NTNU – Trondheim
Norwegian University of
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Distributed energy storage: Market aspects and utility for different roles

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Roles of Energy Storage

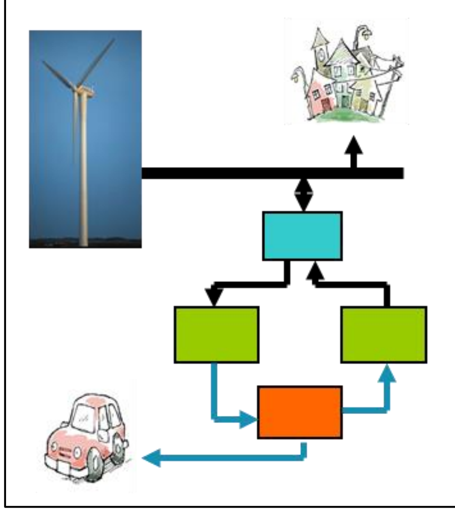
System-wide
- System adequacy
- Energy trade
- Grid utilization
- Ancillary Services

DSO level
- Grid utilization
- Voltage quality
- Fault support

End-user level
- Energy bill reduction
- Self-balancing
- Local power reserve

Interplay with other sectors
- Heat
- Transport
- Hydrogen?

Some (vague) conclusions from my PhD work 2000-2004



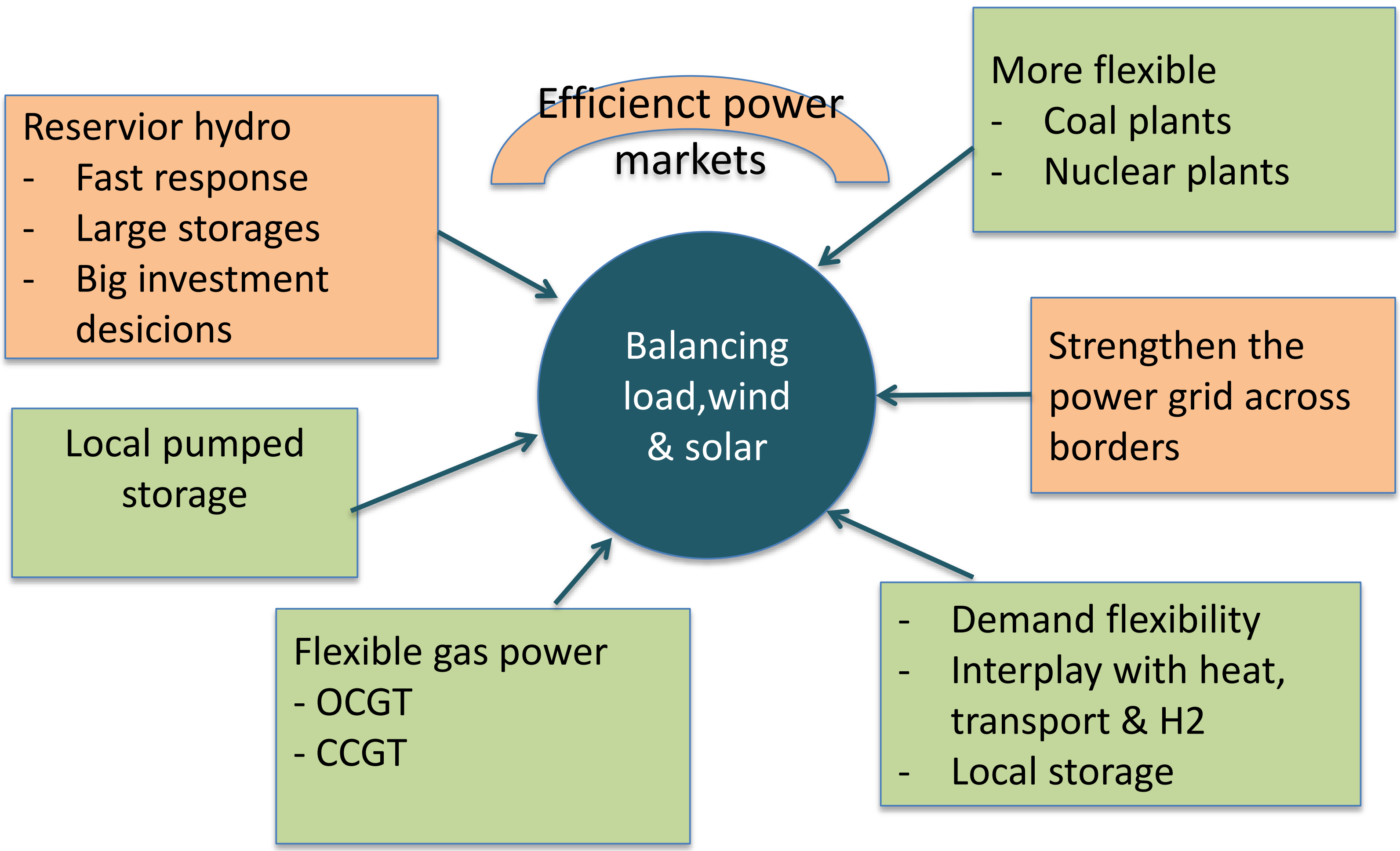
Energy storage in interconnected systems is useful if:

- imbalance costs are significant
- storage efficiency is high
- penetration of wind power is high
- weak grids limit the integration of wind power

Hydrogen storage will become useful if:

- we want to subsitute fossil fuels with renewables
- hydrogen is introduced in the transport sector
- long-term storage costs are reduced
- we take advantage of the flexibility that hydrogen storage offers

Batteries are not the only solution!



Properties of a market that enhances flexibility

- Common markets for spot, balancing og grid service across borders
- More frequent updates of production plans
- Market clearing closer to real-time
- Consumers participate activly

- Allow «extreme» prices or introduce capacity markets
  - The «Merit order effect» of RES

Better forecasts means less need for storage

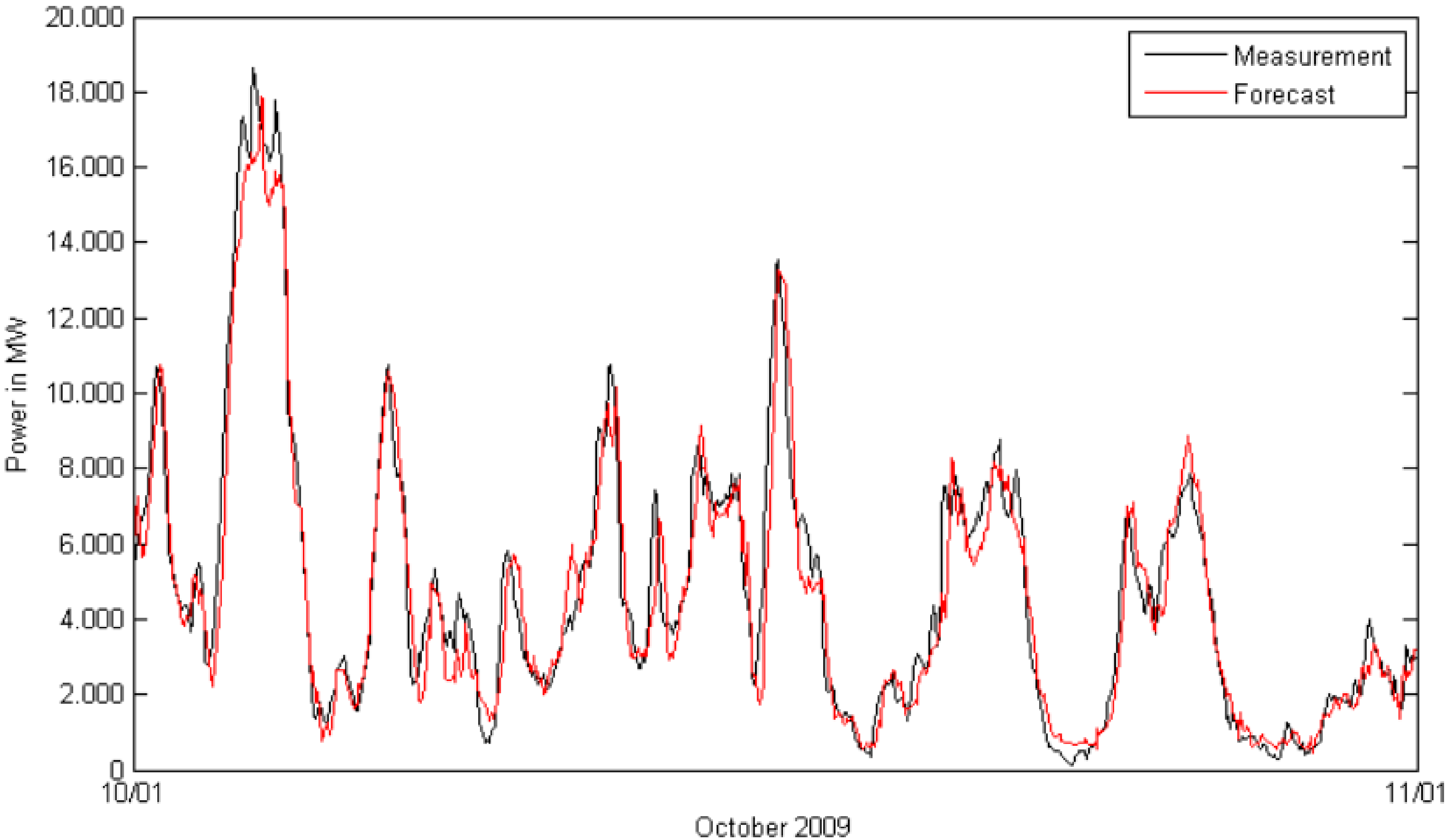
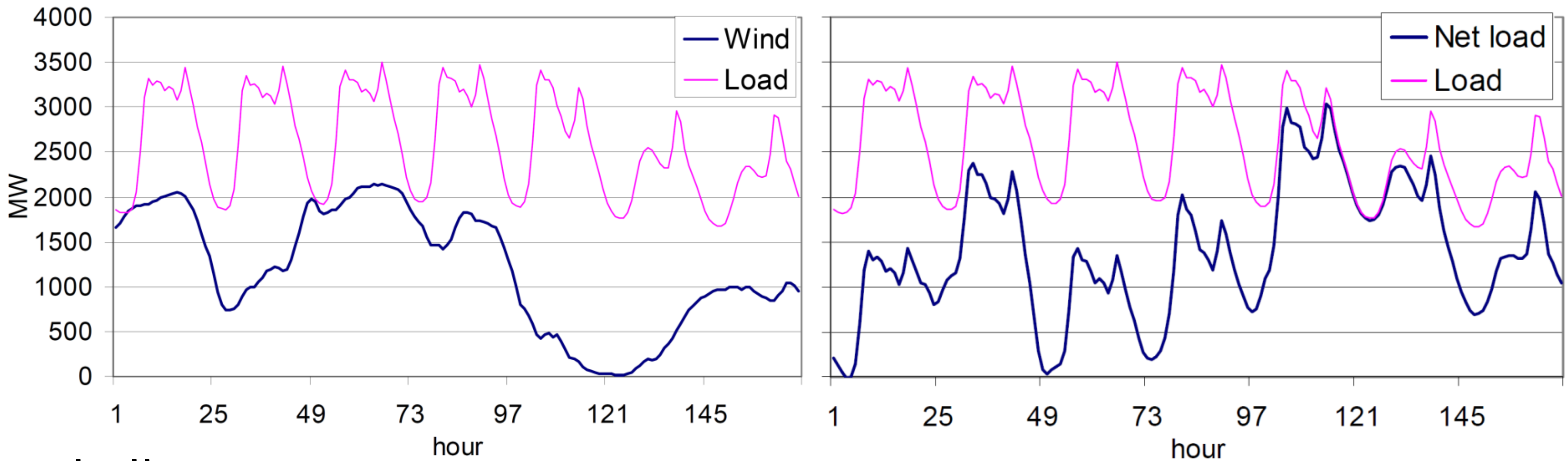


Figure 48 – Wind power production and forecast in Germany, October 2009

A. Gesino, Kassel Univ. 2010

It is the Net Load that matters

- The system will see the aggregated net imbalance
  - Unforeseen variations in load, wind and solar
  - Net load = Load – Wind – Solar

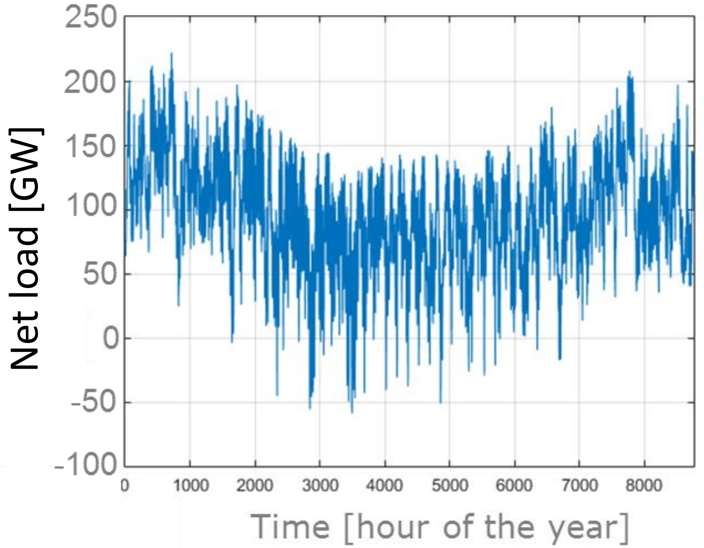


Challenges:

- Flexibility of thermal power plants (ramp rates, start/ stop operation)
- With very high RE share, thermal plants can be pushed out of the market – security of supply has to be fulfilled

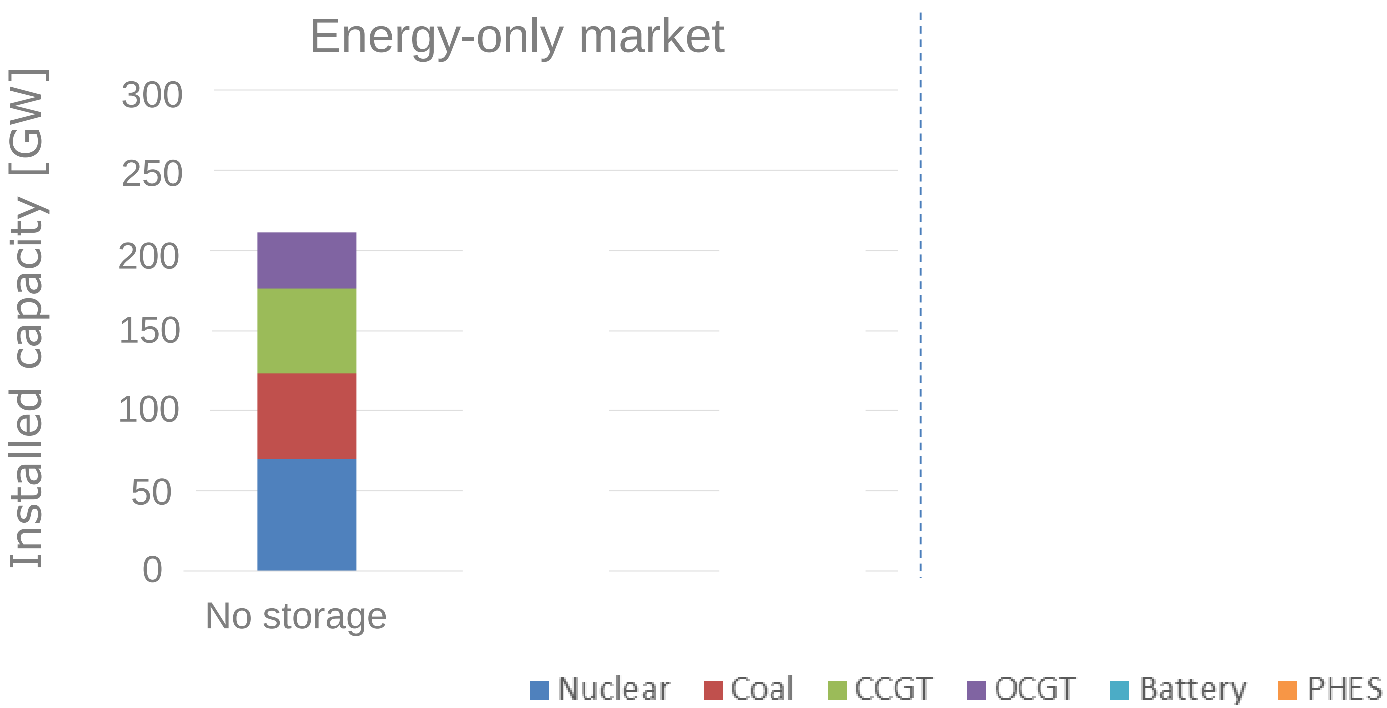
Generation Adequacy Study

- **Given:** Scenarios for large-scale RES and demand for electricty in Europe (ENTSO-E Vision 4)
- **Modelling challenge:** Find the optimal mix of the other energy sources
  - Investment costs
  - Operational characterstics and costs
- **Goal of study:** Analyze how energy storage affects the need for thermal power
  - Distributed batteries
  - Pumped storage from Norway



Results: Installed Capacity

- Introduction of Norwegian PHES decrease coal power
- Battery reduces the OCGT capacity
- The additional capacity with a capacity market is OCGT



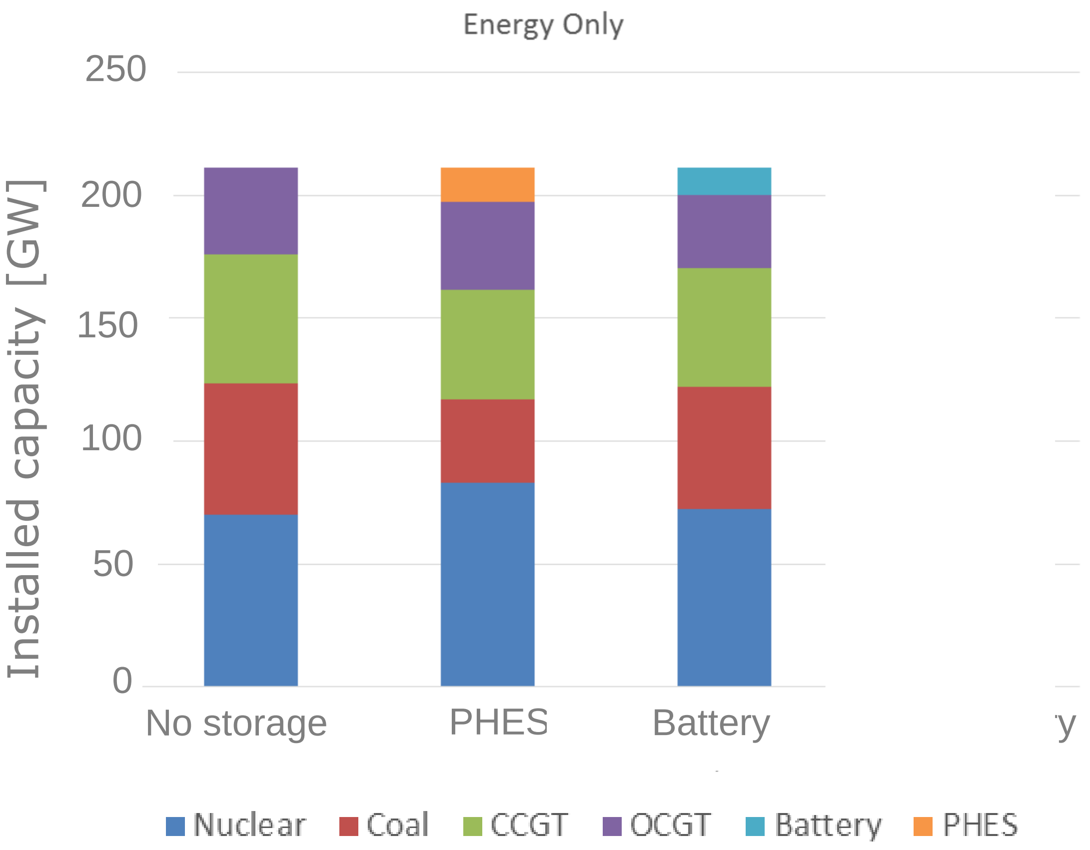
Results: Installed Capacity

PHES + Batteries in the same system: Nearly the same installed capacity.

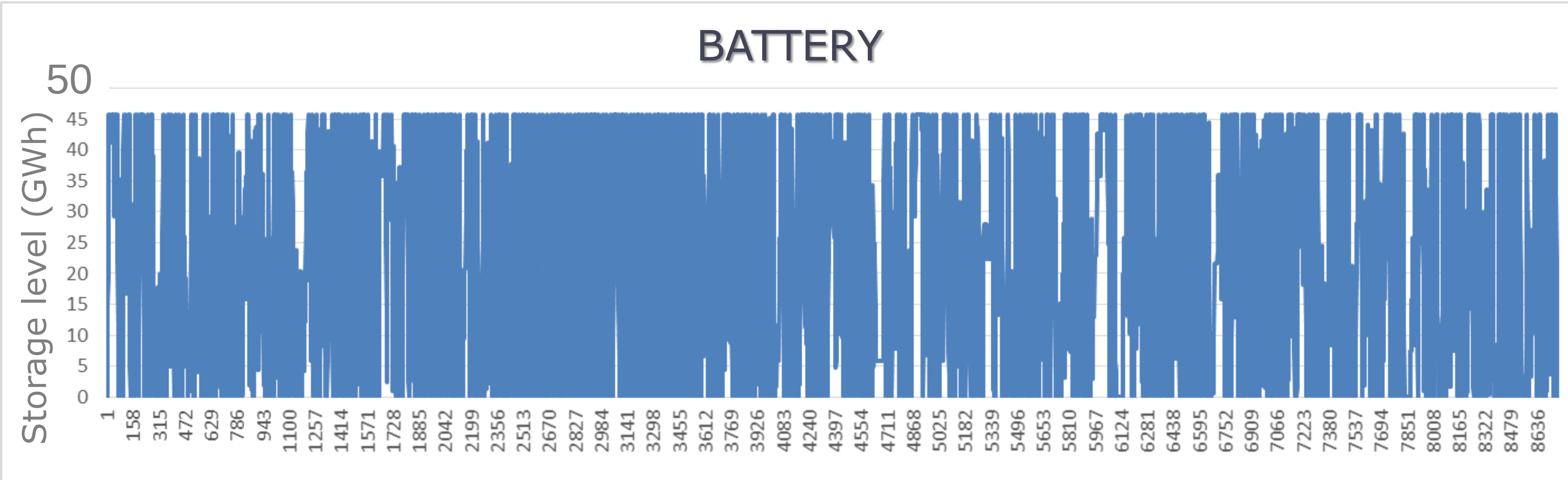
Increased base load capacity.

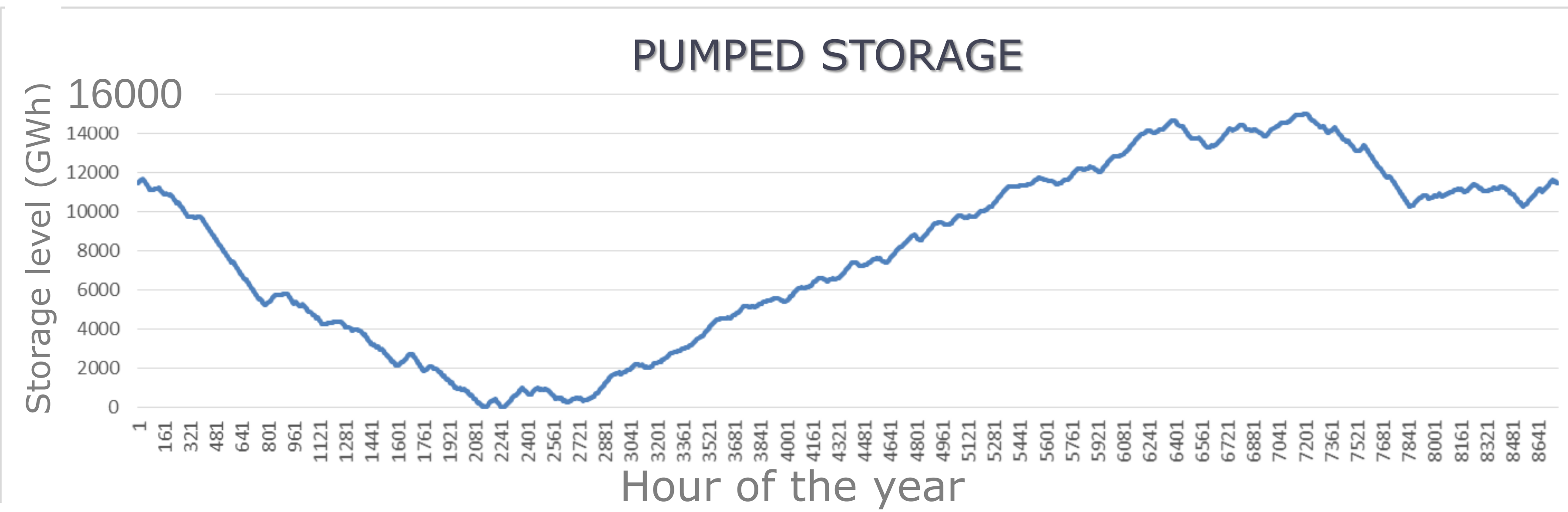
Decreased mid-merit capacity.

This suggests that both technologies are needed in the system.



Which storage technology?





Sensitivity: Battery costs

Optimisitc reference investment cost

Converter cost:

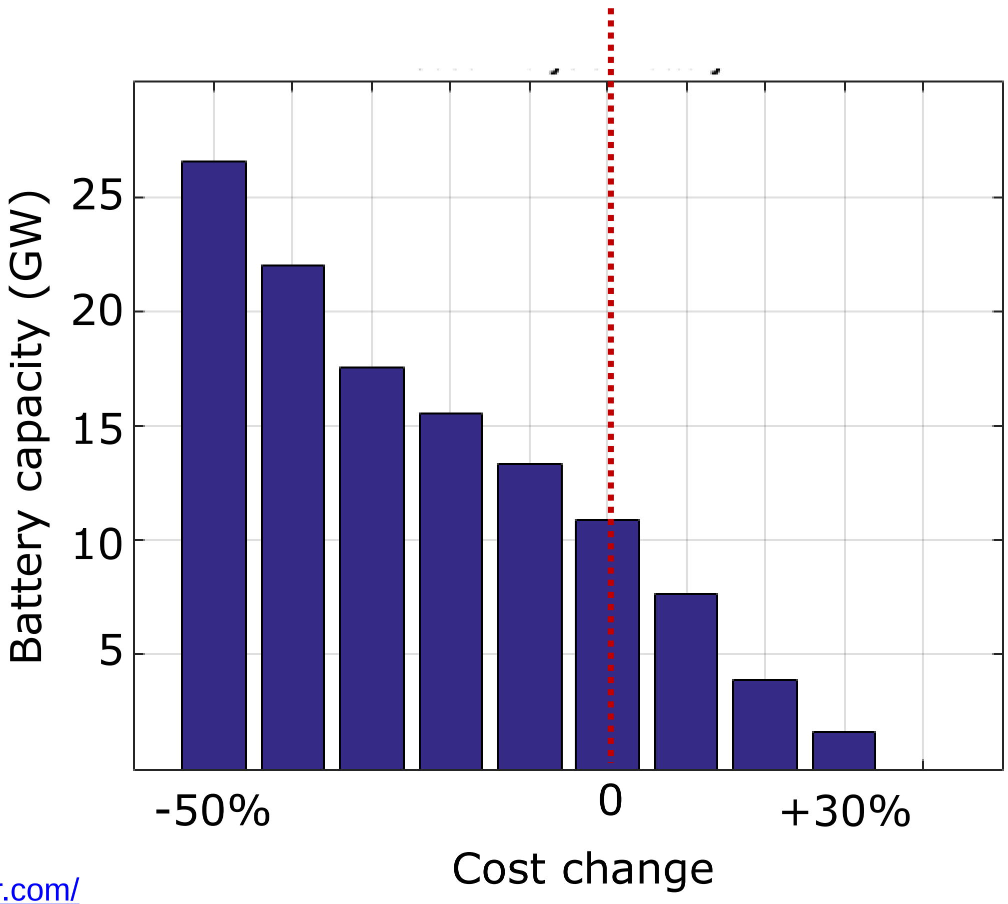
200 EUR/kW

Storage size cost:

50 EUR/kWh

With ~4,5 hour storage capacity, this corresponds to 100 €/kWh (converter included)

Tesla Powerwall (6,4 kWh without converter) presently costs ~3000 $*



* http://www.wholesalesolar.com/

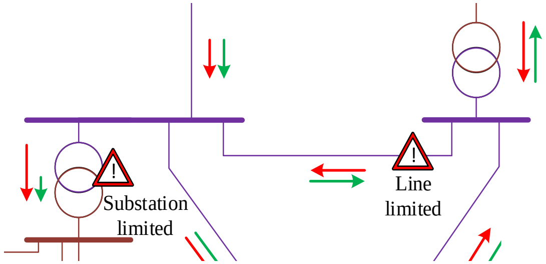
Value of energy storage at distribution level and end-user level

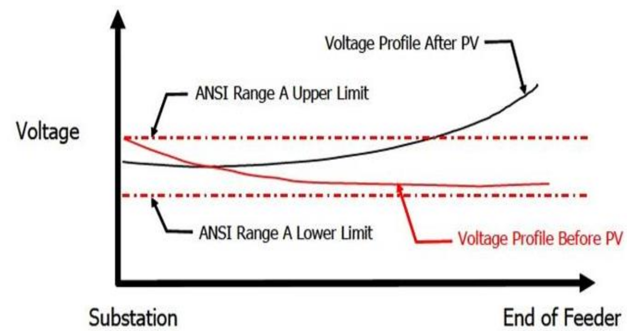
- Flexibility Services prioritized in the EU-H2020 project INVADE
- *Smart system of renewable energy storage based on **IN**tegrated E**V**s and b**A**tteries to empower mobile, **D**istributed and centralised **E**nergy storage in the distribution grid*

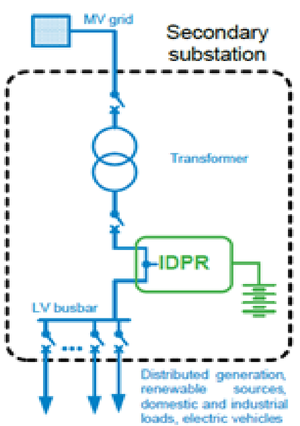
- Budget: 16 M€, Duration: 2017-2019
- Coordinator: Smart Innovation Norway
- http://h2020invade.eu/

Flexibility services for DSO

- **Congestion management**:
  - Avoiding thermal overloads of system components by reducing peak loads
  - Flexibility may defer or even avoid the necessity of grid investments
- **Voltage / Reactive power control**:
  - Typically requested when solar PV systems “push up” the voltage level in the grid
  - Increasing the load or decreasing generation is an option to avoid exceeding the voltage limits
  - It can reduce the need for grid investments or prevent generation curtailment
- **Controlled islanding:**
  - To prevent supply interruption in a given grid section when a fault occurs in a section of the grid feeding into it

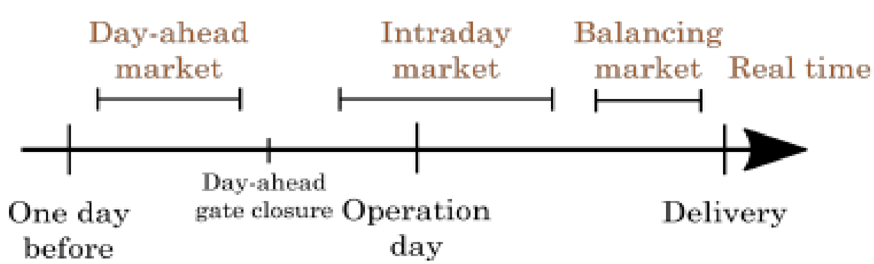






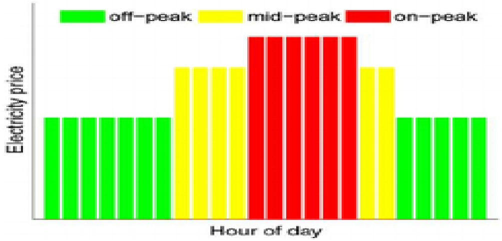
Flexibility services for BRP

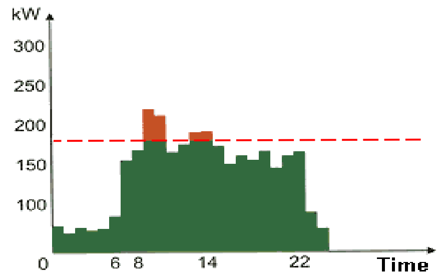
- **Day-ahead portfolio optimization**
  - Shift loads from periods with high-prices to low-prices
  - BRP reduces its overall electricity purchase costs
  - This service is used by BRP to prepare day-ahead market bids
- **Intraday portfolio optimization**
  - Trade after closing of the day-ahead market
  - This service is used by BRP to prepare intraday market bids
- **Self-balancing portfolio optimization**
  - Reduce imbalance of the BRP portfolio to avoid imbalance charges
  - BRP does not actively bid on the imbalance market using its flexibility, but uses it within its own portfolio

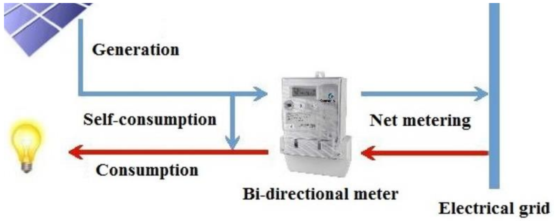


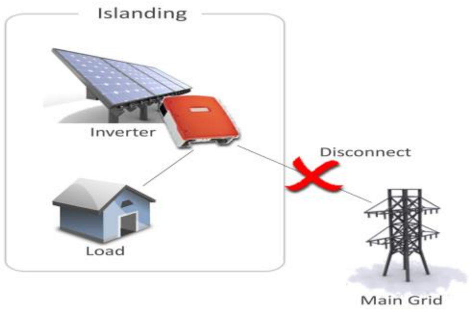
Flexibility services for prosumers

- **ToU optimization**
  - Load shifting from high-price intervals to low-price intervals
  - Special tariff structures are needed
- **kWmax control**
  - Reducing the maximum load of the prosumer within a predefined duration (e.g., month, year)
  - By reducing this maximum load, the prosumer can save on tariff costs
- **Self-balancing**
  - Can be preferred by Prosumers although not necessary economic optimal
  - Value is created through the difference in the prices of buying, generating, and selling electricity (including taxation)
  - Note that solar PV self-balancing is not meaningful where regulations allow for administrative balancing of net load
  - It can include zero-net injection optimization
- **Controlled islanding**
  - It provides supply during grid outages.
  - Added value to the Prosumer depends on the grid's reliability and the potential damage from a grid outage.
  - Islanding may require additional investments, such as storage and synchronization systems



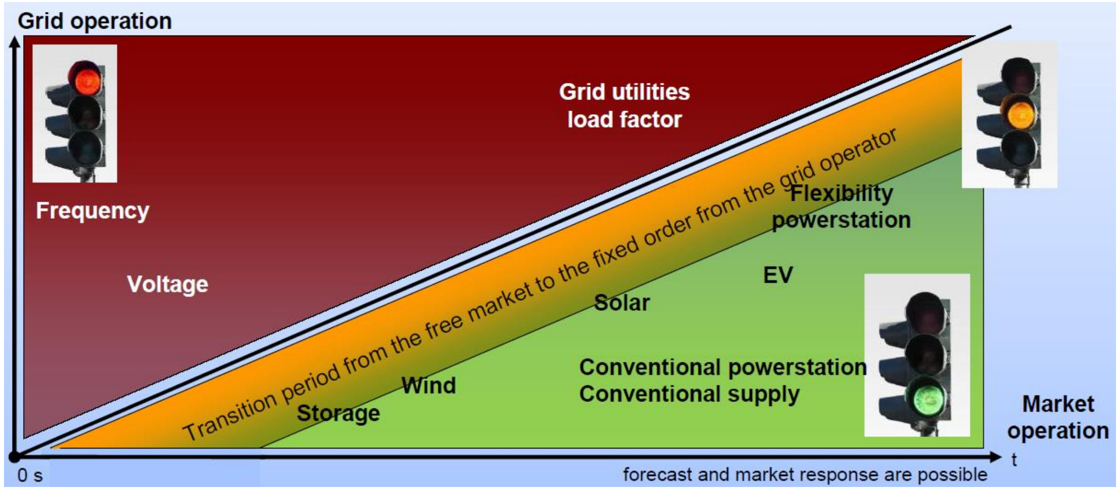


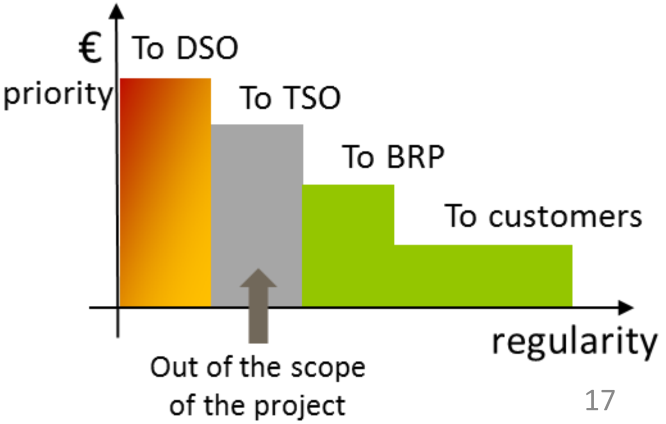




Traffic light concept

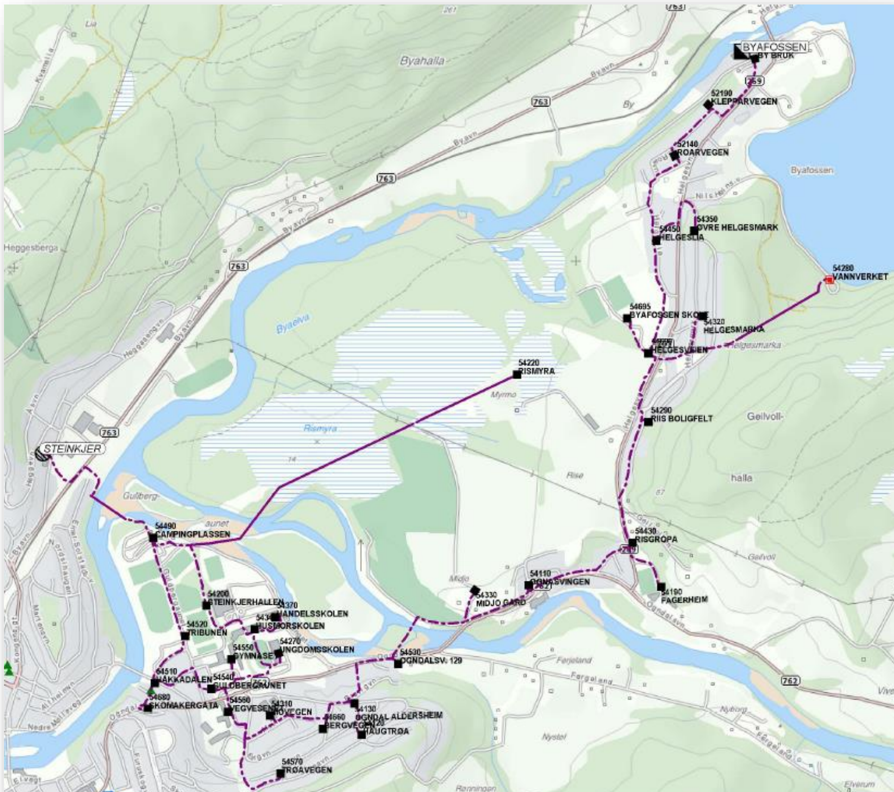
- The traffic light concept defines 3 states based on the condition of the grid:
  - **Green state:**
    - Normal operating state, where the "flexibility market" operates freely.
    - Grid operator may not request flexibility services and market operation has priority
  - **Yellow state:**
    - Grid operator actively engages with the market in order to prevent unsafe grid events
    - Grid operator may request flexibility services and grid operation has the highest priority
    - It is a temporary state until the grid operation becomes safe again
  - **Red state:**
    - Grid operator needs to take control of market interactions in a certain area where a grid constraint has occurred.
    - Grid operator can override contracts existing in the market and execute dedicated emergency actions in order to re-stabilise the system.
- *Services can be requested at the same time and be contradictory!*

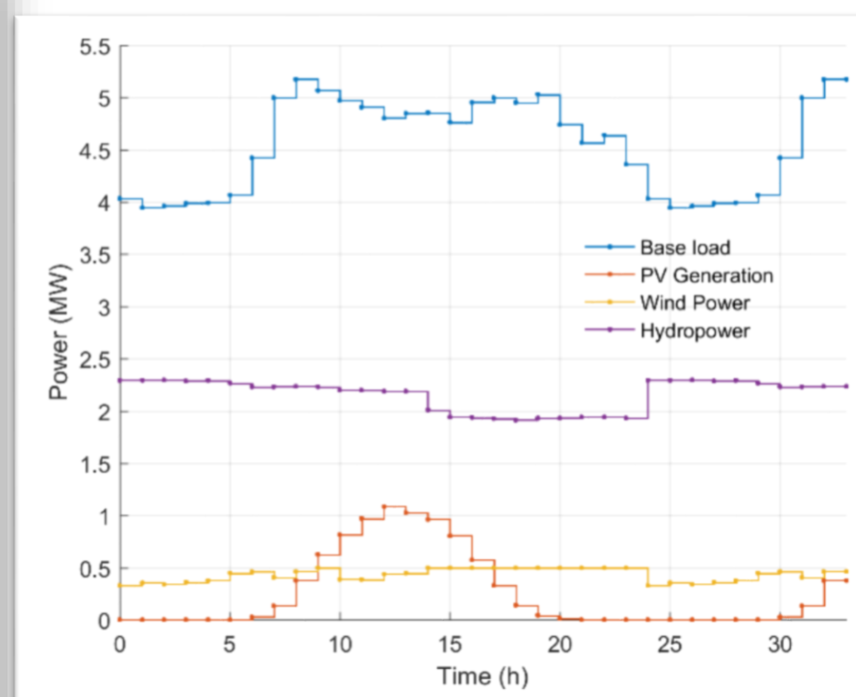




Value of storage for DSO: Example

Grid integration of EV and PV using Dynamic OPF





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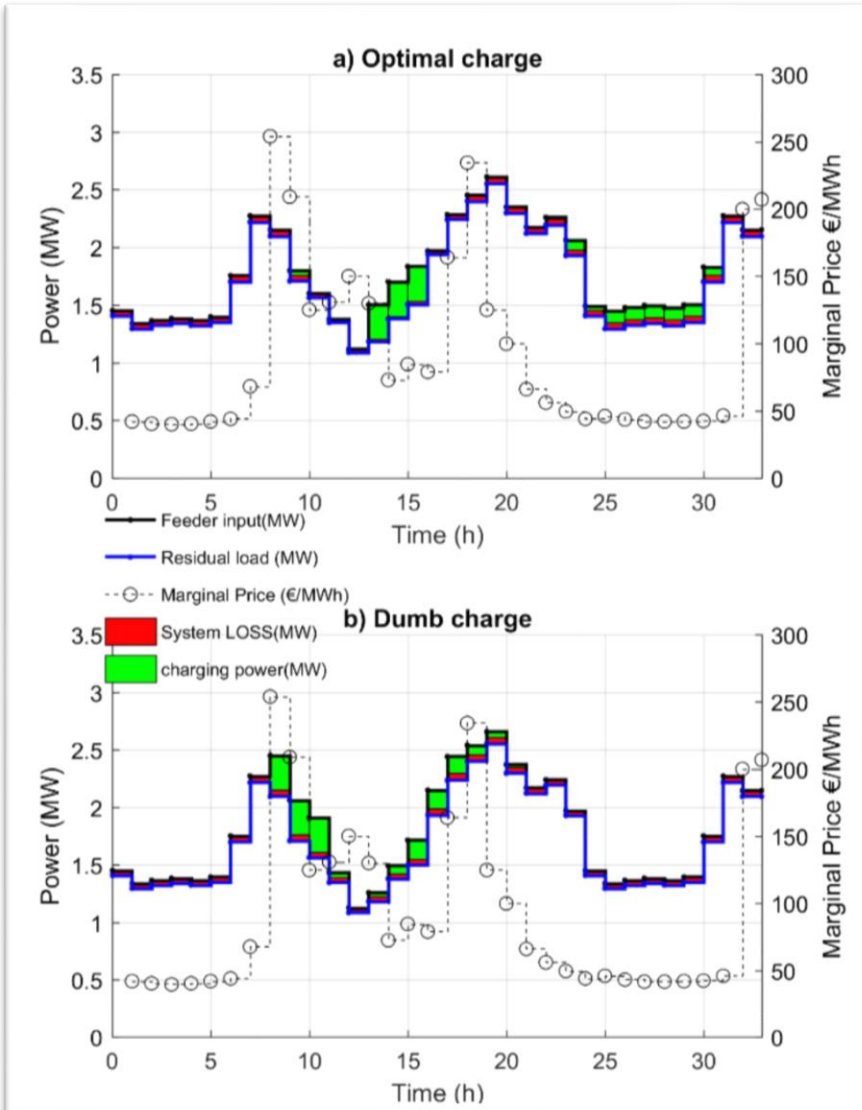
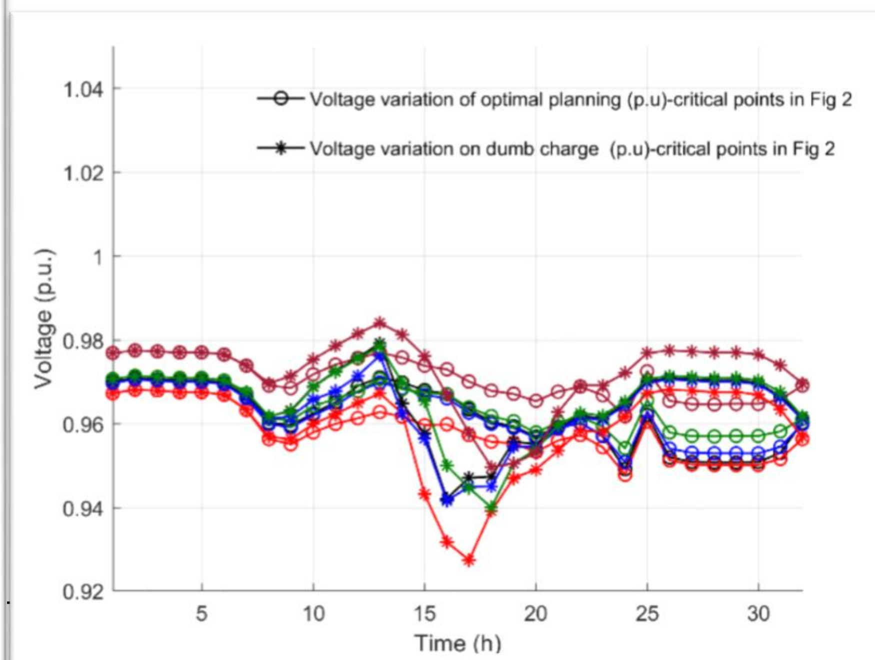
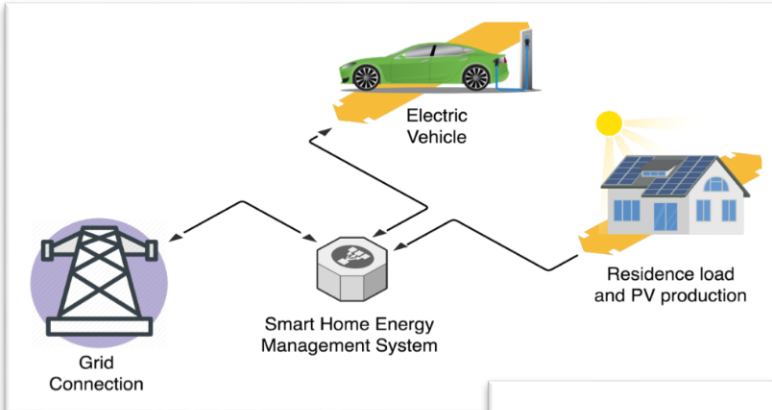
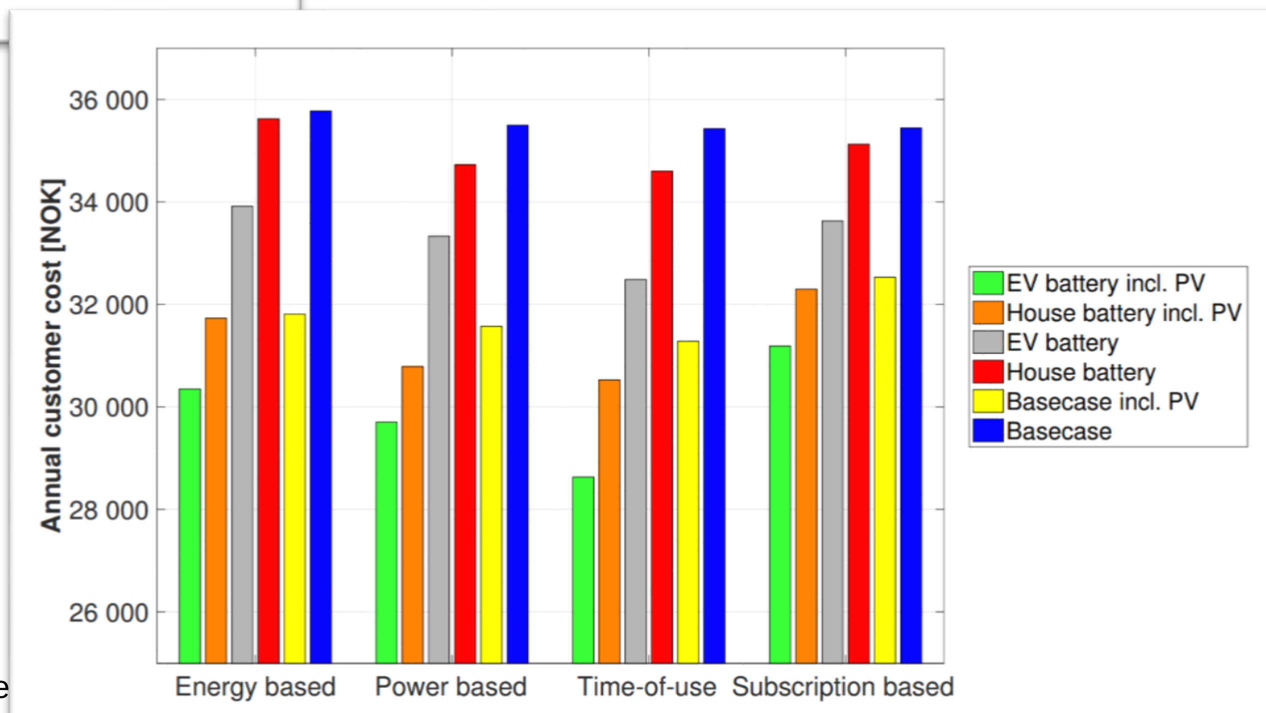


SCENARIO: 50 % of the households has an EV



Value of storage for prosumer: Example





Summary

- Storage can play very different roles in the system
  - System-wide, DSO-level, End-user level, Sector coupling
- Do not overestimate the need for storage
  - Demand flexibility, RES forecasts, market design and grids
- Batteries and pumped hydro are complementary
  - Batteries replaces OCGT; Pumped hydro replaces CCGT
- Controlled charging of EV batteries is beneficial
  - Battery already invested. Cars are usually parked.
  - Value for DSO: Grid utilization and voltage quality
  - Value for end-user: Reduction of energy bill; self-consumption
    - Depends on grid tariff design