



# Revisiting Energy Storage – Ergebnisse der Studie

LEW Hochschultag

21 September 2011

THE BOSTON CONSULTING GROUP

# The challenge: renewable energy fluctuates

Increasing need to uncouple electricity supply and demand

**Wind is a powerful source of energy ....**



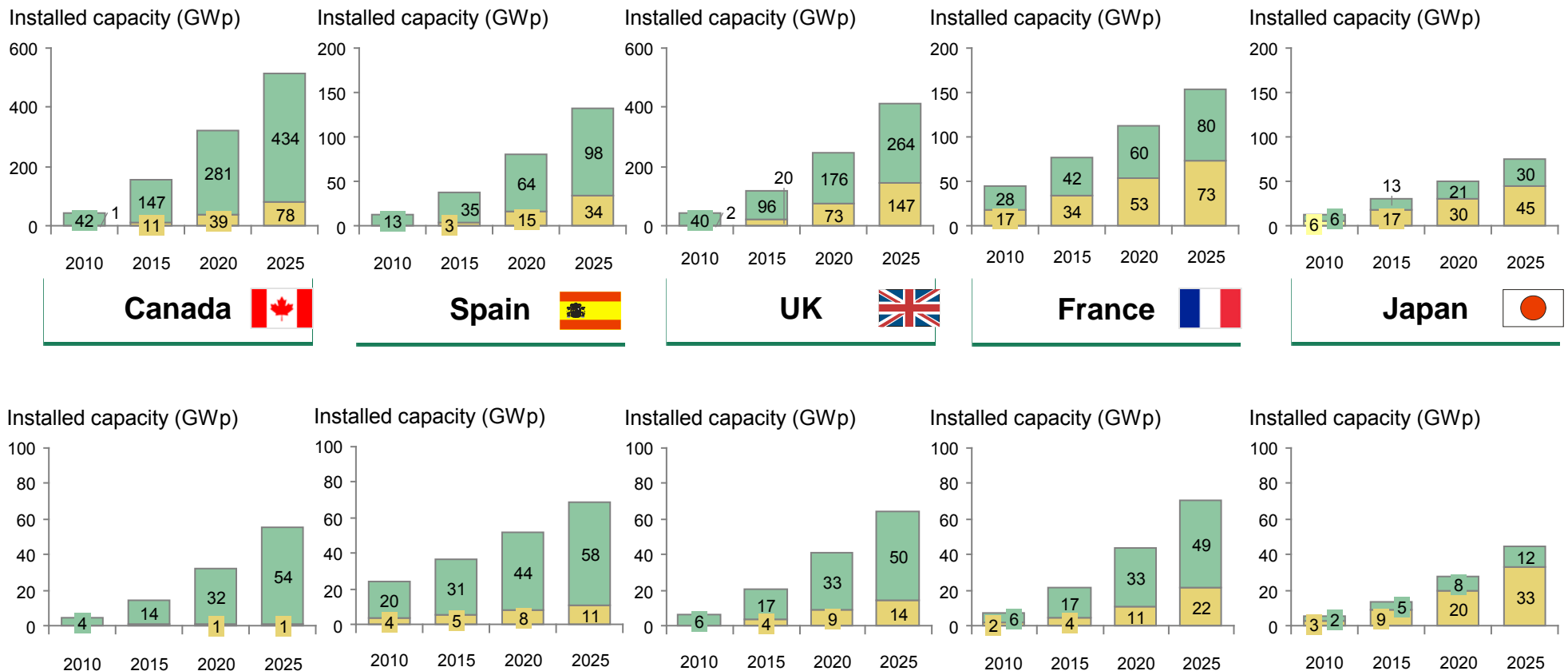
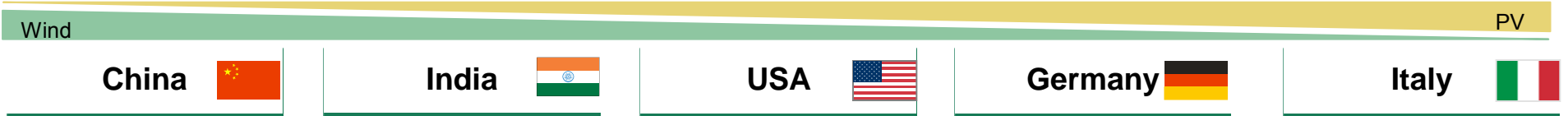
**.... but not always**



**The fluctuations can be (partly) predicted –  
but cannot not influenced**

# Renewable energy continues to grow

## Forecast installed capacity wind/PV for key countries

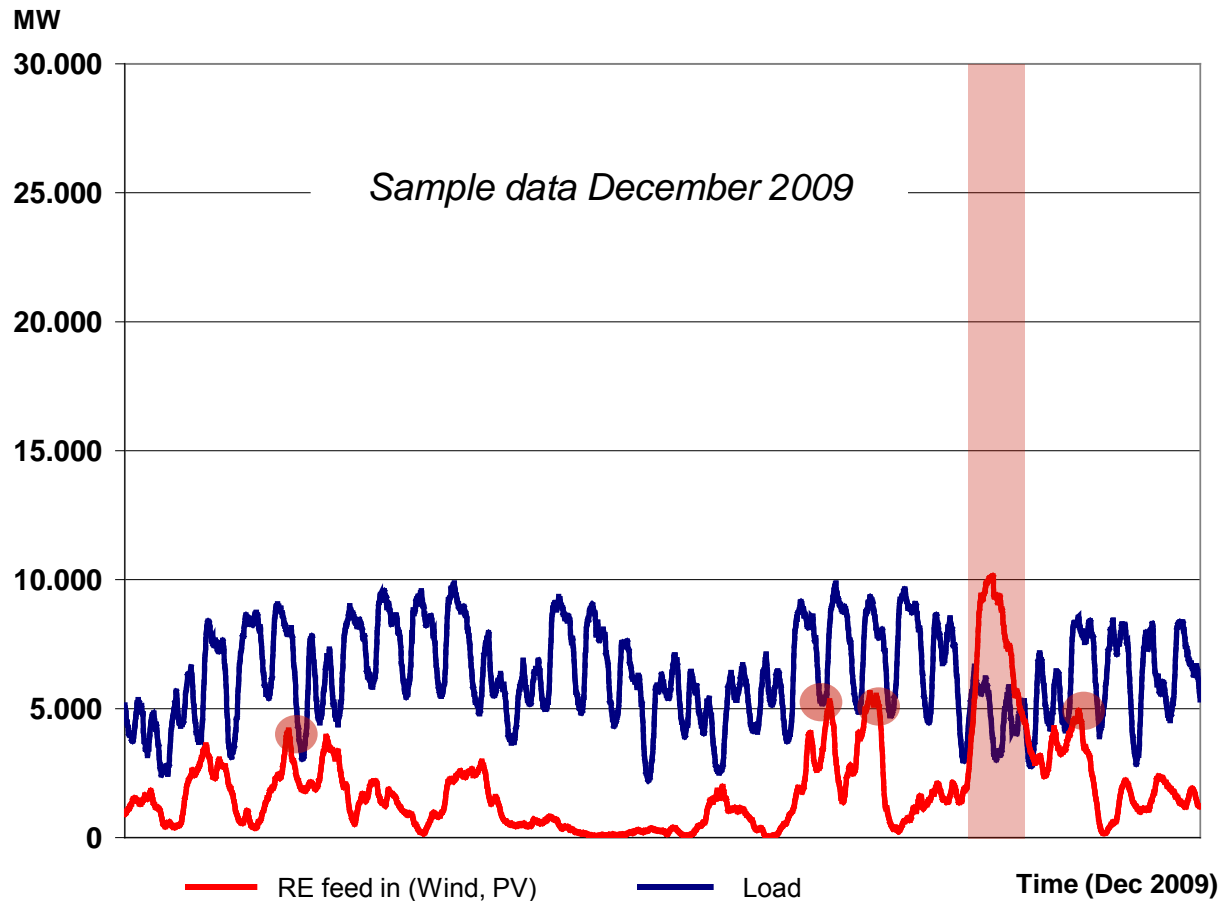


Source: BTM (March 2011); EPIA; European Commission; BCG analysis

LEW Präsentation\_Storage\_Cornelius Pieper.pptx

# Challenges are growing: RE feed-in can exceed total load already today...

## RE feed-in and load in Vattenfall grid, Status Quo 2009

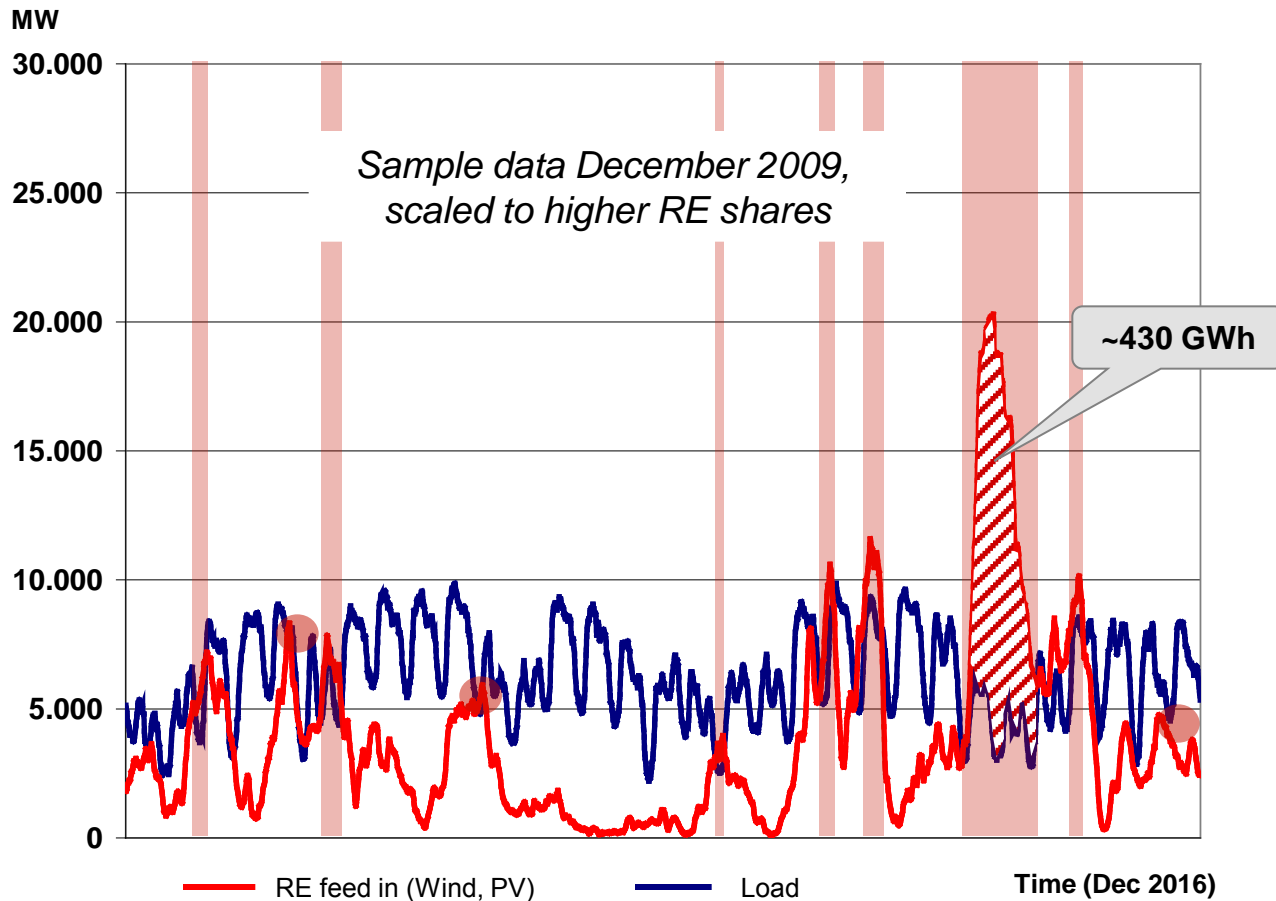


## Comments

- Underlying data: feed-in (15 minute intervals) from actual installed capacity of ~10 GW wind/0.5 GW PV
- "Christmas incident": on Dec. 25th/26th, RE feed-in exceeds total load in Vattenfall grid during 30 consecutive hours
- "Must-run" conventional generation (target ~4 GW) not considered in this illustration
- Load almost provided by RE generation on ~4 other instances during Dec 2009

# ...and will do so more often with increasing RE capacity

## RE feed-in and load in Vattenfall grid, Scenario 2016



## Comments

- Assumed growth of installed base RE to **~20 GW wind/4 GW PV** with same weather and load conditions as before
- Frequent excess of RE generation over total load
- "Must-run" conventional generation (target ~4 GW) not considered in this illustration
- Significant amounts of energy, e.g. 427 GWh during "Christmas incident" need to be exported, stored or throttled

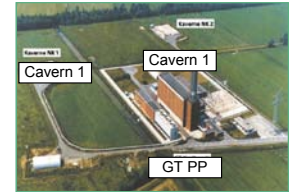
# Storage is a key pillar to provide compensation capacity

	Conventional back-up	Inter-regional compensation	Decoupling supply and demand	
			<i>Demand side management</i>	<i>Central/decentral energy storage</i>
Description	Adopting conventional power plant fleet to flexibly match renewable generation – fewer base load, more peak load PPs	Extension of transport grid capacity to balance fluctuations between regions leveraging different weather conditions	Use of suitable control and energy management technologies to defer/bring forward) energy-intensive activities	Balancing fluctuation between periods – charging at high feed-in/ low demand, discharging in periods of low feed-in/ high demand
Assessment	Well suited to compensate troughs in renewable generation but no solution for peak mitigation – throttling of renewables as only alternative	Requires long reach of transmission lines to leverage weather differences, challenging when participating regions all have high renewables shares	Strong in providing short-term, high-powered compensation – challenging coordination, limited energy and counteracted by energy efficiency improvements	Most flexible and self-sufficient approach in terms of compensation – downside efficiency losses during storage/conversion process

**Combination of approaches likely – future compensation need too large to be accommodated without storage**

# Storage has different applications...

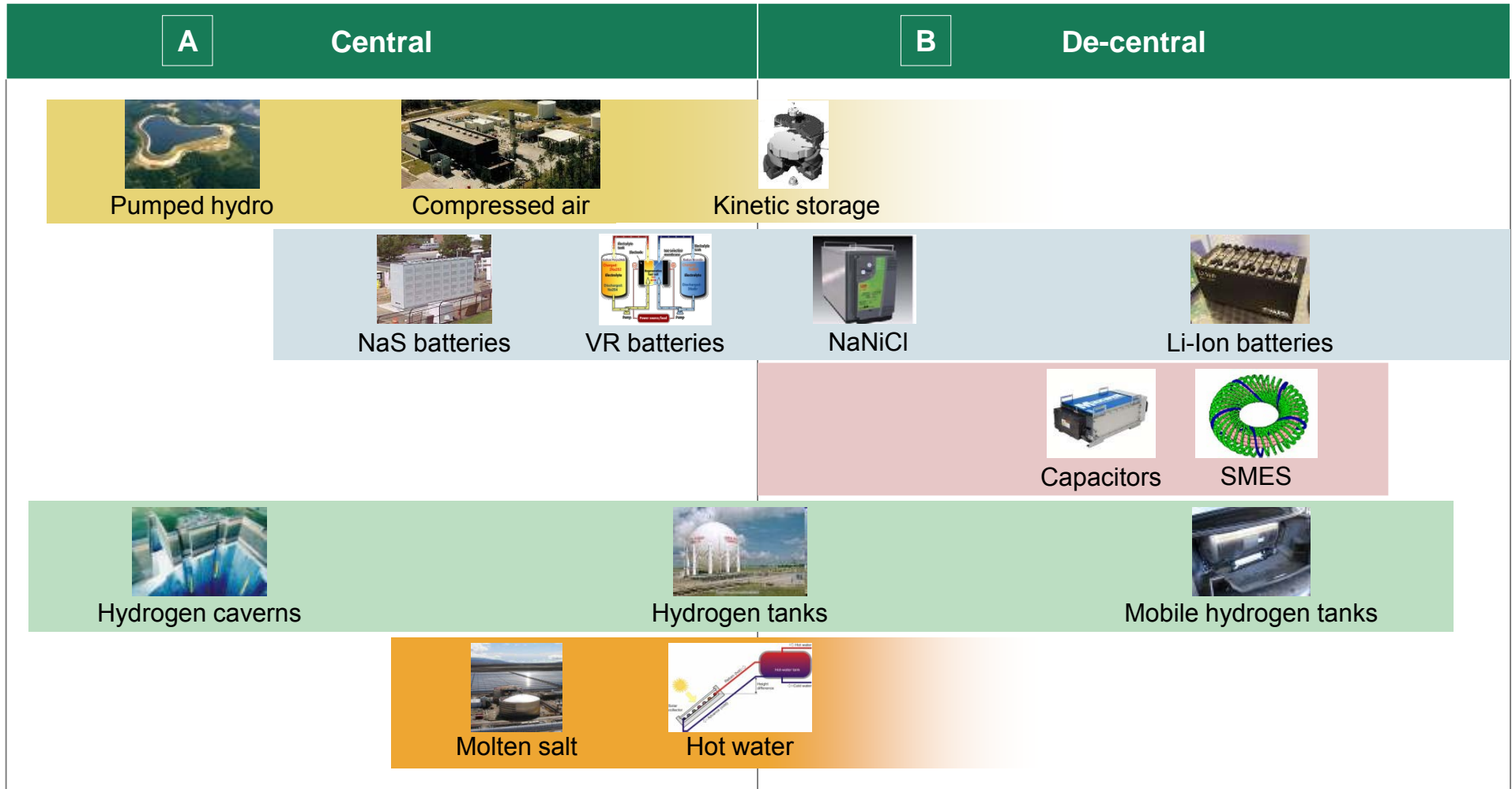
	Application type		Example
<b>A</b>	<b>Central-stationary energy storage</b> <ul style="list-style-type: none"> <li>Storage at generation site</li> <li>Transmission grid storage</li> </ul>	→	<ul style="list-style-type: none"> <li>Storage close to PV-farm or offshore windpark</li> <li>Thermal storage system of CSP-plant</li> <li>Large-scale storage at strategic point in the grid</li> </ul>
<b>B</b>	<b>Decentral-stationary energy storage</b> <ul style="list-style-type: none"> <li>Community/Metropolitan</li> <li>Commercial/Industrial</li> <li>Residential</li> </ul>	→	<ul style="list-style-type: none"> <li>End-point storage systems with grid link</li> <li>Peak control systems at industrial sites</li> <li>Residential self-supply</li> </ul>
<b>C</b>	<b>Decentral-mobile energy storage<sup>1</sup></b> <ul style="list-style-type: none"> <li>Road (E-Cars, hybrids)</li> <li>Rail (Trains/trams "last mile")</li> </ul>	→	<ul style="list-style-type: none"> <li>Power unit car/train</li> <li>Charging stations and E-vehicle batteries</li> <li>Energy management</li> </ul>



1. Consumer electronics are also decentral-mobile applications but are not considered here. Also planes could be a future application but fossil fuels are likely to prevail. Source: BCG analysis

# ... for which the right technology needs to be selected

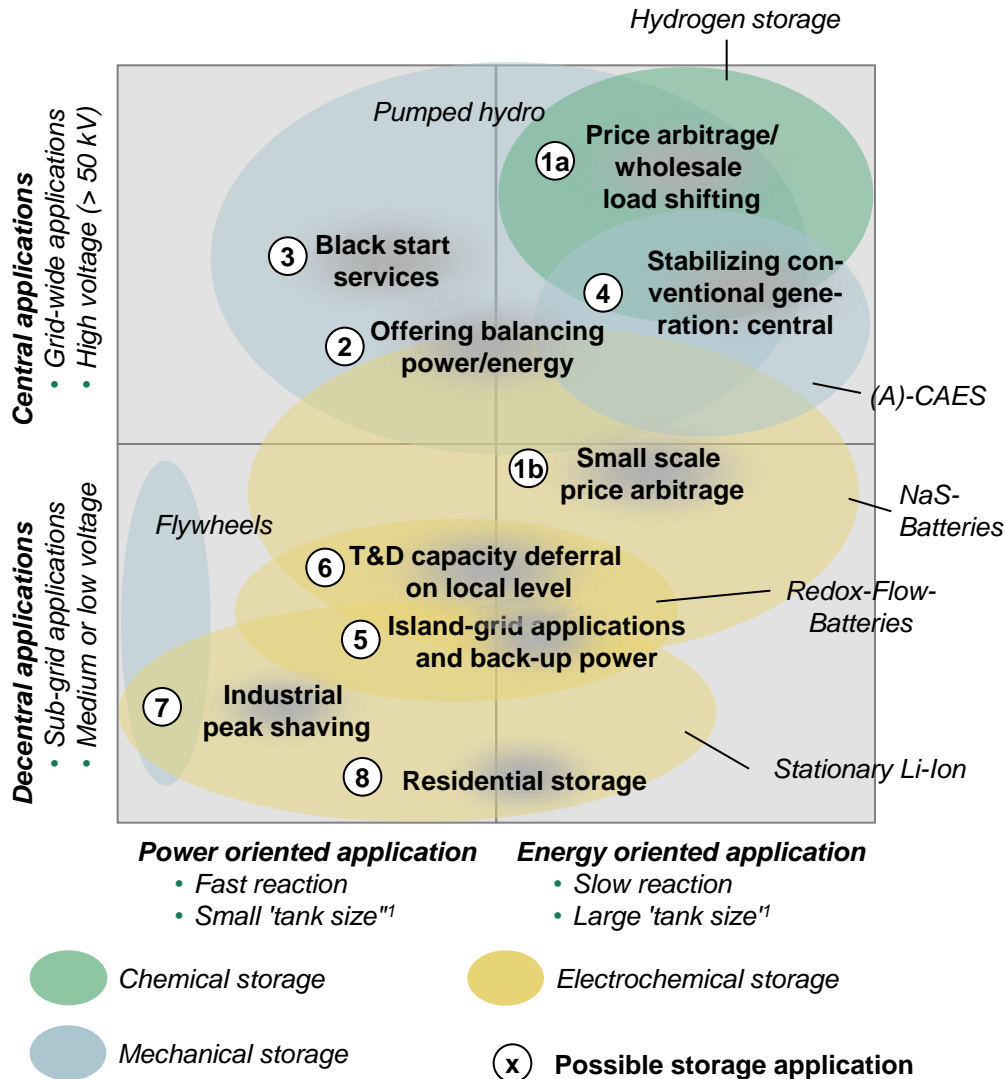
Overview of most important storage technologies and their application areas



Note: SMES = Superconducting magnetic energy storage Source: BCG analysis

# Eight possible storage application areas identified

Landscape of storage applications and technologies along two major dimensions



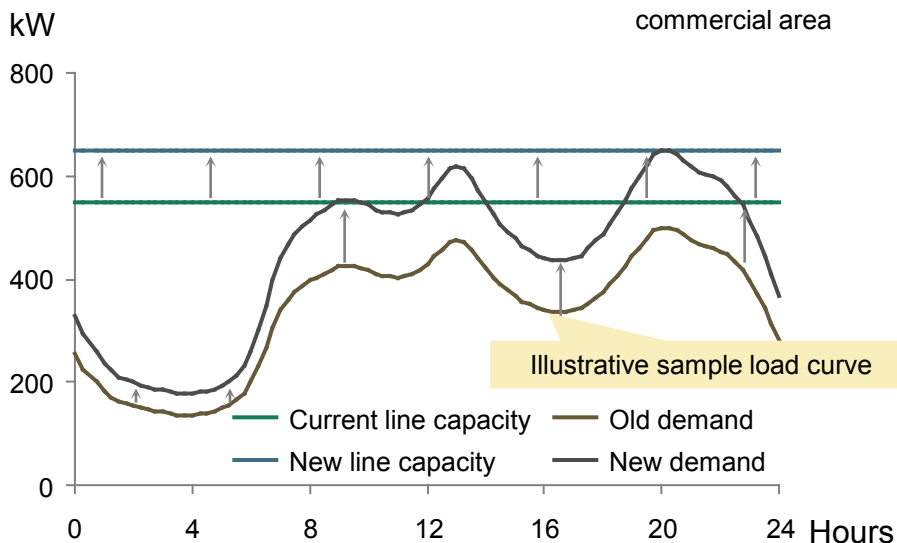
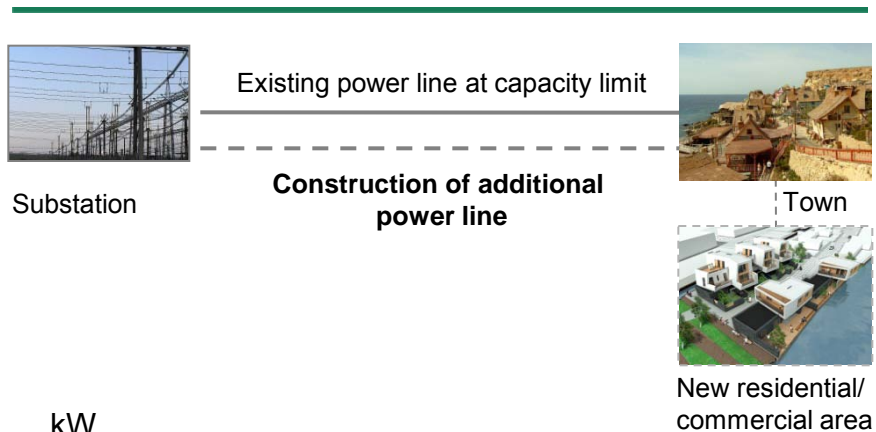
- ① **Leverage price differences by charging at low prices and discharging at high prices**
- ② **Offer balancing energy – primary and secondary as well as minute reserves (ideally negative)**
- ③ **Offer black-start services to grid operators to re-start generation after large-scale black-out**
- ④ **Stabilizing conventional generation by using storage for flexibilization – decentral or central**
- ⑤ **Use of storage in island grid applications to enable RE power supply and grid stabilization**
- ⑥ **Avoid grid extension investments by using energy storage (T&D deferral)**
- ⑦ **Flatten peak demand in industrial context using storage to achieve cheaper power tariff**
- ⑧ **Use residential/municipal storage to enable self-supply based on own RE generation**

1. Small tank size refers to low capacity compared to power of storage and vice versa

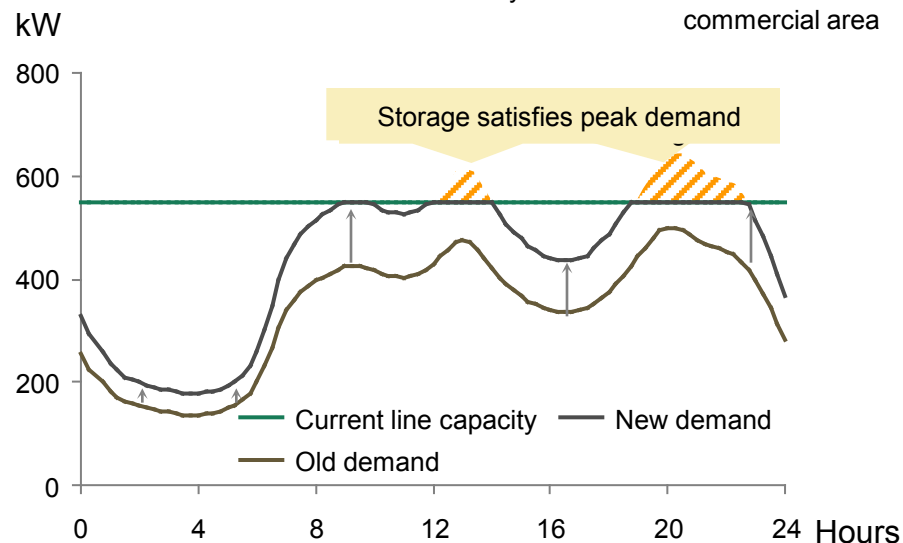
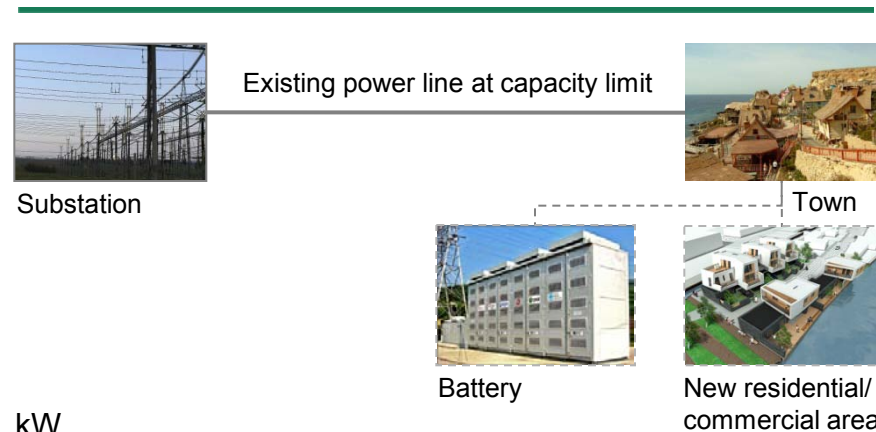
Source: GTM research "Grid scale energy storage" 2009, NREL "The Role of Energy Storage with Renewable Electricity Generation" 2010, BCG storage study 2009, dena 2010, BCG analysis

# T&D deferral application can be a short/mid term solution to the black out issue

## Grid capacity extension



## Installation of energy storage

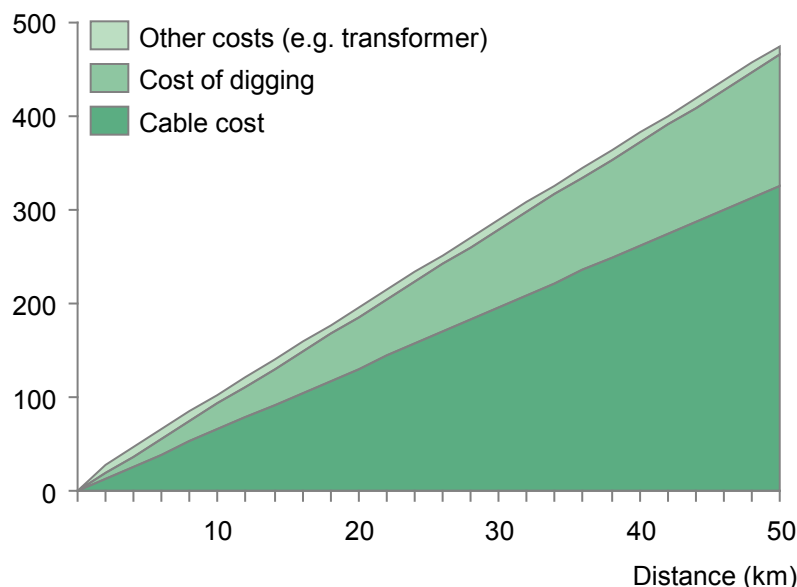


Source: BCG analysis

# Costs of grid extension vs. storage solution driven by different drivers

## Cost for grid extension

Costs (k€) for 50kW power extension

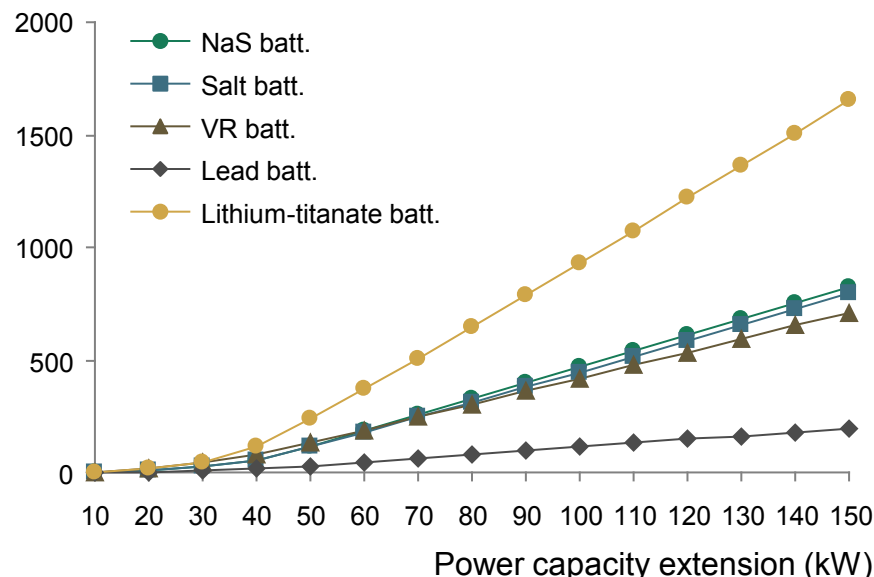


### Assumed power capacity extension of 50kW

- Cable costs proportional to substation distance with cost jumps because higher voltage losses due to longer distances require thicker cables
- Digging cost directly proportional to cable length
- Constant costs for transformer and power electronics

## Cost for storage solution

Initial storage CAPEX (k€)



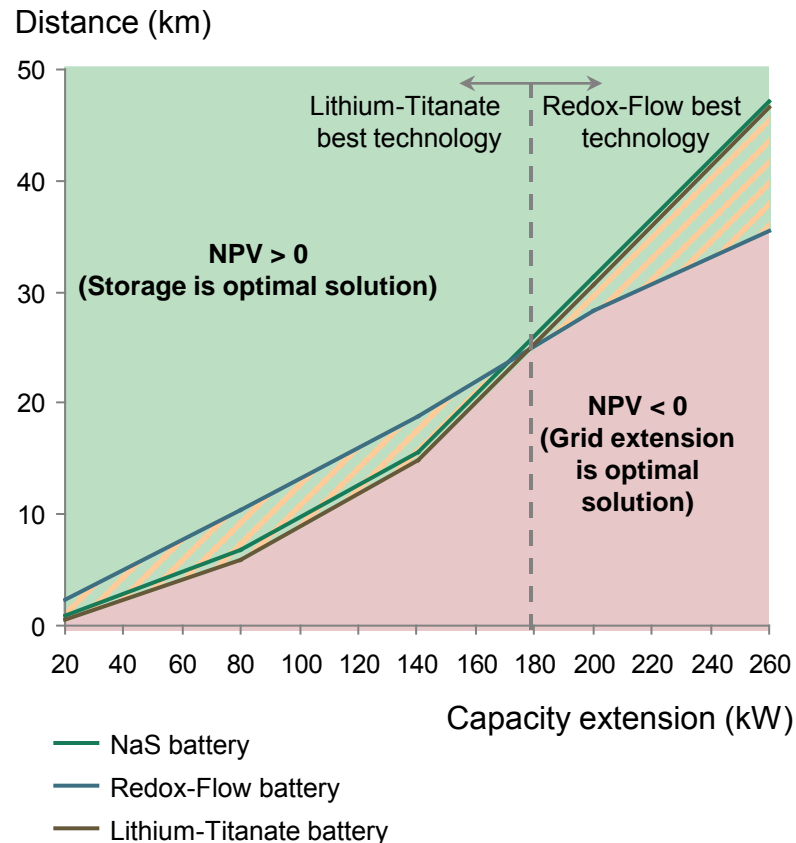
### Optimal storage technology depends on capacity extension

- For small capacity extensions, Salt show a high relative cost advantage vs VR, Lithium and NaS batteries are
- For higher capacity extensions, increasingly more storage capacity is necessary, which makes Redox-Flow batteries more attractive compared to Lithium-Titanate batteries
- NaS batteries show a very similar investment costs of Salt for all degrees of capacity extension, but require a higher level of

# Accordingly, storage solution is favorable for certain situations – when capacity is low and distance is large

## NPV sensitivity analysis

## Explanation



**Curves show for which combinations of capacity extension and grid extension distance, storage solution and grid extension are equivalent**

- For situations above or left of the curve, the storage solution results in a higher NPV
- For situations below or right of the curve, the grid extension solution results in a higher NPV

**If storage is attractive (NPV > 0), lowest curve determines most attractive technology**

- For capacity extensions below 180 kW, Lithium-Titanate is most attractive
- For capacity extensions above 180 kW, Redox-Flow batteries have the best performance

# Several reasons behind rise of residential storage – first products are available, based on lithium and lead acid

## Key rationale

### Increase self-consumption of PV-generated electricity

- Without battery, self-consumption of approx. 30% of generated electricity may be possible
- Storage solutions increase this share to up to 70%

### Attractive for end-users beyond economic considerations

- Reducing dependency on electricity generated from fossils from the grid
- Hedging risks of electricity price increases

### Impact on grid may be stabilizing

- Reducing peak load around noon
- BUT: questioning financing model of grid

## Products on offer (examples)



### BYD Home Energy Storage

- 2.6 kWh storage capacity
- Battery lifetime 8 years
- Li-Ion battery



### Conergy Sonnenspeicher

- 13.2 kWh storage capacity
- 7000 cycles
- Li-Ion battery



Energy management system  
Inverter  
Batteries



### Solarworld SunPac

- 6.9 kWh storage capacity
- 2000 cycles
- Lead-acid battery



**In addition to increased self-supply,  
stabilizing effect on distribution grid need**

# Two variants of PV storage business case can be considered

## I Short term: subsidy-driven

Only few countries currently offering incentives for self-consumption of PV electricity

Germany most innovative country offering specific EEG incentives (supporting self-consumption)

Subsidies rationale is to help the start up of the technology until it reaches a self-sustaining economical convenience

All incentives expected to decrease in the medium to long term

**Only in some specific countries  
(lead market: Germany)**

## II Mid term: grid parity driven

Decreasing PV panels cost trend can significantly change the cost of self produced kWh

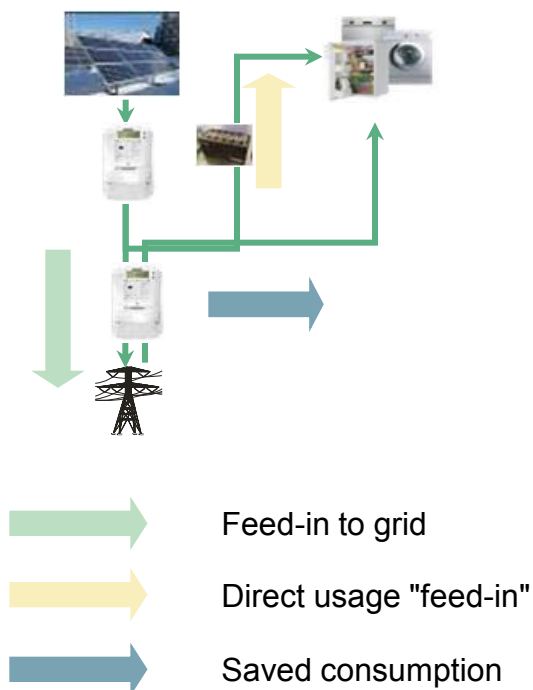
Increasingly more efficient panels produce relatively more energy per square meter and €invested

Increasing cost of energy will shorten the time when PV self production will reach grid parity cost

**Works in all countries as soon as grid advantage is sufficient**

# Residential storage in Germany: Self-supply supported by favorable compensation for direct usage

## Scheme



## EEG feed-in tariffs / compensation after Jan 1st, 2011

€ct / kWh	Share	in focus			
		<30 kW	>30 kW	>100 kW	>1000 kW
<b>Feed-in to grid</b>		28,75	27,33	25,86	21,56
<b>Direct usage "feed-in"</b>	≤ 30%:	12,36	10,95	9,48	
	> 30%:	16,74	15,33	13,86	
<b>Saved consumption</b>		25,88	12,63	In case of storage, only 90% consumption are saved due to cycle efficiency <sup>1</sup>	
<b>Total direct usage</b>	≤ 30%:	38,24	23,58		
	> 30%:	42,62	27,96		
<b>Delta</b>	≤ 30%:	9,49	-3,75		
	> 30%:	13,87	0,63		

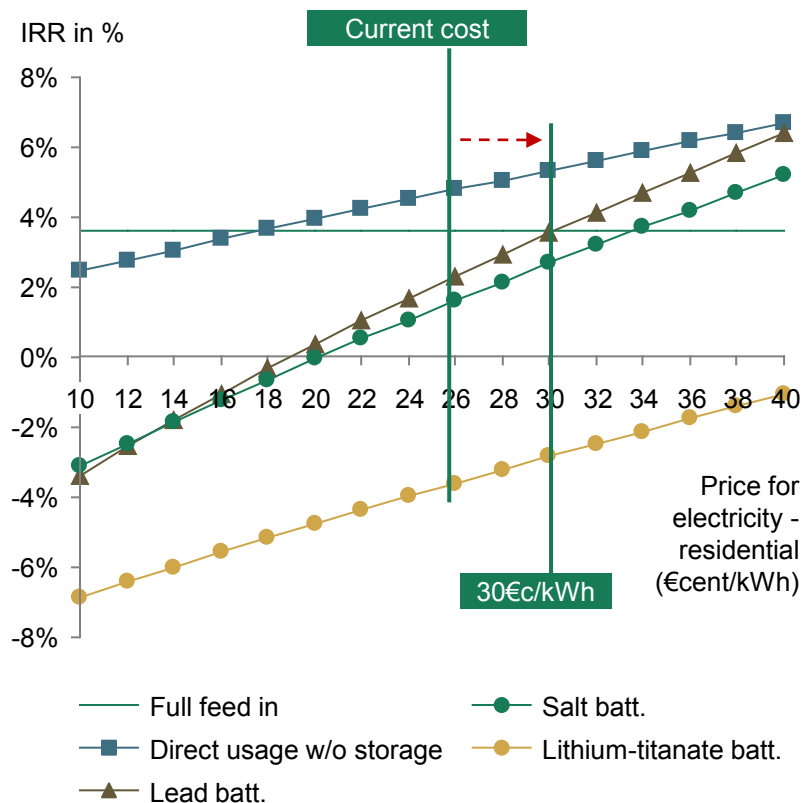
First 30% with lower compensation; after 30% with higher compensation

Direct usage energy with revenue advantage compared to feed-in for residential applications

1. In case of Li-Io battery; no additional inverter required  
 Note: For all cases constant EEG tariffs / compensation is assumed  
 Source: EEG, BCG analysis

# Investment doesn't pay off with 2011 power prices – but at ~0.30 €/kWh, business case becomes attractive vs. full feed-in

## Residential electricity tariff...



**At 30€/kWh electricity cost, storage with lead better than full feed-in (expected by 2015)**

## ... determines profitability of direct usage

### Higher price for residential electricity<sup>1</sup> would make direct usage more profitable

- Direct usage of PV electricity replaces consumption from grid at residential tariff (assumed at 25,88 €Cent/kWh today)
- Profitability with storage reaches level of full feed-in at electricity price of ~30 €cent/ kWh for lead batteries
- Salt battery solution breaks even at ~34 €cents/kWh, reaching attractive IRR level (>5%) at ~40 €cent/kWh

### If residential tariff falls below 18 €cent/kWh, direct usage loses advantage over full-feed-in

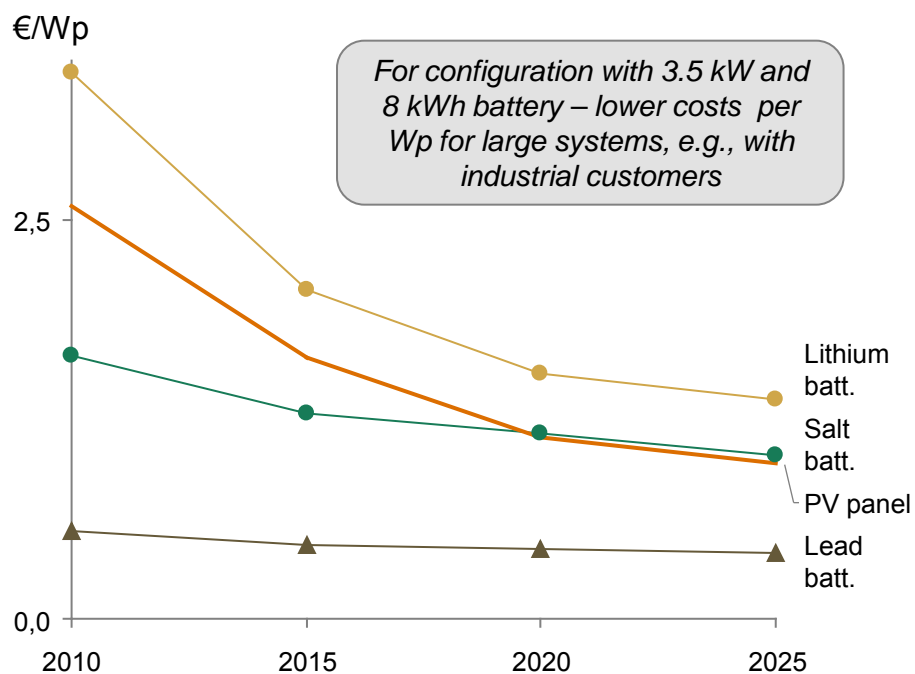
- Below 18 €cent/kWh, energy feed-in financially more attractive than direct usage (assuming 2011 feed-in tariffs)

**However, most residential market participants considering factors beyond economical view as well (independency, image, hedging against power price increases etc.)**

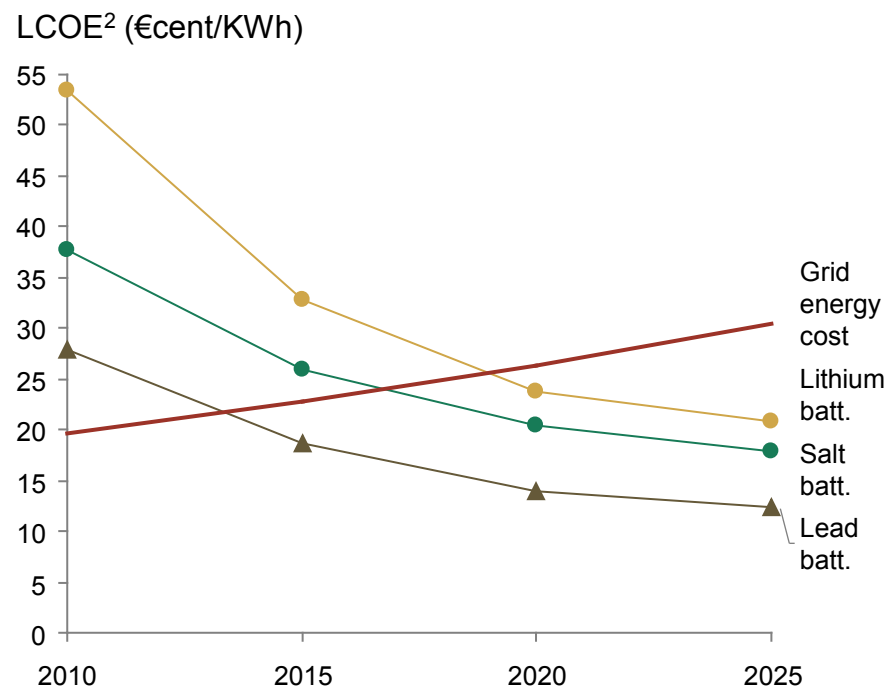
1. EEG values are fixed for 20 years after investment however residential price for electricity is flexible  
Source: BCG analysis

# The Italian case: self production of energy becomes attractive with grid parity – for residential and industrial customers

PV and Storage €/Wp evolution



Combined with storage, PV can largely substitute grid



What does this development imply for the traditional utility business model?

1. LCOE: levelized cost of energy generation, full system cost  
 Source: Research Centre of the European Commission, PVGIS; internet search, BCG Analysis

# In short: Two technology clusters emerging until 2015

Application	Pumped hydro	CAES	A-CAES	Hydrogen	NaS	VRB	Li-Ion
1 Price arbitrage	●	●	●	●	●	●	●
2 Balancing power	●	●	●	●	●	●	●
3 Black-start	●	●	●	●	●	●	n.a.
4 Central stabilization of conventional generation	●	●	●	●	●	●	n.a.
5 Island grids	n.a.	n.a.	n.a.	●	●	●	●
6 T&D extension deferral	n.a.	n.a.	n.a.	n.a.	●	●	●
7 Industrial peak shaving	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	●
8 Residential storage	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	●

Pooling of very many dispersed installations needed to achieve minimum power

### Attractiveness of business case based on expected 2015 cost

- Attractive today<sup>1</sup>
- Attractive in 2015<sup>1</sup>
- Needs further cost depression and/or subsidies to be viable

Financial attractiveness depending on location, retail price and PV cost development – also non-financial motives relevant

1. Expected IRR 7% or above  
Source: BCG analysis

# Storage market outlook: some large potential forecasted....

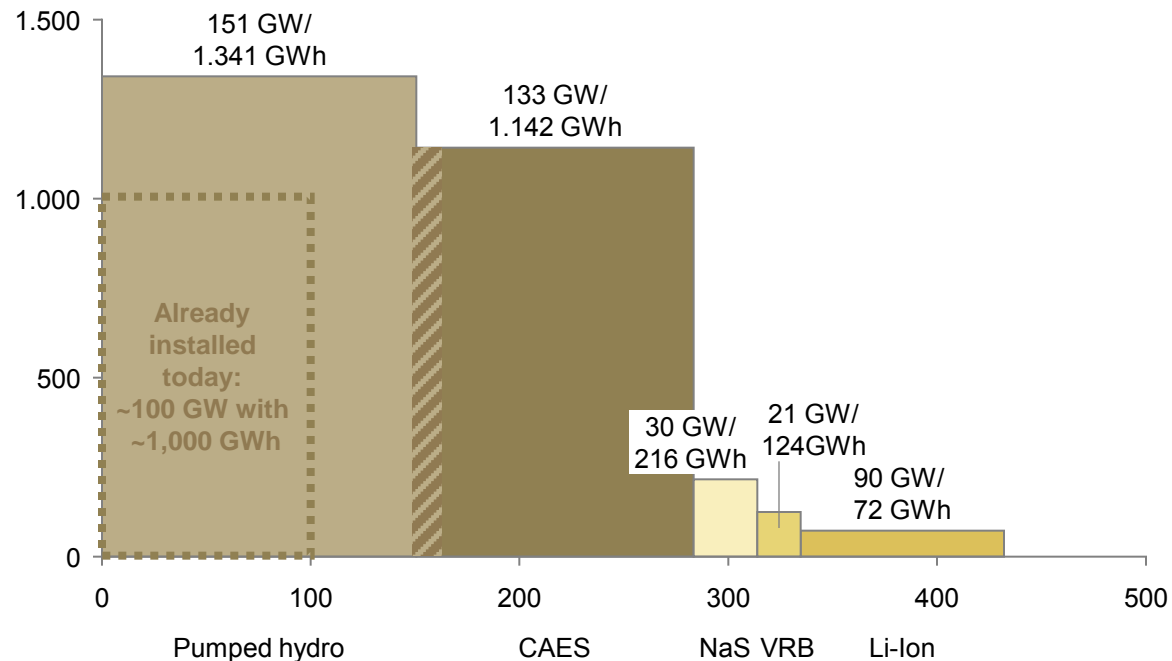
Market potential per technology in terms of power, capacity, and monetary units

Cumulated market sizes based on 2030 parameters

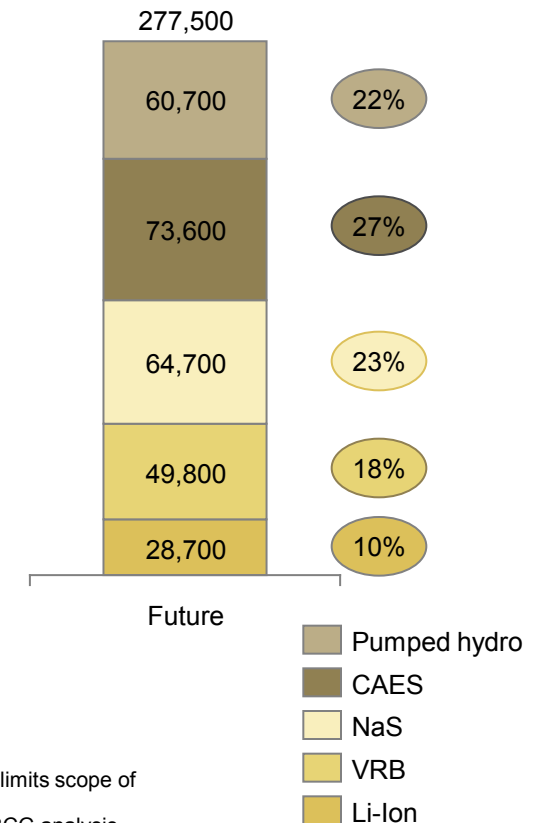
In terms of power, batteries account for half of market but for significantly less in terms of capacity

Batteries stand for ~50% of cumulated market potential

Cumulated market potential until 2030 per technology (GWh)<sup>1</sup>



Cumulated additional market potential per technology (M€)<sup>1</sup>



1. Without price arbitrage, driver trees based on 2030 values, 2015 technology costs until 2030 per technology (GW)<sup>1</sup>

2. Assumption: Installed base (~100 GW/1,000GWh) can be used for analyzed applications. Geographical location of existing pumped hydro plants limits scope of available applications, e.g. 1,140 MW pumped hydro plan Siah Bisheh in Iran

3. Future split Pumped Hydro vs. CAES driven largely by site restrictions – after 2020 gradual replacement by H2 storage expected

Source: BCG analysis

# ... which raises the interest of many different players

Potential players – current or new – who may play a role in the future storage market

Exemplary list

