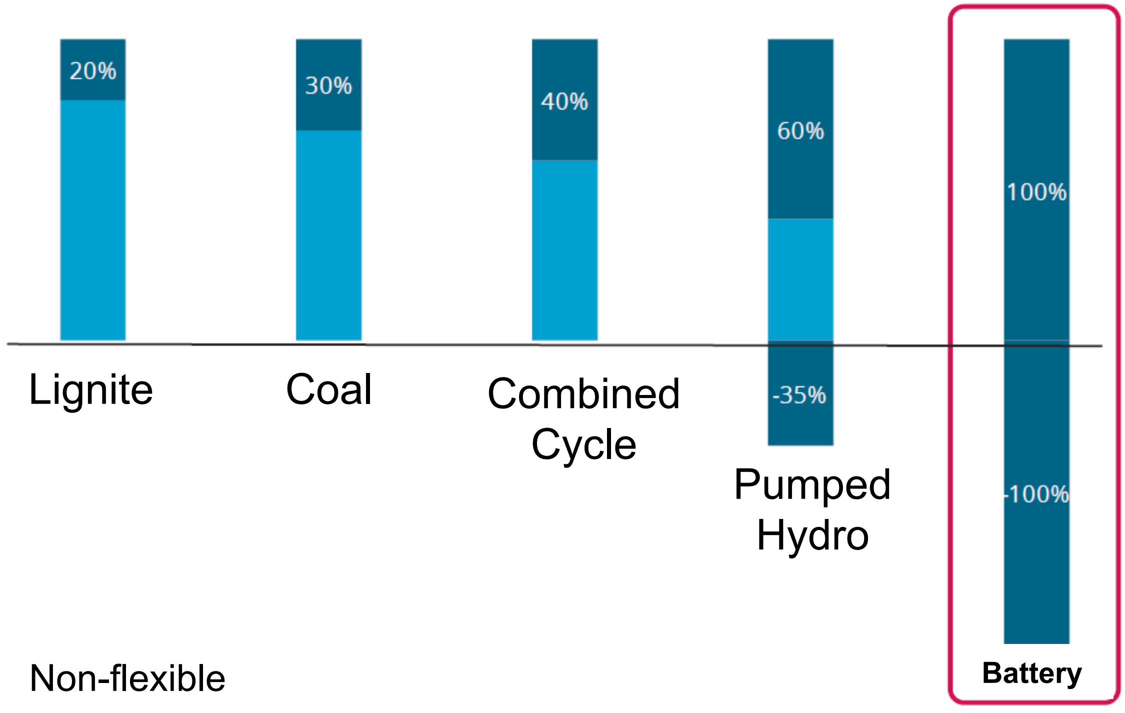
Peak load:	150 kW	Arbitrary limit: 100 kW
Energy above limit:	6 MWh	Max. daily energy above limit: 175 kWh

Model predictive control for peak shaving



EKZ

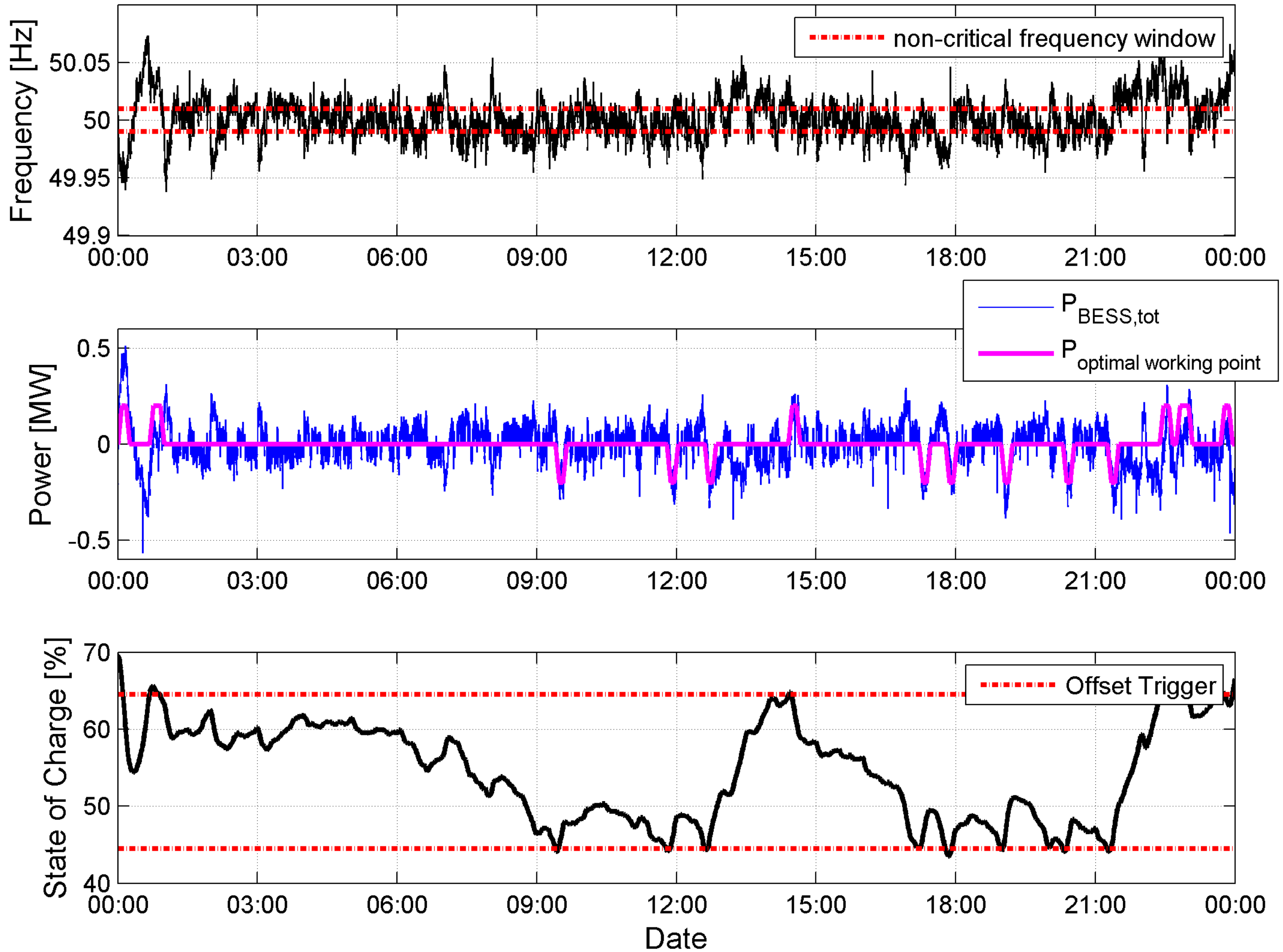
Provision of primary frequency control



Source: Younicos.

- Decentralized control, based on locally measured frequency
- BESS provides at least twice the flexibility of an equivalent power plant (decoupling of energy and power)
- Active state of charge management to ensure permanent availability

Smart working point adjustment to control State of Charge – Measurements from real life operation

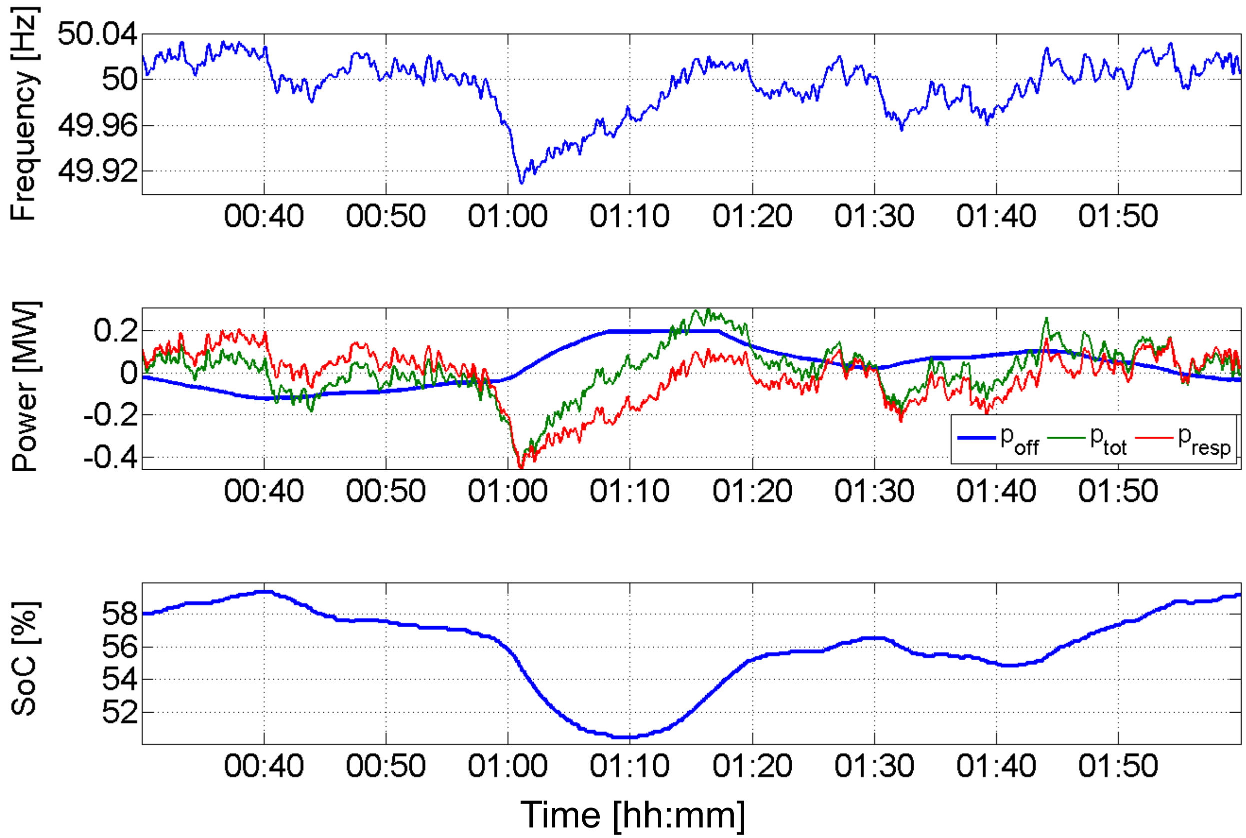


Source: Jonas Schmutz, semester thesis, Power Systems Laboratory, ETH Zürich, 2013.

Smart working point – Moving average (meas.)

$$p_{off}(k) = \frac{1}{a} \sum_{i=k-a}^{k} \left(-p_{resp}(i) + p_{loss}(i)\right)$$

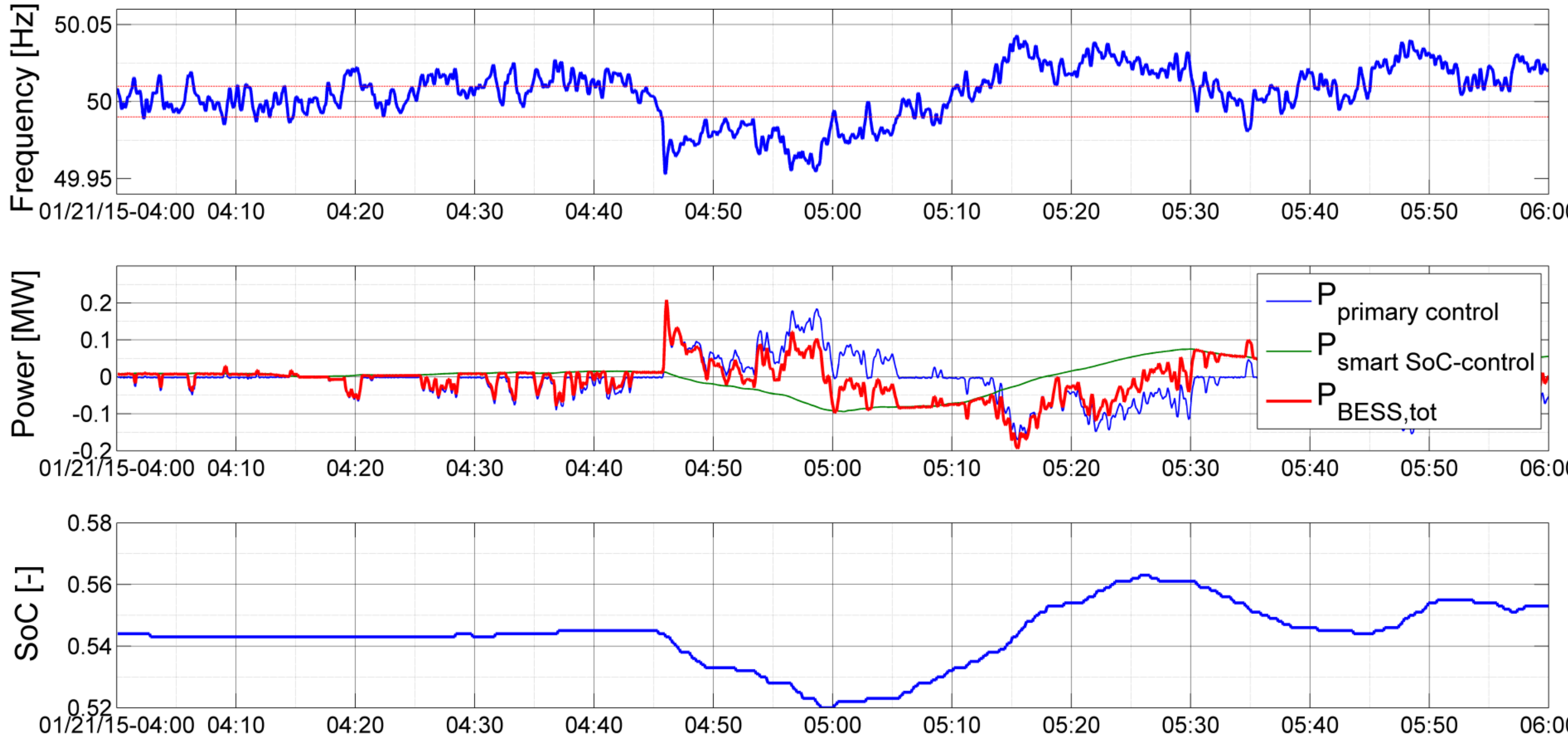
$$a = 900\ s$$



Frequency reserves with the Zurich 1 MW BESS

Zurich 1 MW BESS fully certified to participate in market for primary reserves since July 2014

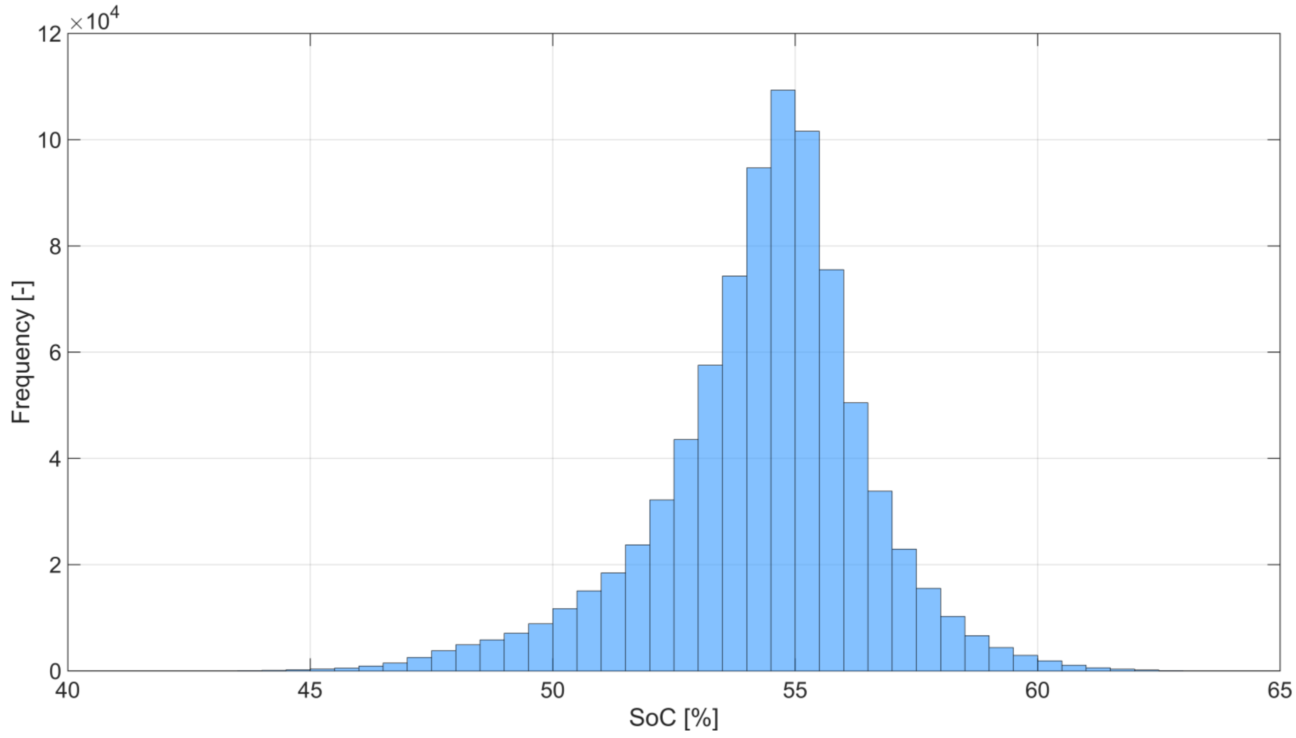
Outage of a Swiss nuclear power plant of 1 GW at 04:46 am UCT



EKZ

SoC range during primary frequency control operation

- **State of Charge (SoC) recharging algorithm kept SoC between 40.2% and 75.7% at all times (580 kWh storage capacity)**



EKZ

Is regulation rewarding the benefits?

- **ENTSO-E network codes put no emphasis on response times**
- **New network code and regional TSO's fine print requires energy storage systems to have 8x more storage capacity per MW of primary frequency reserves offered than technically needed**

PCR usage requirements	Zurich BESS strategy	Intra-day market
Normal PCR usage	220 kWh	640 kWh
Normal PCR usage + ±15 minutes full activation requirement	720 kWh	1140 kWh
Normal PCR + ±30 minutes full activation requirement	1220 kWh	1640 kWh

Source: Koller et al. in Cigré 2016.

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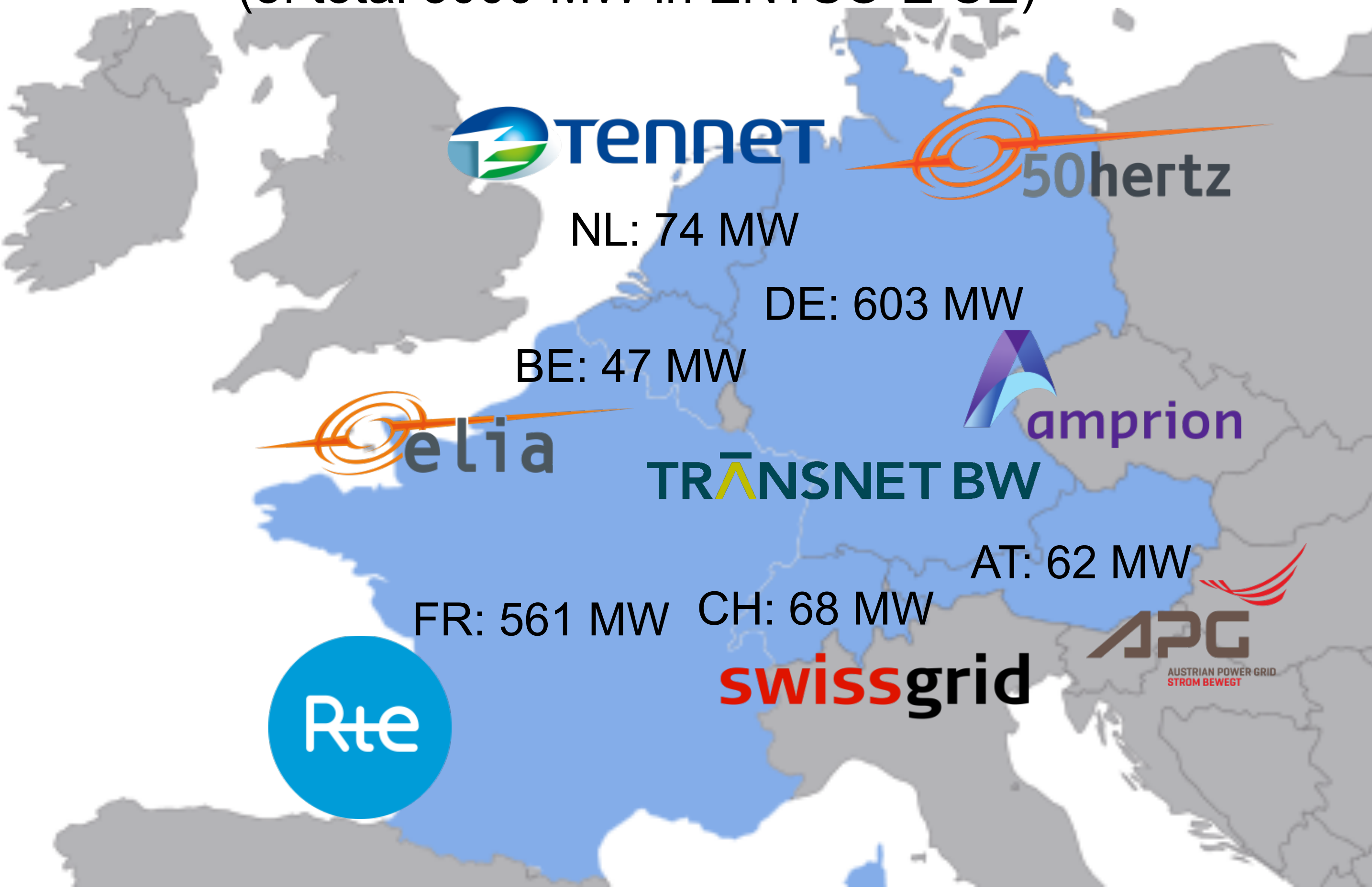
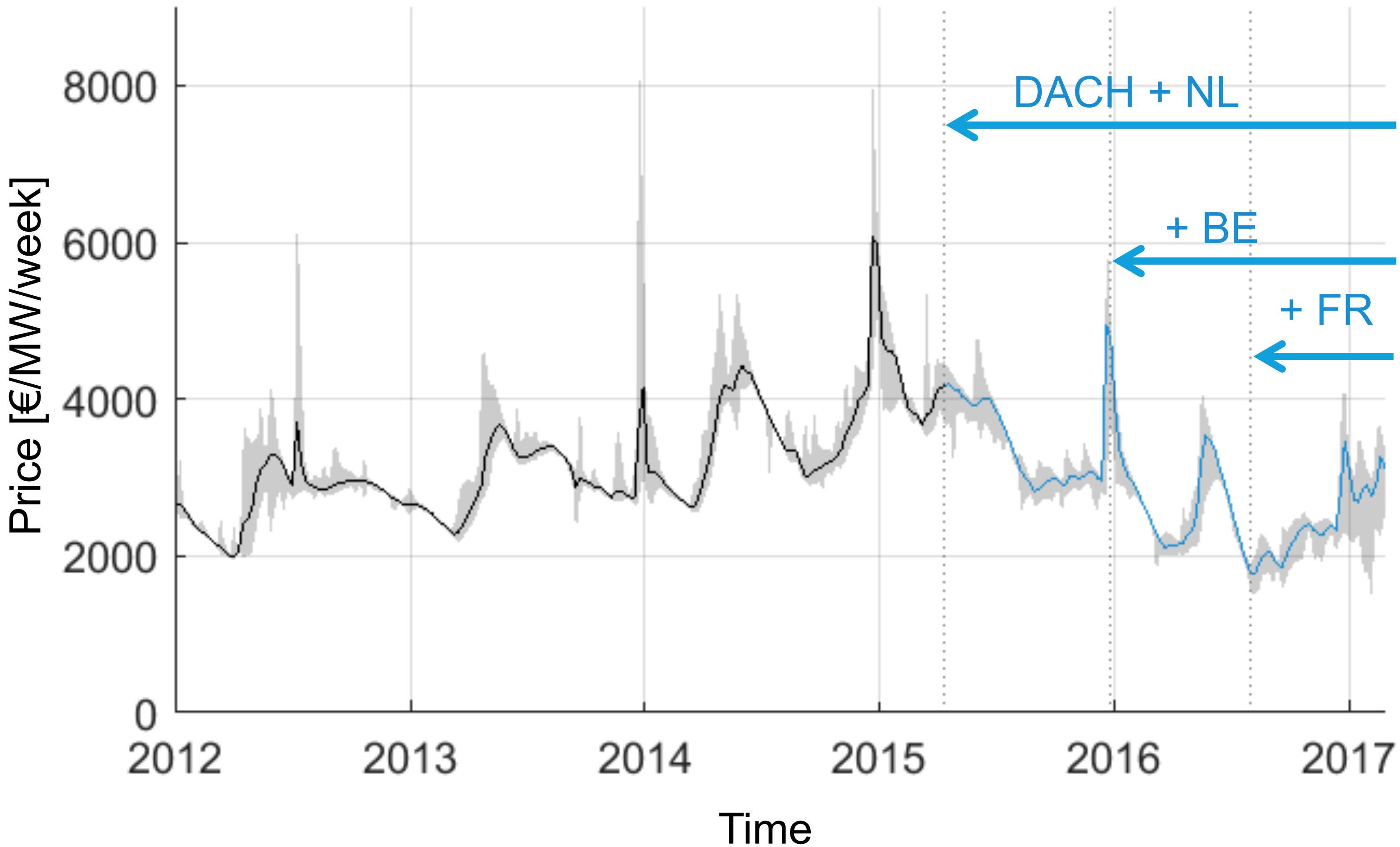
Reserve requirements and market structure for primary reserves since January 2017

Total market size: ~1400 MW

(of total 3000 MW in ENTSO-E CE)



Price evolution for primary frequency control in Germany



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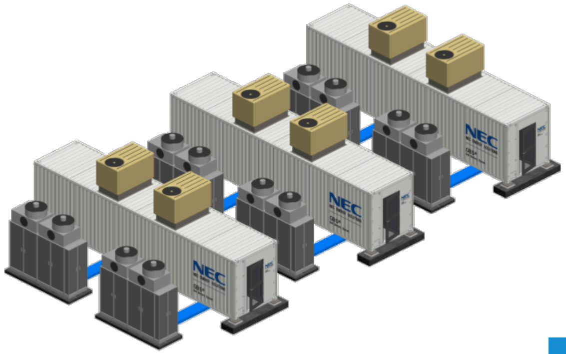
Key facts Dietikon BESS vs. Volketswil BESS

feature	Dietikon BESS	Volketswil BESS
Power	1.1 MW	18 MW
Capacity	580 kWh	7.5 MWh
System integrator	ABB	NEC
Manufacturer	LG Chem	LG Chem
Battery technology	Li-Ion	
Life time	5 years (guaranteed)	10 years (guaranteed)
Project costs	~ 2.5 MCHF	~ 6 MCHF



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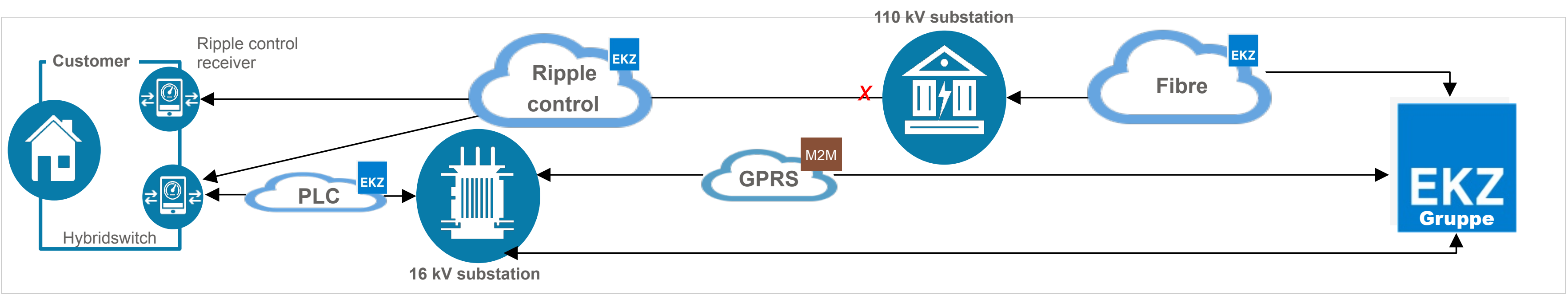
Impressions from 18 MW BESS

Impressions from 18 MW BESS

Ripple control and residentail demand response

- Introduced in the 70s
  (mostly France, Switzerland and parts of Germany)
- Mandatory over-dimensioning of residential hot water tanks
- Replacement with Smart Metering infrastructure



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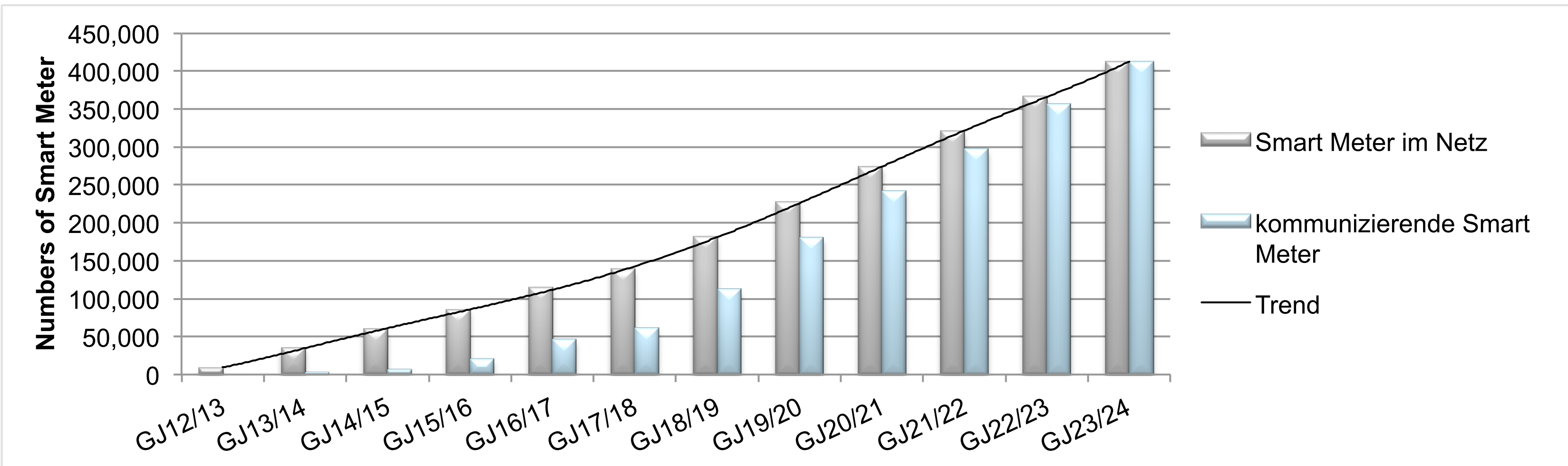
EKZ Smart Meter Rollout



Data concentrator

Smart Meter

Hybrid switch

Dynamic demand response pilot project based on Smart Metering Infrastructure

- **Application:**

  Individual switching of electric water heaters in one secondary substation to flatten out PV generation peaks

Research project 2011-2015 → Pilot project 2016 - 2017

Landis+Gyr manage energy better

ETH Zürich

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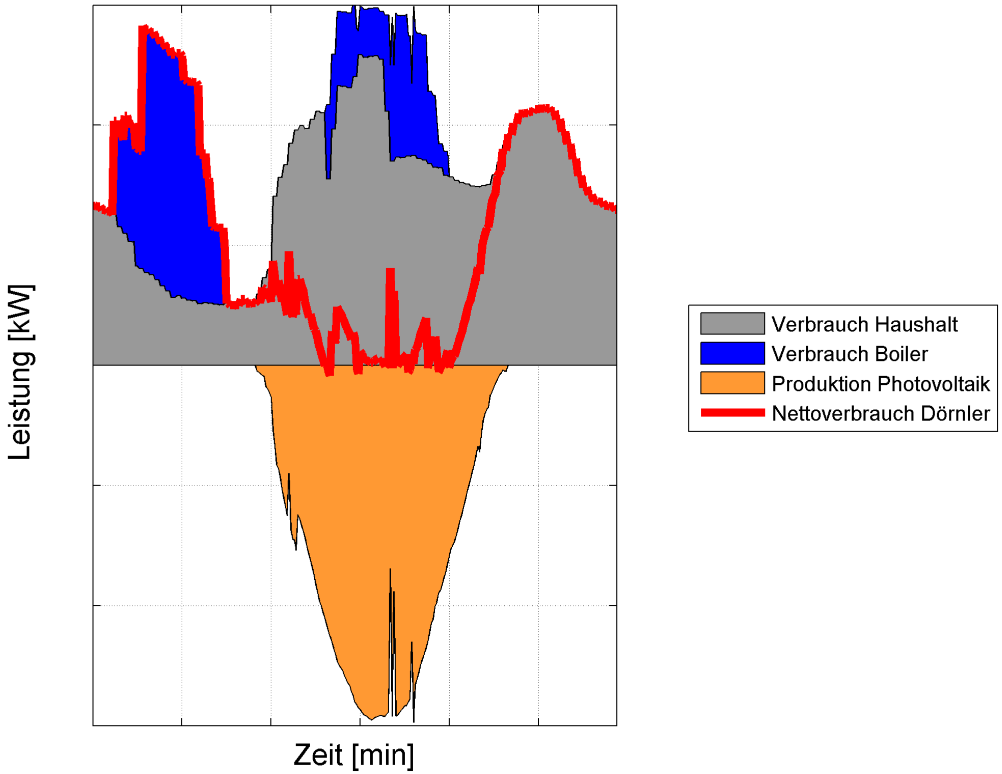
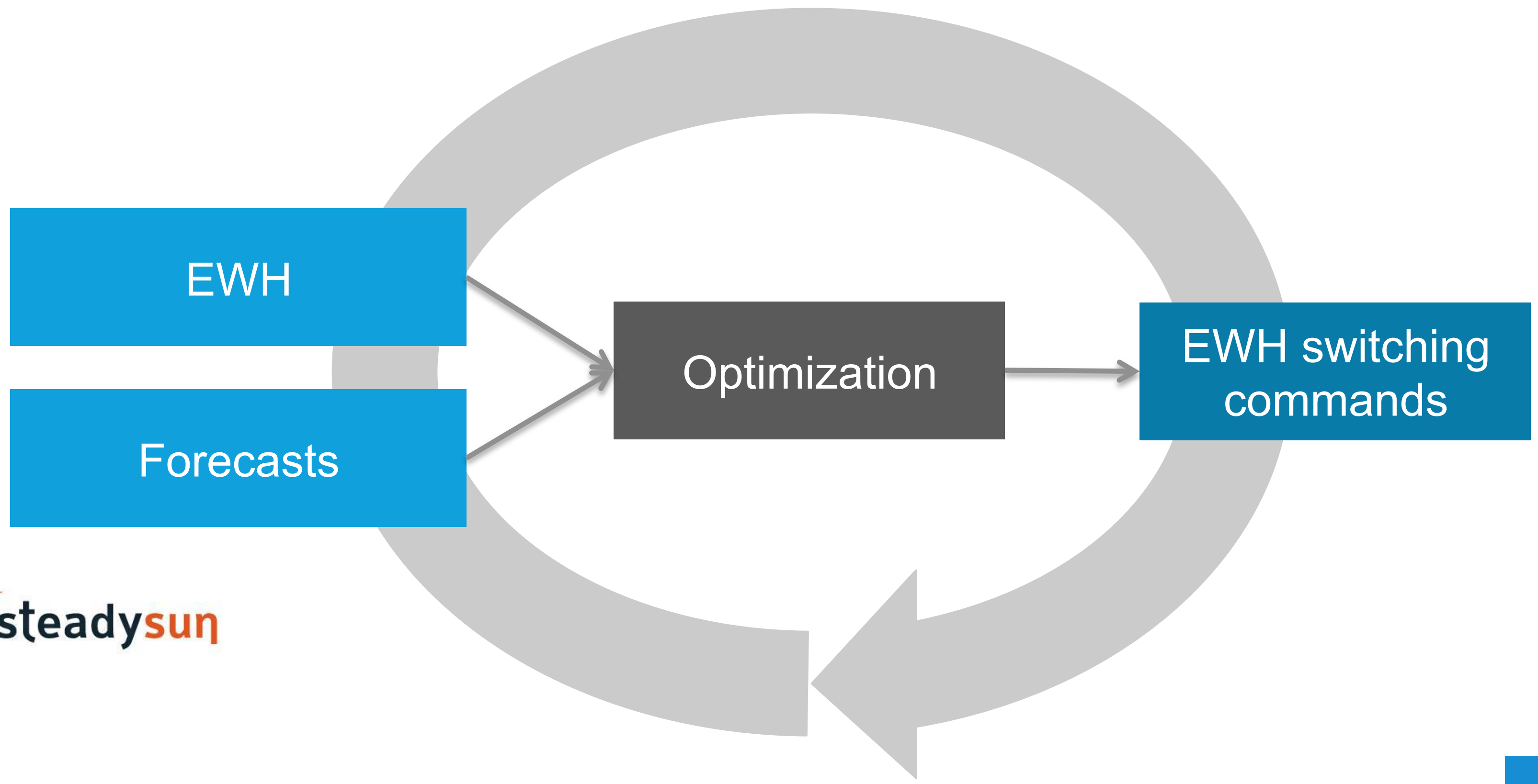
General concept of demand response for PV integration



Model predictive control approach

Load forecast seconary transformer station, PV generation forecast and adaptive electric water heater (EWH) model



Pilot project in Rickenbach-Sulz

	Value
Transformer (16 / 0.4 kV)	630 kVA
Installed PV power	466 kW
Peak load	350 kW (summer)
Installed EWH power	314 kW

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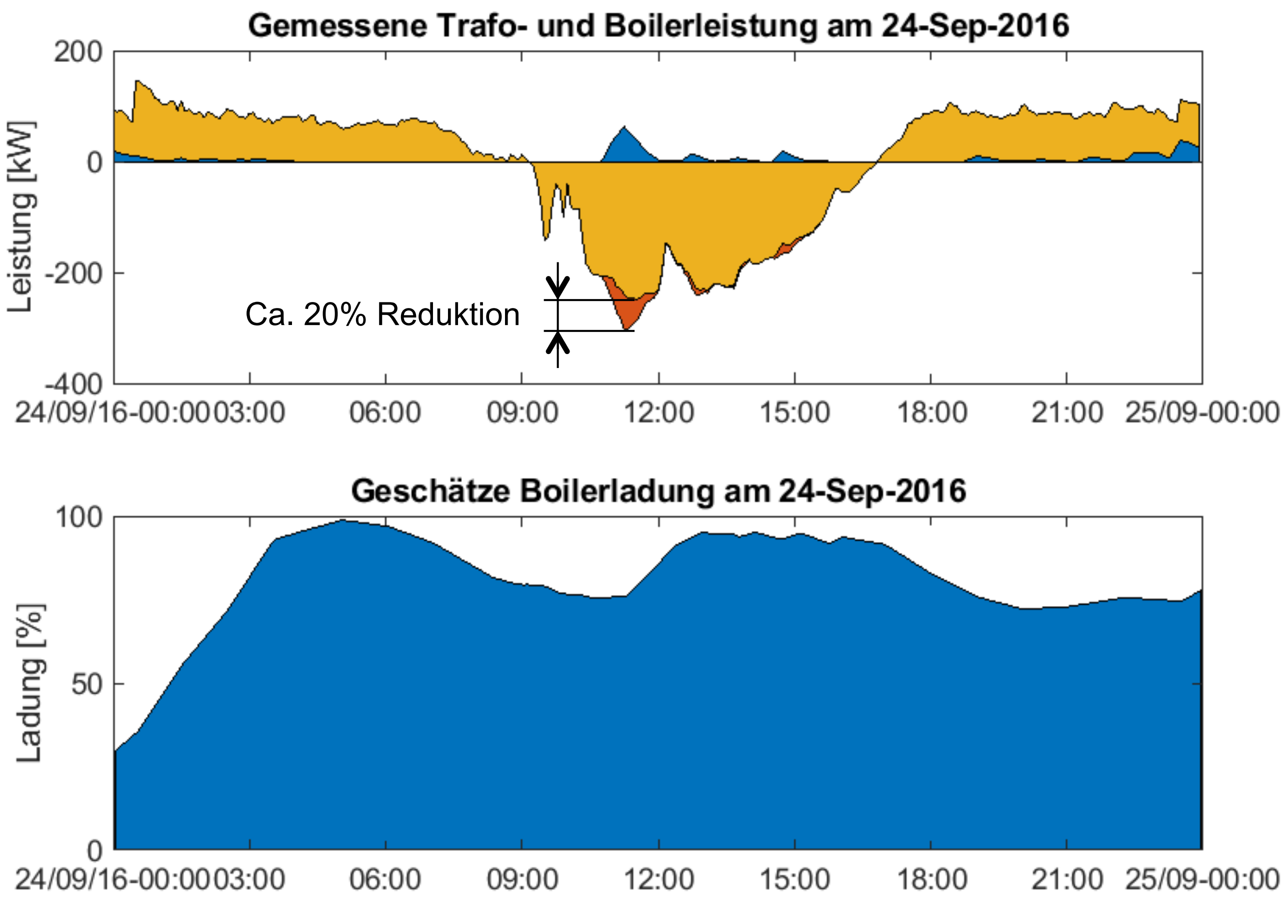
Example for the MPC in operation



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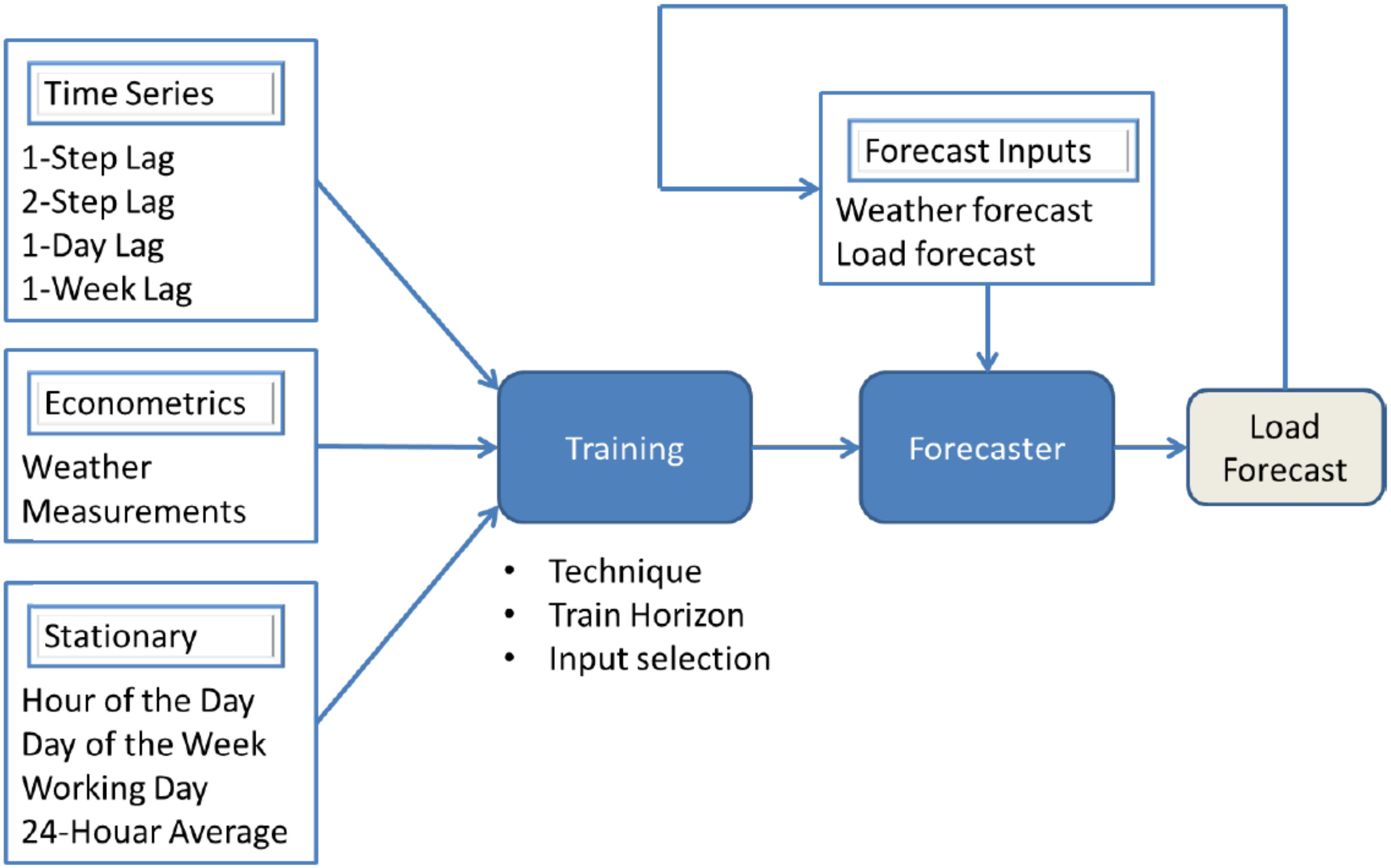
Load forecast



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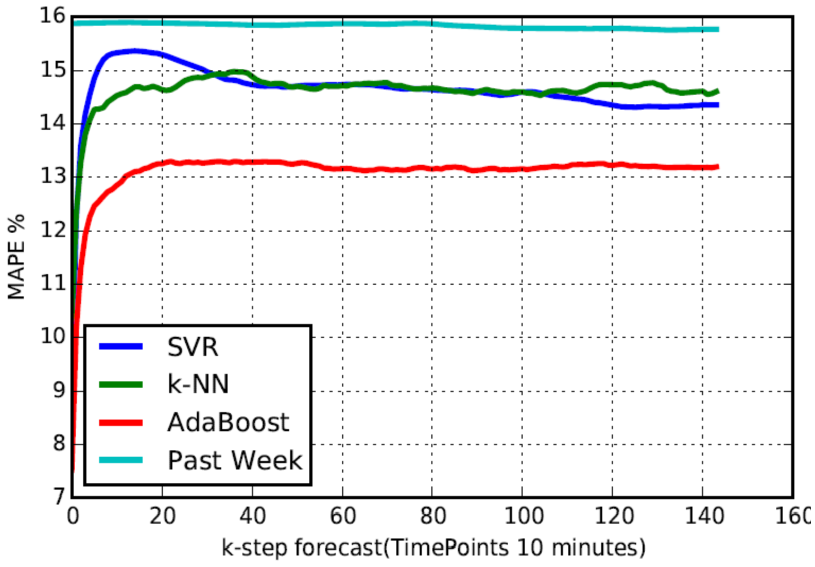
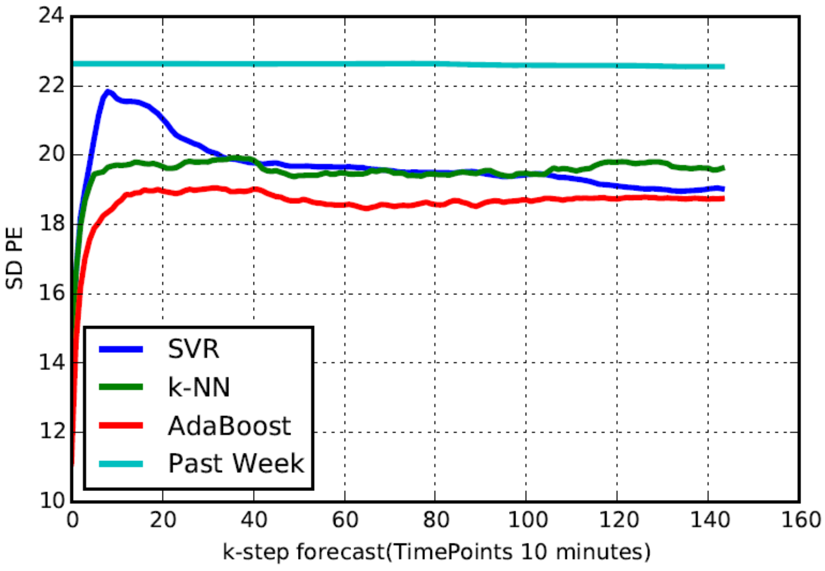
Load forecast secondary substation

- **Regression Partitionen pro Regression Tree: 10**
- **Boosting depth 300**
- **KPIs:**
  - Mean Absolute Percentage Error
  - Standard Deviation of the Percentage Error





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PV forecast

Commercial service from French startup SteadySun based on two bottom up approaches updated every 5 minutes

- 1 - 2 Tage: Meteo
- 30 min – 6 h: Satellite

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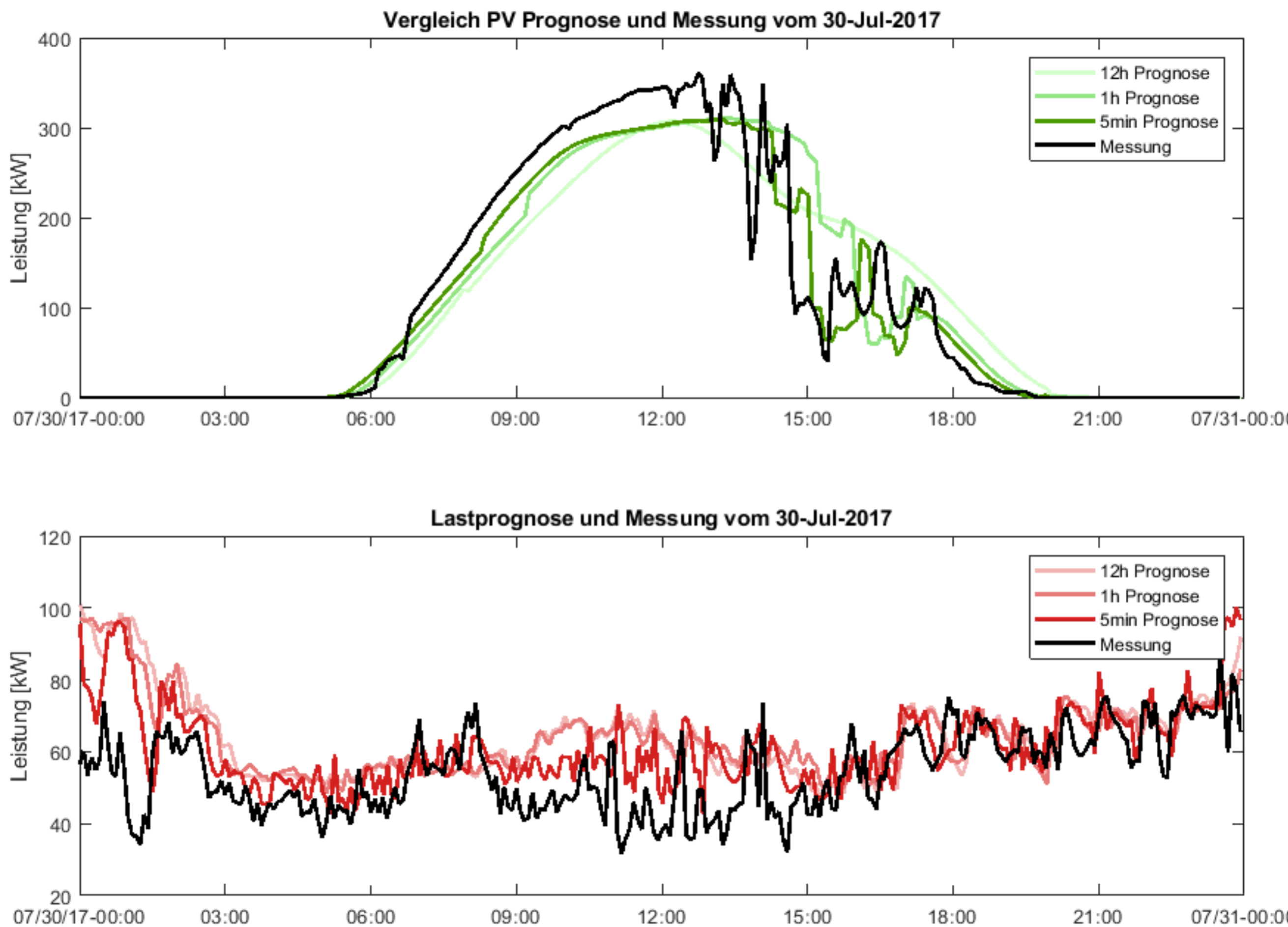
PV- & load forecast



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Performance Analysis

KPI 1: RMS maximum backfeed power (PV from LV to MV)

- How much can the PV curve be «flattened»?
- $\sqrt{\sum_{i}^{N} (|P_{i}|^{-})^{2}}$ **N**: Number of time steps, $|P_{i}|^{-}$ **:** Power i
  - ➢ Important to judge controller performance

KPI 2: Average maximum PV backfeed per day

- How much can the daily worst-case event be reduced?
- $\mathbf{1/M \sum_{i}^{M}} 1/N \sum_{j}^{N} |P_{ij}|^{-}$ **M**: Number of days, **N**: Number of time steps, $|\boldsymbol{P_{ij}}|^{-}$ **:** Backfeed power i on day j
  - ➢ Important to achieve grid savings

Performance analysis

	07/06/2016 – 17/05/2017		18/05/2017 – 05/11/2017	
	KPI 1 (RMS), before introduction of EWH model	**KPI 2 (average), before introduction of EWH model**	**KPI 1 (RMS), after introduction of EWH model**	**KPI 2 (average), after introduction of EWH model**
Flexibility potential	100	100	100	100
Flexibility potential with night activation	**67**	**56**	**53**	**44**
Achieved	**16**	**16**	**18**	**12**
Effect of PV forecast	69	44	63	56
Effect of load forecast	87	89	89	87
Effect of EWH model	0	14	44	61

- Example: realized KPI1 after introduction of adaptive EWH model → 18% of potential reduction in average daily maximum backfeed power achieved (room for improvement 82%)
- Theoretical flexibility potential: perfect forecast, continuous and individual EWH switching, 100% of EWH energy can be moved.

Performance analysis conclusion

- **Night activation of EWHs greatly reduces potential but necessary due to unreliable comm channels**
- **Local PV forecasts are more unreliable than loand forecasts, especially for short term peaks**
- **Adaptive EWH model very important to gauge available flexibility and estimate state of charge**

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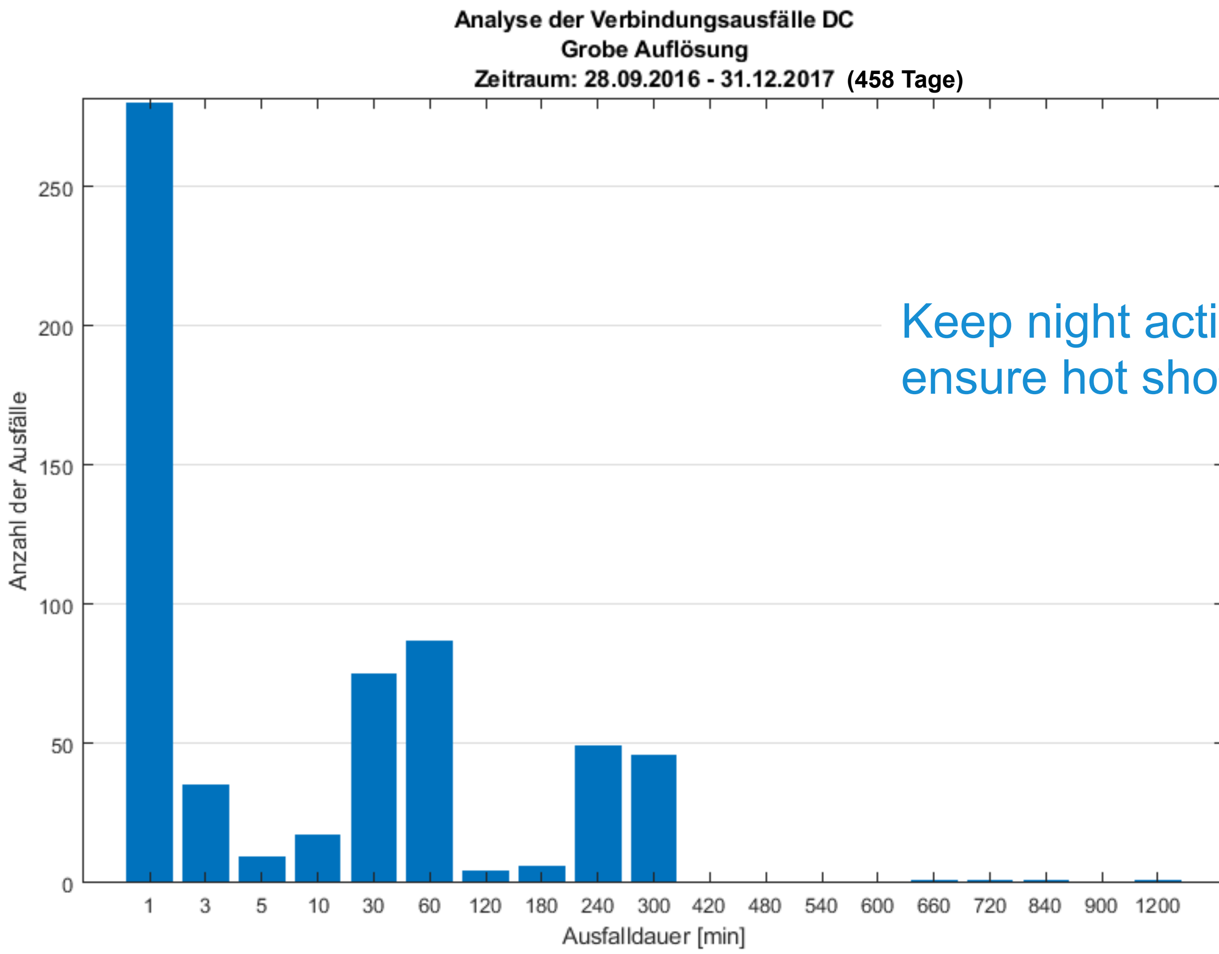
Reliability of GPRS



Keep night activation to ensure hot showers!

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Reliability of Power Line Communication

Data concentrator in secondary substation creates the LV PLC network (Smart Meter act as repeaters)

- Unreliable switching commands can be identified when controller tries to turn off the EWH but the EWH continues to draw power
- 6.3% of the relevant switching commands did not turn off the EWH (93.7% availability)

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Conclusion

- **A lot of challenges ahead in the Swiss electricity sector**
- **Flexibility at the core of EKZ’s efforts to**
  - ensure reliable and cost-efficient distribution grid
  - enable new customer services such as PV self-consumption and VPP
- **EKZ collaborates with partners from academia and industry to drive R&D and product development**

Thank you

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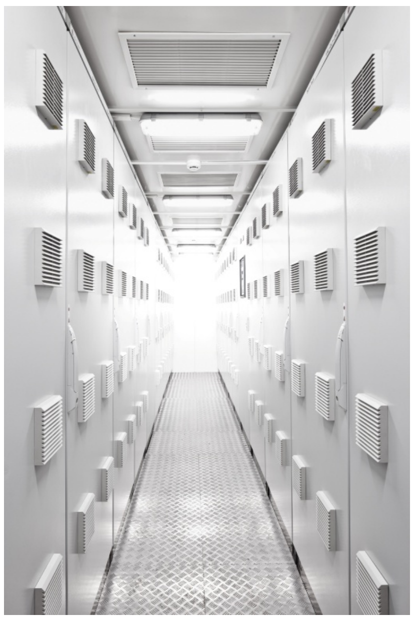
Questions?



Further reading on the Zurich 1 MW BESS

CIRED 2013

M. Koller and B. Völlmin, *Preliminary findings of a 1 MW Battery Energy Storage demonstration project*, CIRED 2013.

IEEE PowerTech 2013

M. Koller, T. Borsche, A. Ulbig and G. Andersson, *Defining a degradation cost function for optimal control of a battery energy storage system*, IEEE PowerTech 2013.

IEEE Power & Energy Society General Meeting 2013

T. Borsche, A. Ulbig, M. Koller and G. Andersson, *Power and Energy Capacity Requirements of Storages Providing Frequency Control Reserves*, IEEE PES General Meeting, 2013.

CIRED Workshop 2014

M. Koller, J. Schmidli and B. Völlmin, *Frequency regulation and microgrid investigations with a 1 MW battery energy storage system*, CIRED 2014.

World Congress of the International Federation of Automatic Control 2014 (IFAC'14)

T. Borsche, A. Ulbig, G. Andersson*, Impact of Frequency Control Reserve Provision by Storage Systems on Power System Operation,* IFAC 2014.

Electric Power Systems Research – special issue on Smart Grid implementation

M. Koller, T. Borsche, A. Ulbig and G. Andersson, *Review of Grid Applications with The Zurich 1 MW Battery Energy Storage System*, 2015.

C**igré 2016**

M. Koller, M. Gonzalez Vaya, A. Chacko, T. Borsche, A. Ulbig, *Primary control reserves provision with battery energy storage systems in the largest European ancillary services cooperation,* Cigré 2016.

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