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Systemic effects of hydrogen economy to power systems

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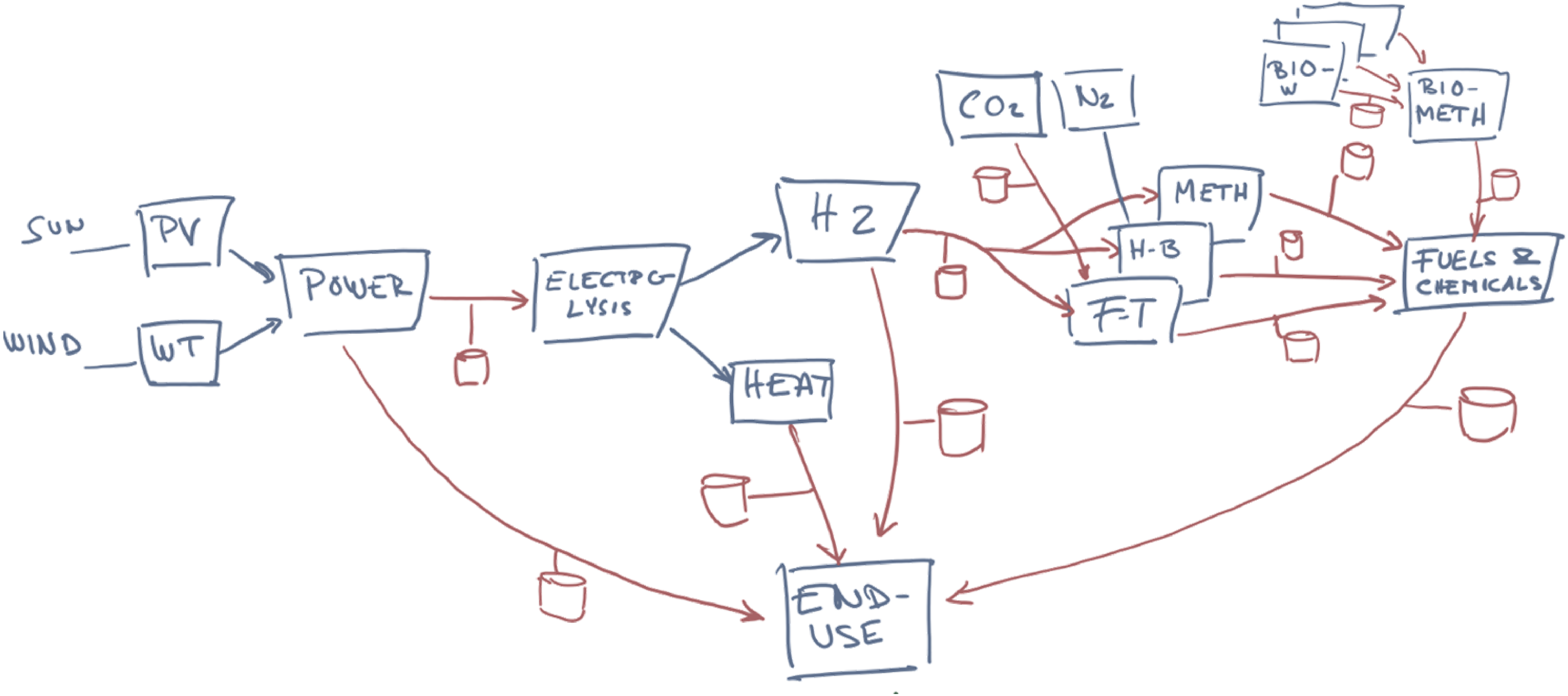
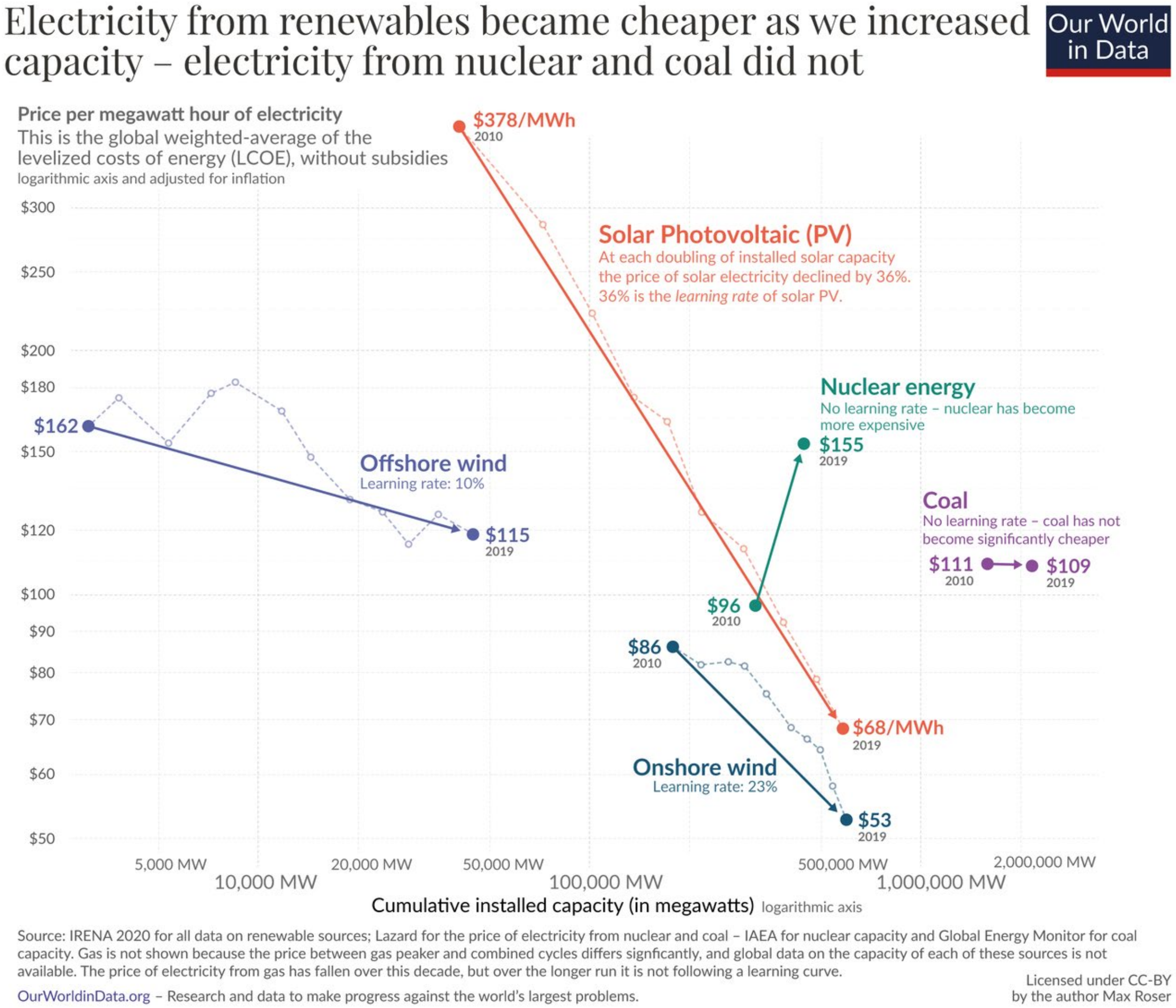
Introduction – System of hydrogen economy

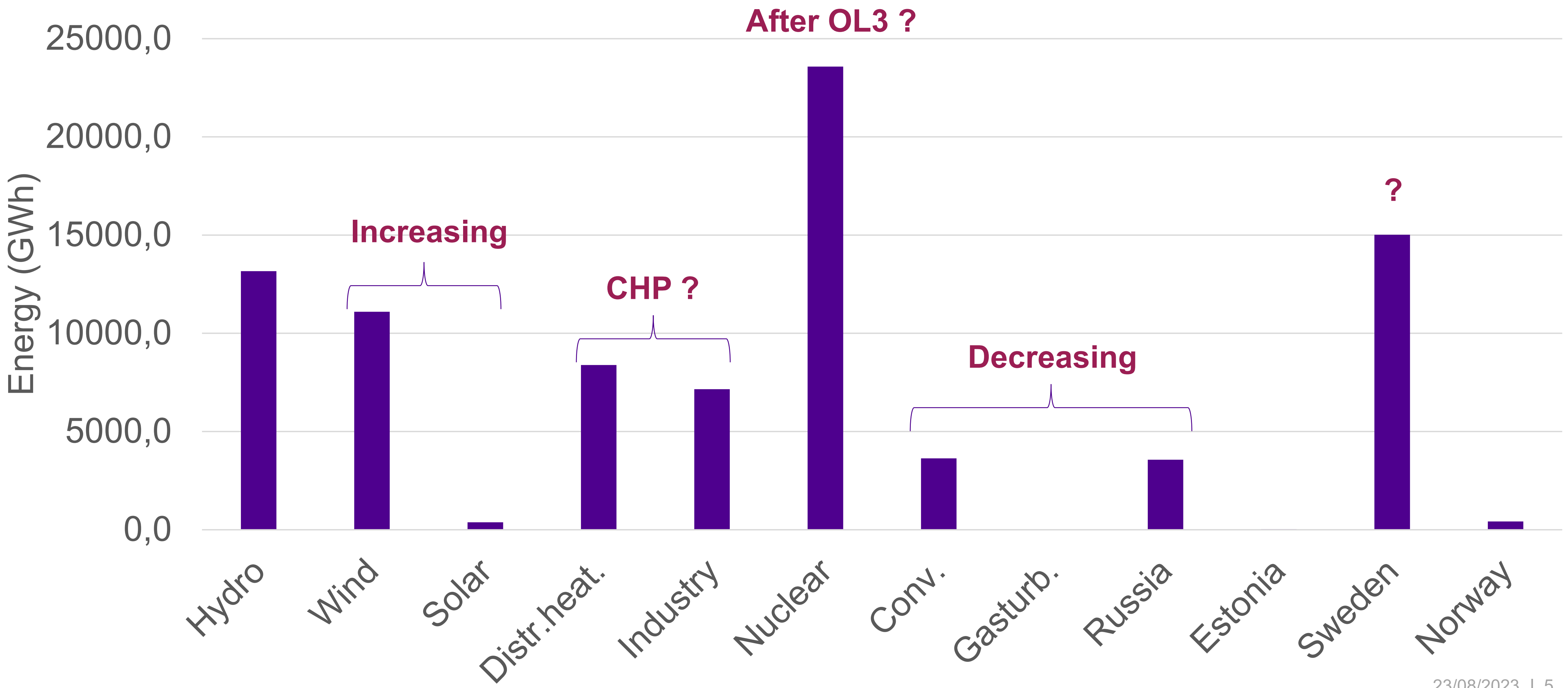


Wind power is the cheapest electricity source

- Technical potential >100 TWh
- Year 2022
  - 5.7 GW
  - 11 TWh
- Year 2025 (investment decisions)
  - 8.7 GW
- Scenarios
  - 66 GW (Finnish wind power association's list of wind projects)
  - 15-39 GW wind + 5-12 GW PV (Fingrid, 2035)
  - 15-85 GW wind + 8-25 GW PV (Fingrid, 2045)



Electricity production and import - 2022



Fundamental changes

Figure 3 Electricity production in the different scenarios.

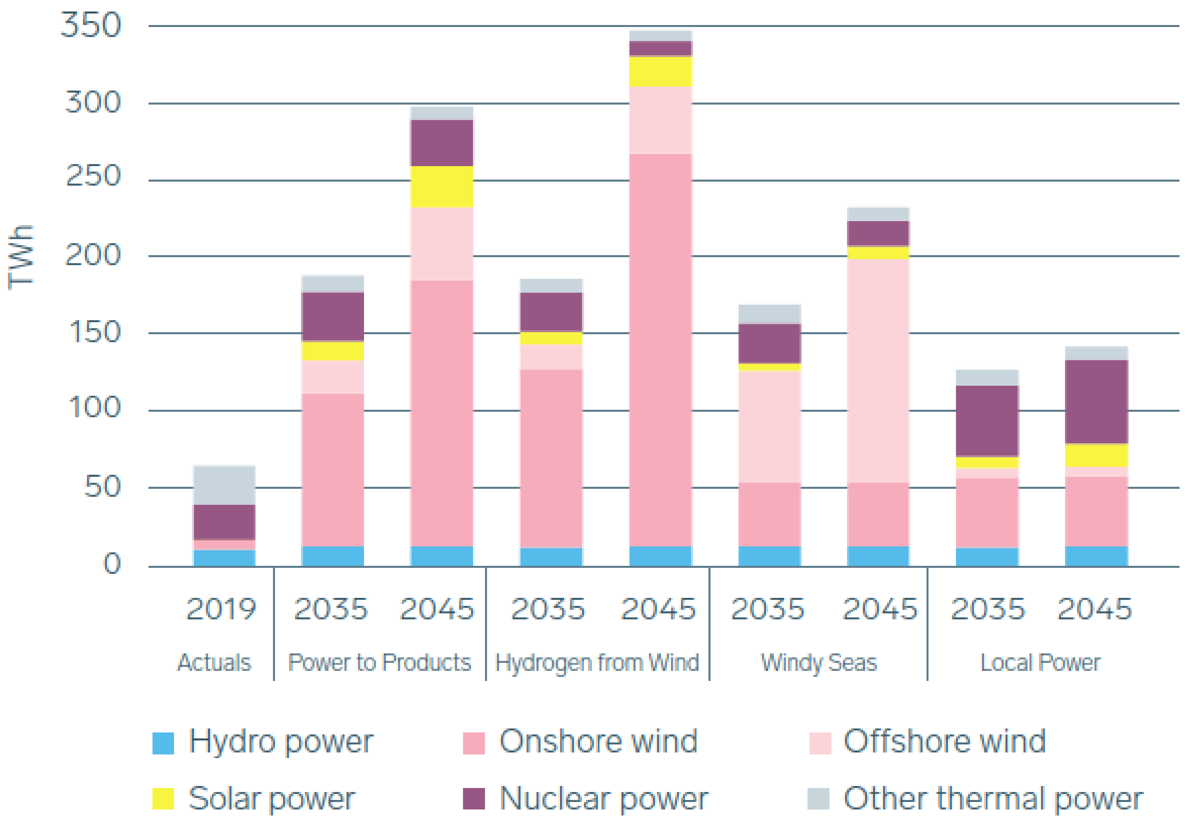
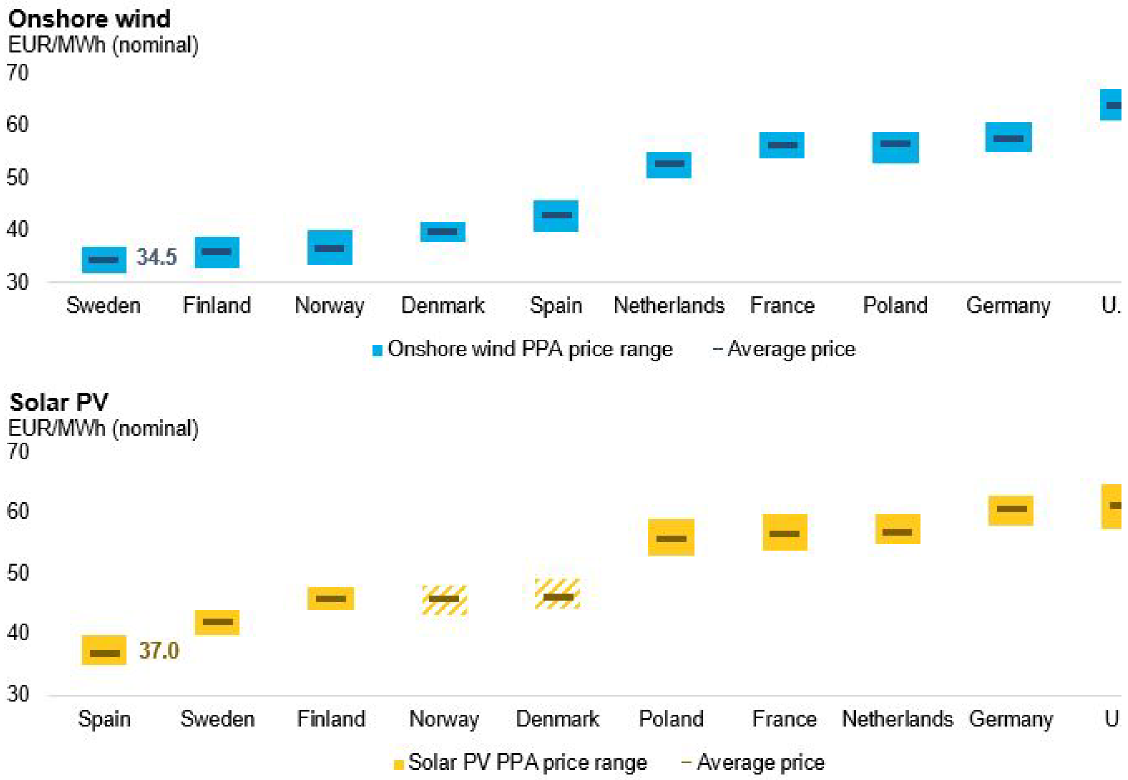
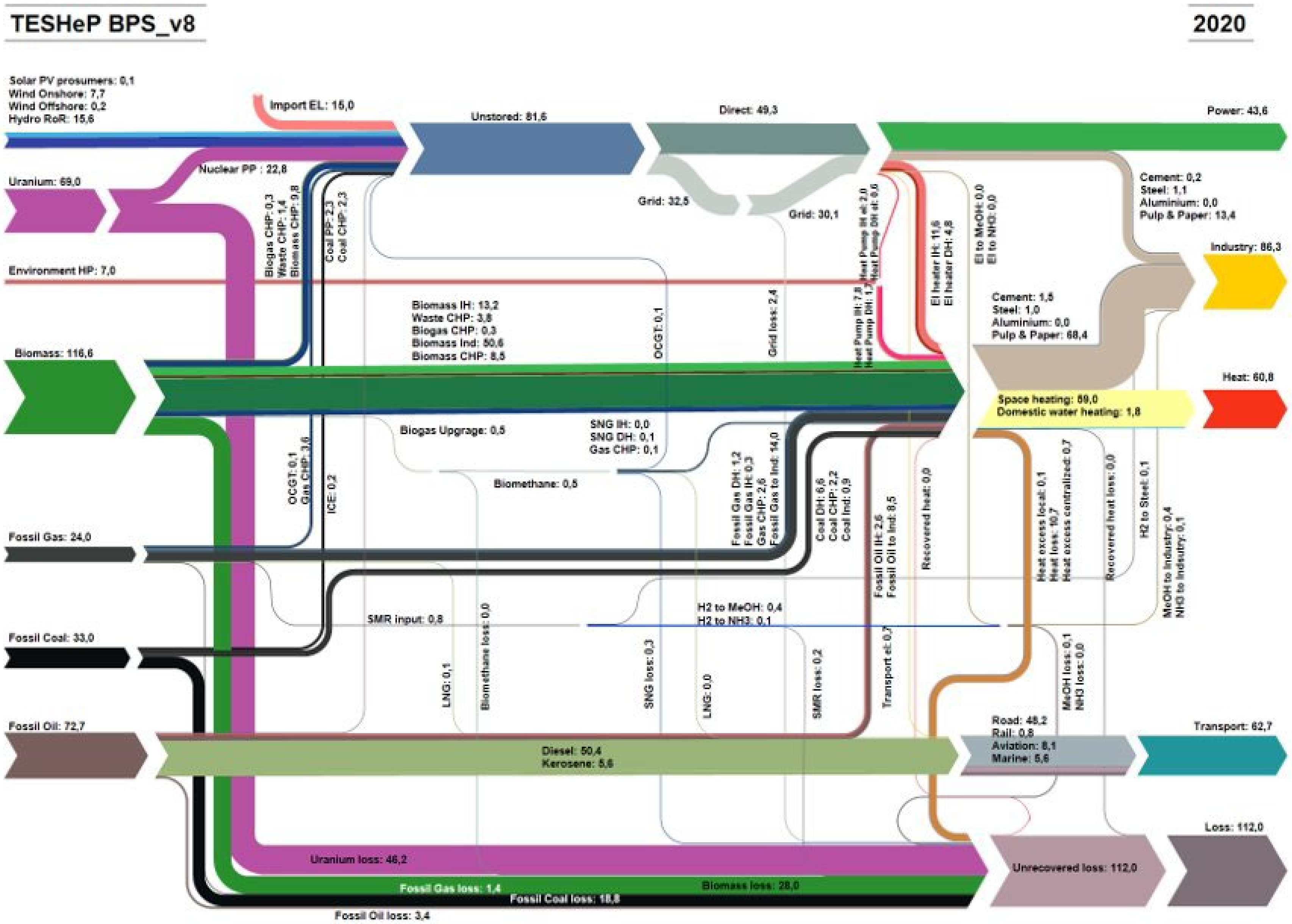


Figure 1: Onshore wind and solar PV pricing, H1 2022



Source: BloombergNEF, survey participants, Zeigo. Note: Data collected January–March 2022. Hatched infil indicates that no PPAs have been announced to date.

Energy flow chart Finland today



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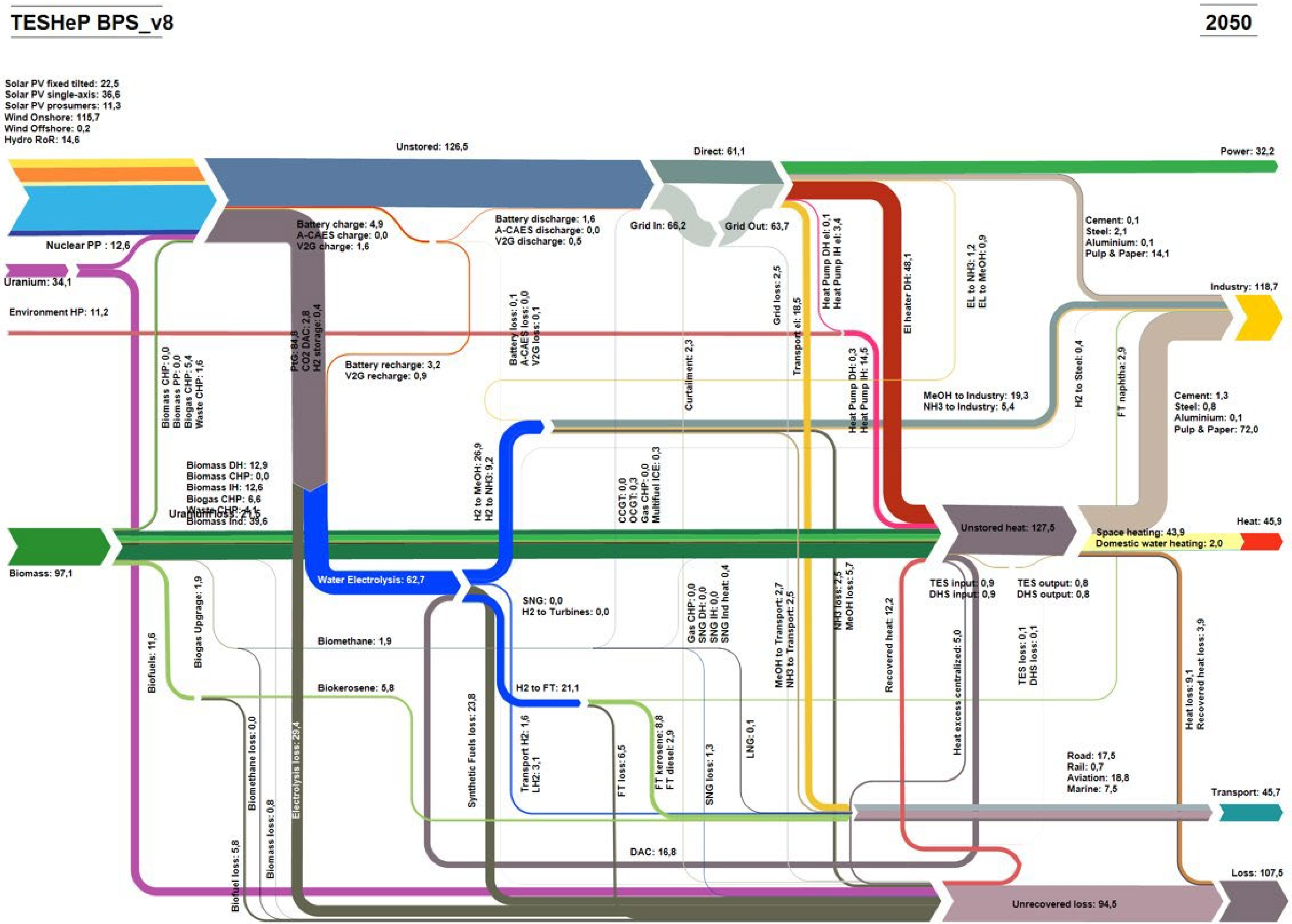
Energy flow scenario of 100 % RES based system

- Fossil fuels disappeared
- Slightly less biomass
- Hydrogen has a central role to produce industrial and transportation fuels
- Final energy consumption 242 TWh (2020: 253,4 TWh)
  - Energy efficiency
  - Energy saving
- Low-cost wind and solar and phasing out of higher cost fossil-nuclear leads to cost reduction

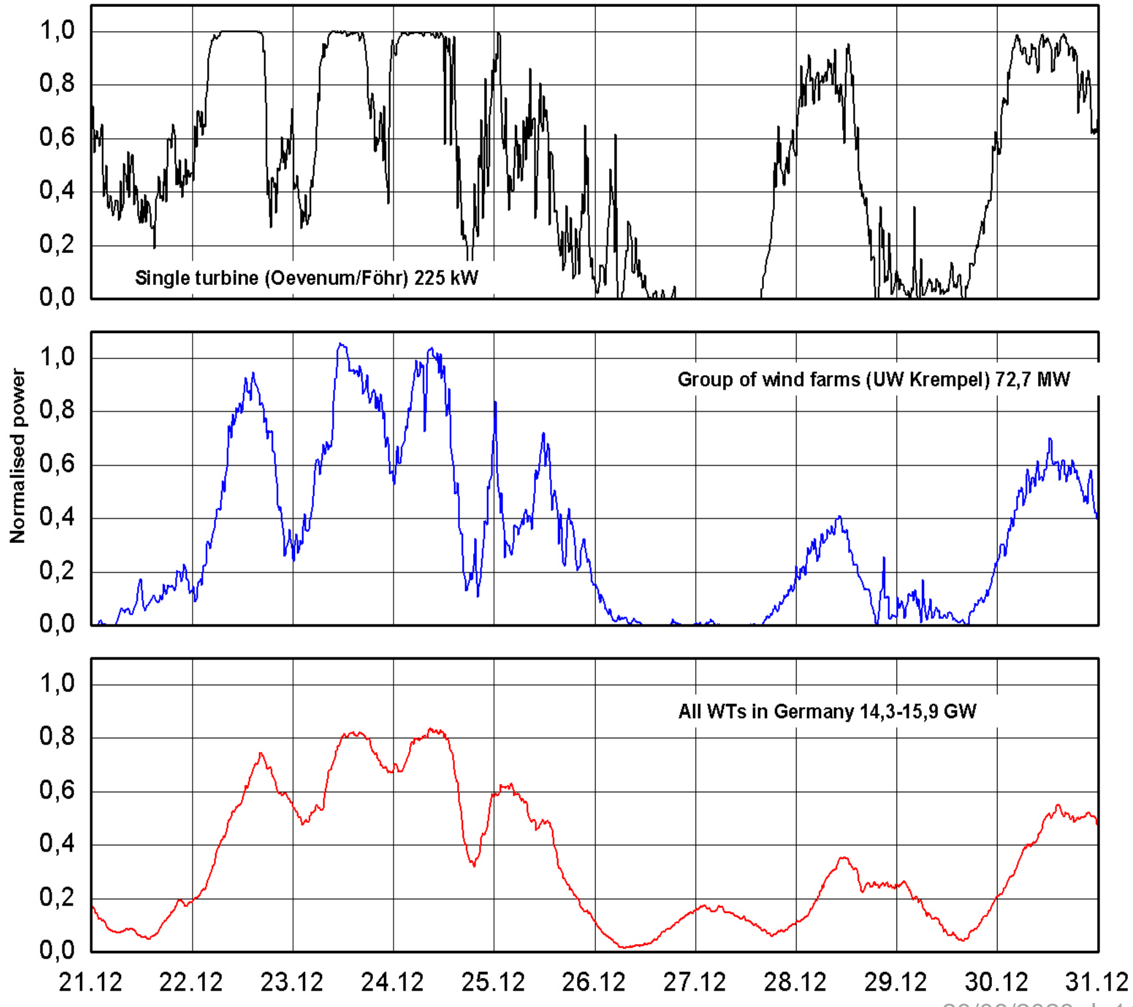


Source: HYGCEL project, Christian Breyer

Technical impacts

Electricity availability

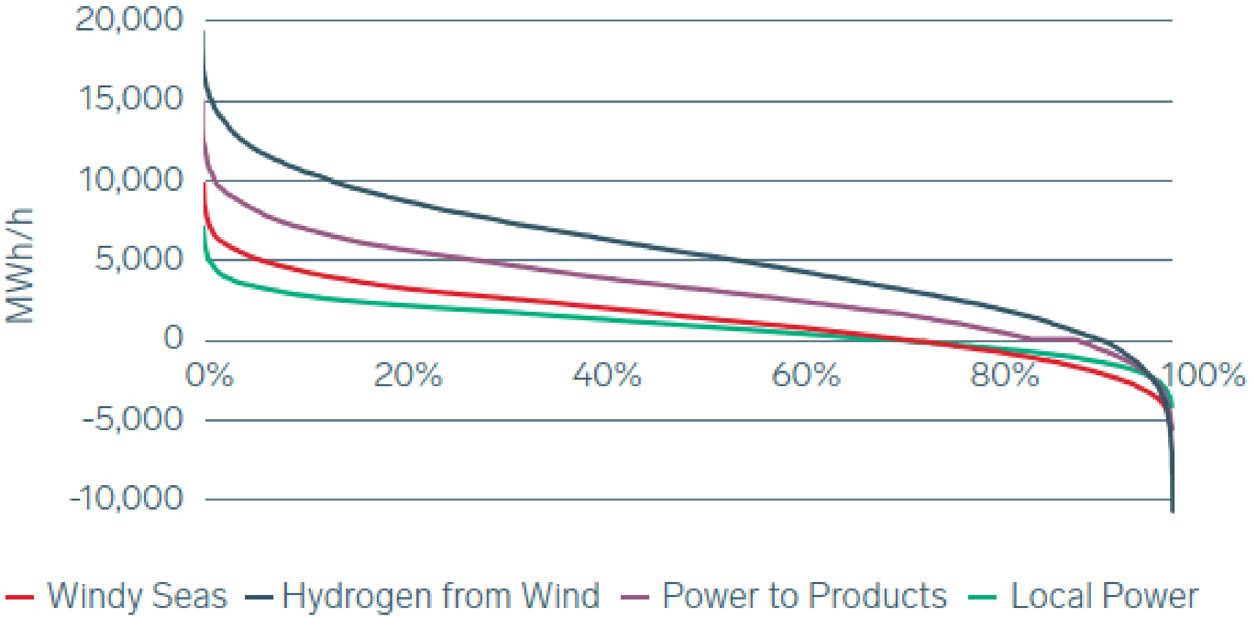
- **Electricity availability**
  - Supply from market
  - Power purchase agreement (PPA)
  - Self-generation
- **Electrolysis demand**
  - Becomes very price sensitive
  - Operating ~4000 h/a
  - Utilization of heat
- **Storage**
  - Multiple places and forms
  - Optimal siting and sizing?



Grid congestion

- **Transmission grid**
  - Price areas
  - Non-firm connections
  - Hydrogen delivery
  - CO_2 delivery for synthesis
- **Electrolysis demand**
  - Price sensitive demand is not solving grid issues
  - Siting is essential
- **Storage**
  - Multiple places and forms
  - Optimal siting and sizing?

Figure 19 Transmission needs over cross-section central Finland in the 2035 scenarios, if all energy were transmitted as electricity. The duration curves of all scenarios show a peak of the curves, meaning that large transmission situations rarely occur, but the transmission need is very high.



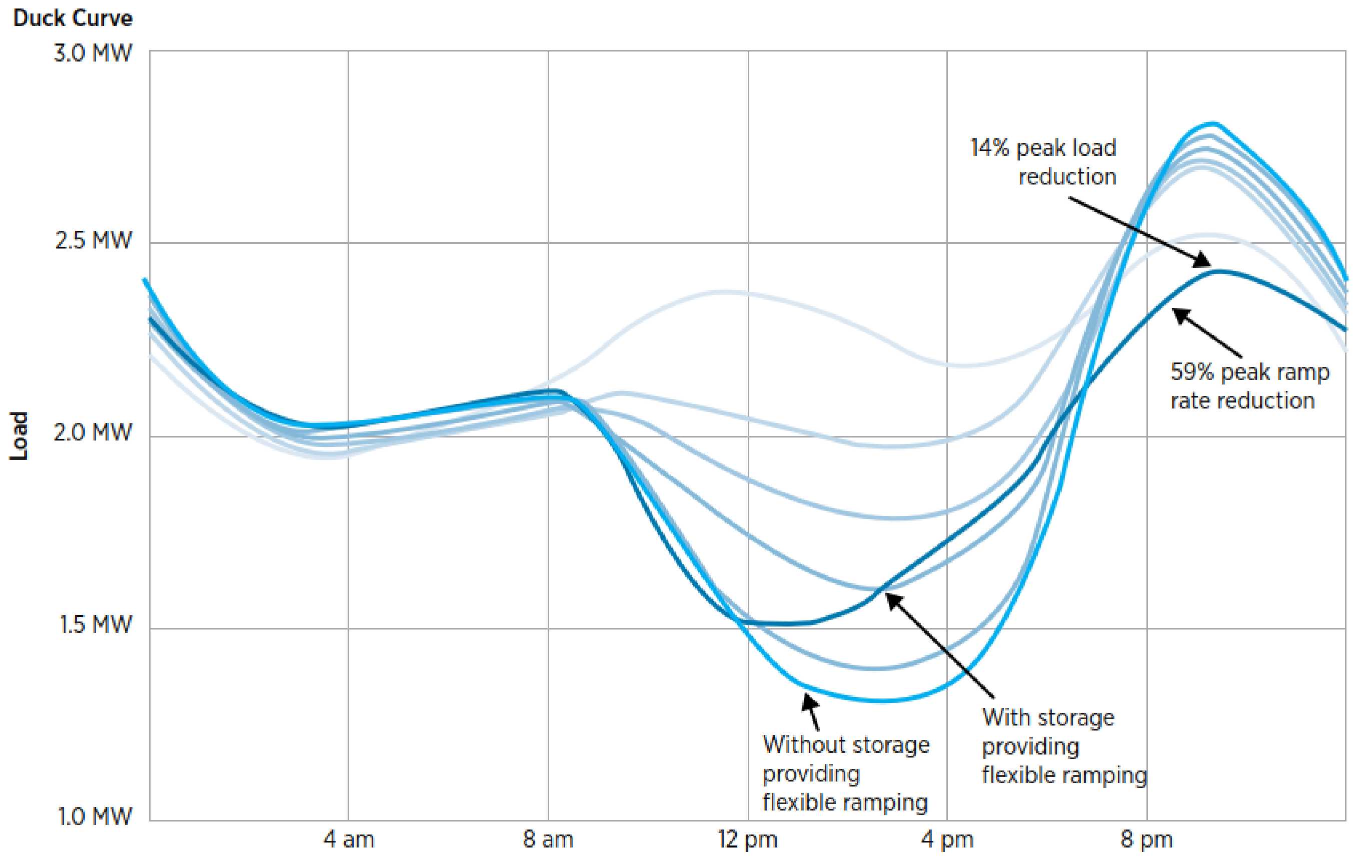
Capacity deferral – Grid investments

- TSO / DSO
  - Transmission capacity allocation to markets
  - Price zones
  - Counter-trading within a price zone (Fingrid utilize balancing power market offers)
  - Postponing investments due to occasional congestions
  - Local flexibility market
- Customer
  - Non-firm connection should be cheaper than firm connection, but almost the same supply security

Peak load reduction of a grid

- PV dominated system the load profile becomes as a duck curve
  - Incentives load shifting by time-of-use energy and grid tariffs
  - Power based grid tariff to limit peak loads of individual customers
  - Congestion management service contracts with flexibility resources or aggregators
  - Local flexibility market

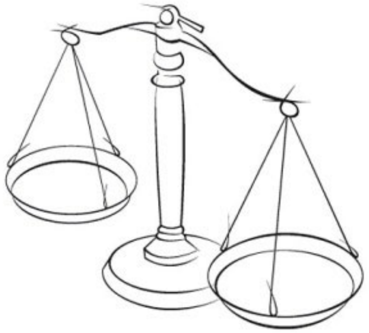
Figure 40: Impact on the duck curve of energy storage providing flexible ramping: the example of one 3 MW feeder



Note: Figure shows impact for one feeder, not the entire CAISO system.
Source: Sunverge (2015).

Basic challenge of power balancing

- **Technical balance**
  - Load demand + export = Power production + import



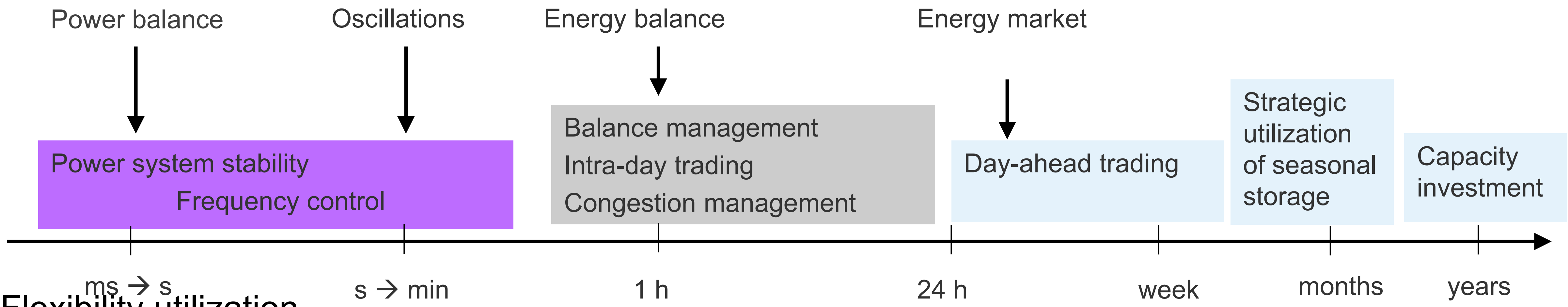
- **Market balance (physical commodity market)**
  - Price negotiation based on auction on day-ahead market
  - Every buyer and seller have they own balance
    - Intra-day market to minimize imbalance cost
    - Balancing power market for TSOs to keep technical balance (intra-hour market)
    - Balance settlement afterwards

What is flexibility in power system and markets?

- Flexibility resources
  - Production
  - Demand response
  - Storage

Think what resources are flexible?

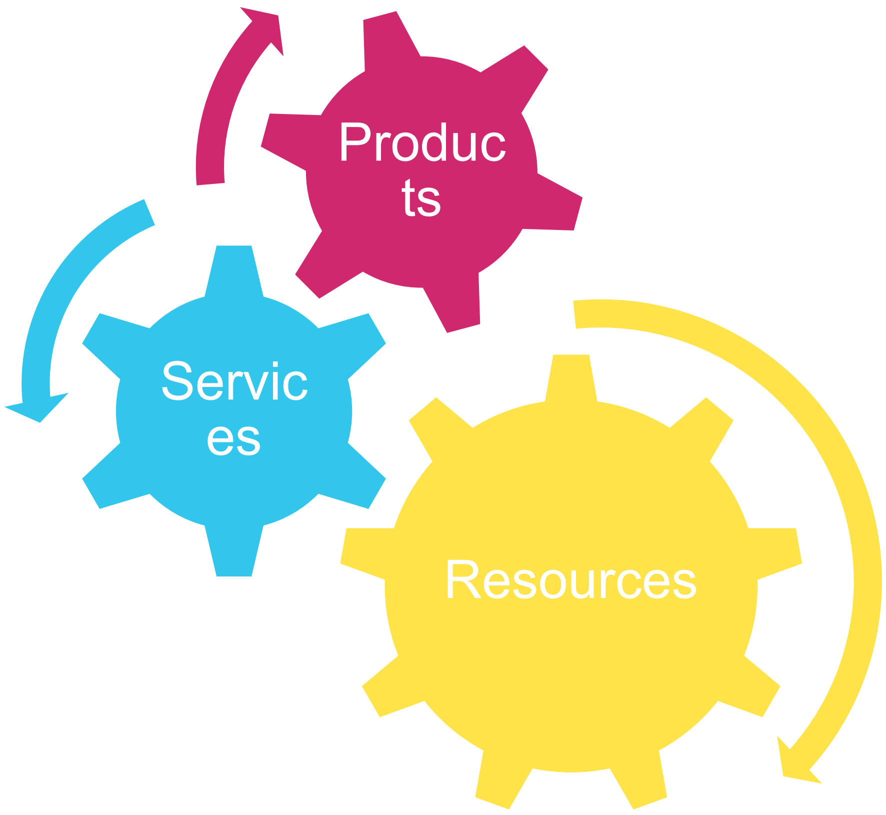
- Flexibility time-scale



- Flexibility utilization
  - Power system security
  - Energy market trading
  - Capacity deferral

Flexibility

- Flexibility is a concept – It is not very exact
- Defining characteristics on three level simplify the understanding of flexibility and how it impacts on systems
  - **Resources**
    - Physical resource or process, which may be controlled
    - Technical and operational limitations important to understand
    - Aggregation of resources is many times wise
  - **Services**
    - Abstract description of flexibility resource utilization for a specific function
    - Resource may be utilized for many services depending on limitations
    - Service description should be resource independent and defined as a flexibility responce or output
  - **Products**
    - Flexibility trading and contracts
    - Explicit or implicit control
    - Products are defined with attributes: location, bid size, activation type, duration, up or down-regulation



Examples of flexible resources

Production

Hydro power with reservoir

Gas turbine

(Condensing power)

Wind and solar power below maximum power point

Demand response

Heating
- Heat pumps in district heating and in buildings
- Thermal inertia of buildings

Cooling
- Supermarkets
- Logistic centers

Lights
- Greenhouses
- Offices

Ventilation

Pumping

Industrial processes

Storage

Pumped hydro

Batteries

Power to X (sector-coupling)

Power to X to power (X=heat, hydrogen)

Hybrid systems
- RES smoothing (e.g. PV + battery)
- Enhanced controllability on flexibility markets and asset management (e.g. run-of-river hydro + battery)
- EV charging optimization (e.g. stationary battery + EV charging points)
- Self-consumption (e.g. PV + battery + demand response + other loads)

Examples of flexibility services

- Energy cost minimization
- Energy saving
- Balance management
- Peak clipping
- Strategic DA/ID trading
- Portfolio optimization
  - Production following
  - Wind + PV + hydro + DR
  - Keeping nuclear unit connected to grid during excess wind+PV production
- Voltage control
- Frequency control
- Congestion management
- Supply security: Blackstart and Grid forming

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Power balancing

- **Large-scale wind and solar power** will change profitability of other production types → How to keep enough capacity for peak demand?

Electricity production and import (MW)

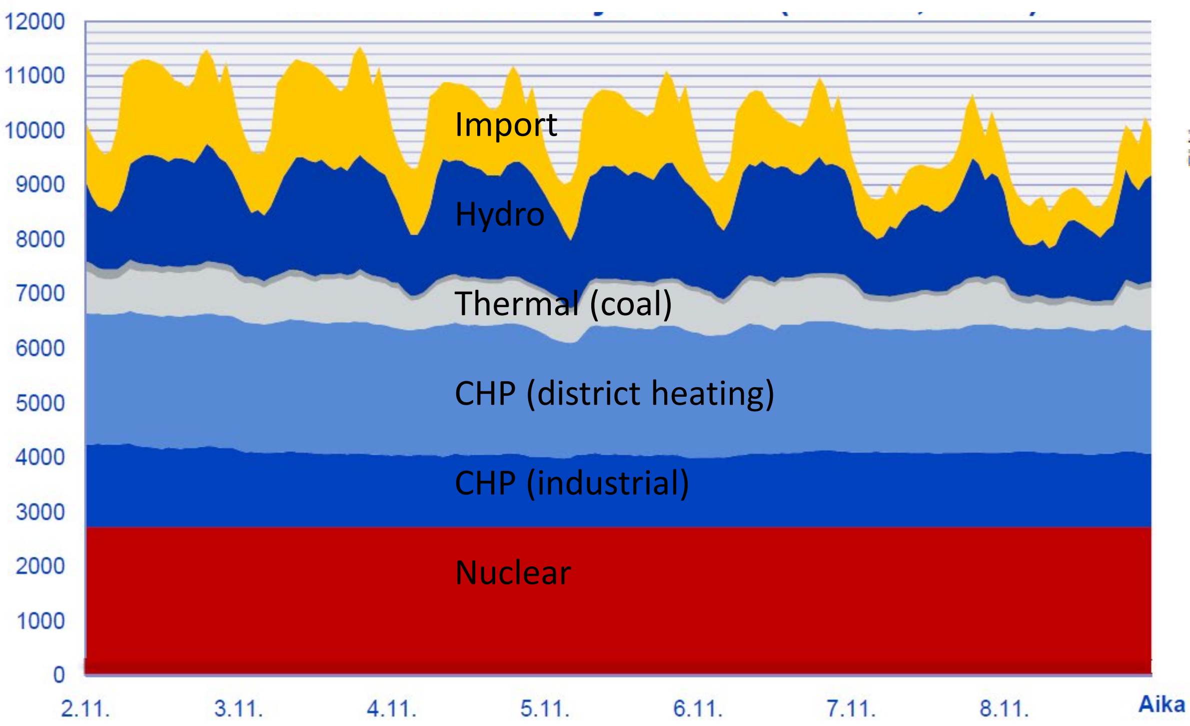
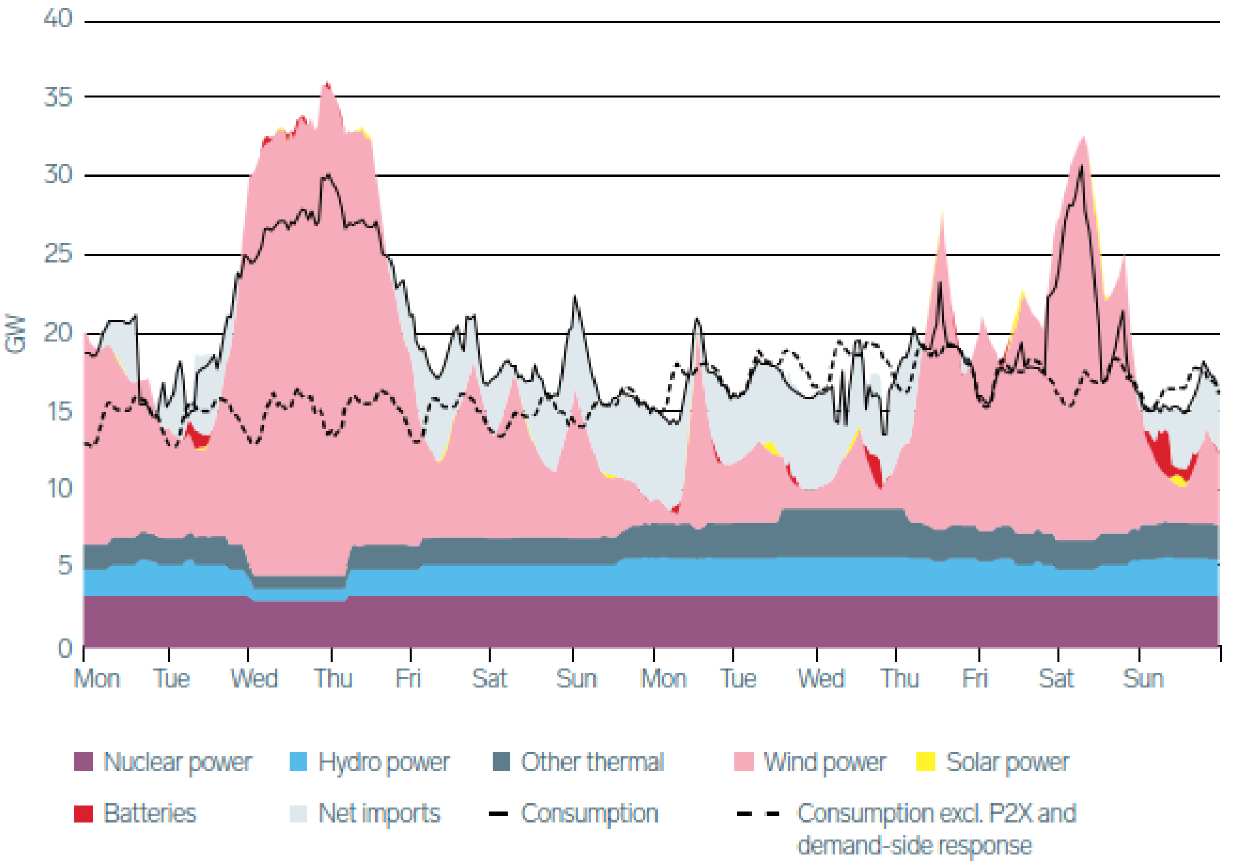


Figure 14 An example of hourly electricity production and consumption in the scenario hydrogen from wind in the first two weeks of the reference year 2035.



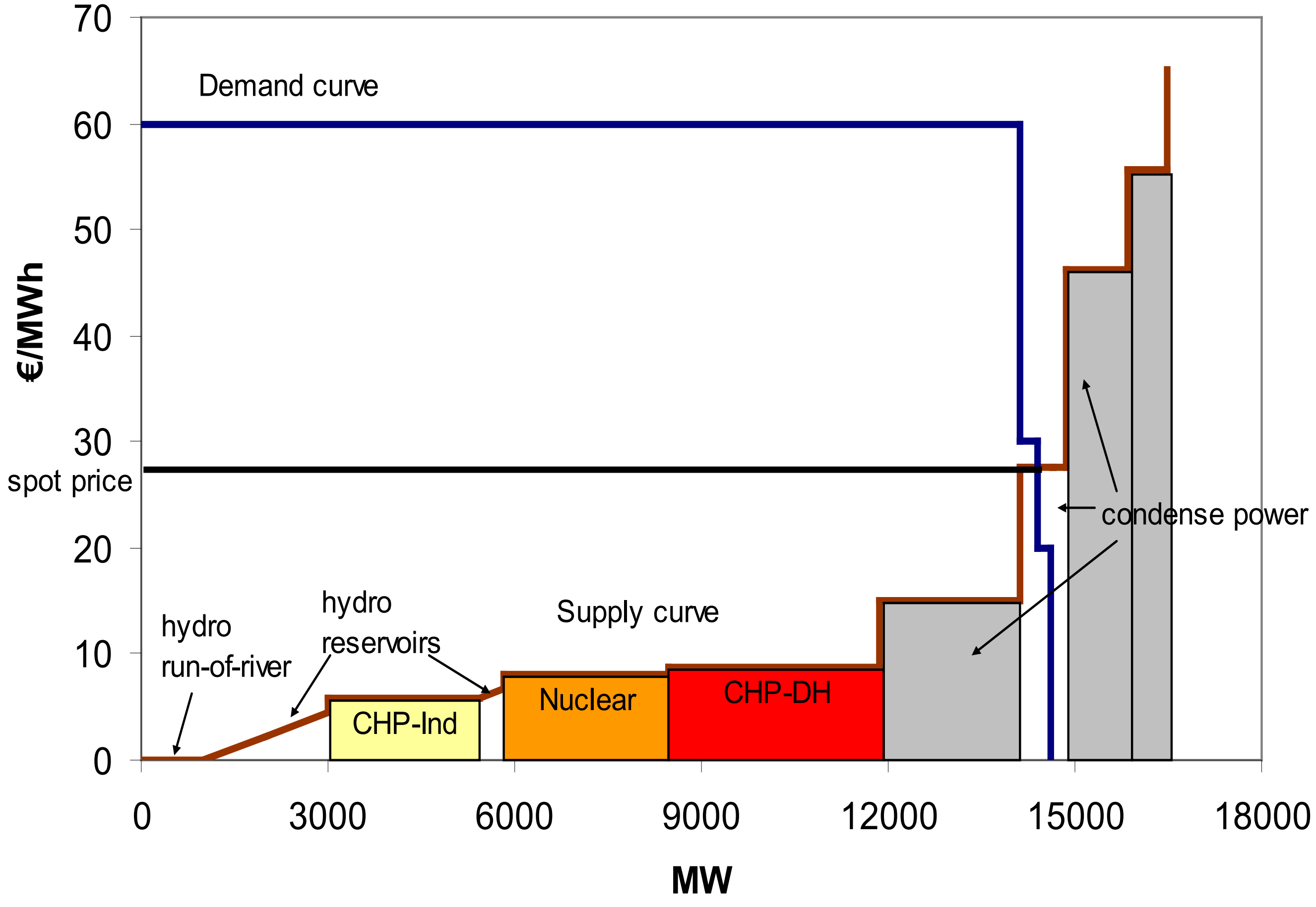
Capacity deferral – peaking plants

- Need for peaking power plants will be reduced in short-term
  - More flat load profile vs. Production following
  - For example combined wind + PV + hydro + demand response optimization
- Need for peaking plants in the long-term?
  - Supply availability
  - Who’s responsibility?
  - Power capacity reserves (tehoreservi)
  - Capacity market?

Market impacts

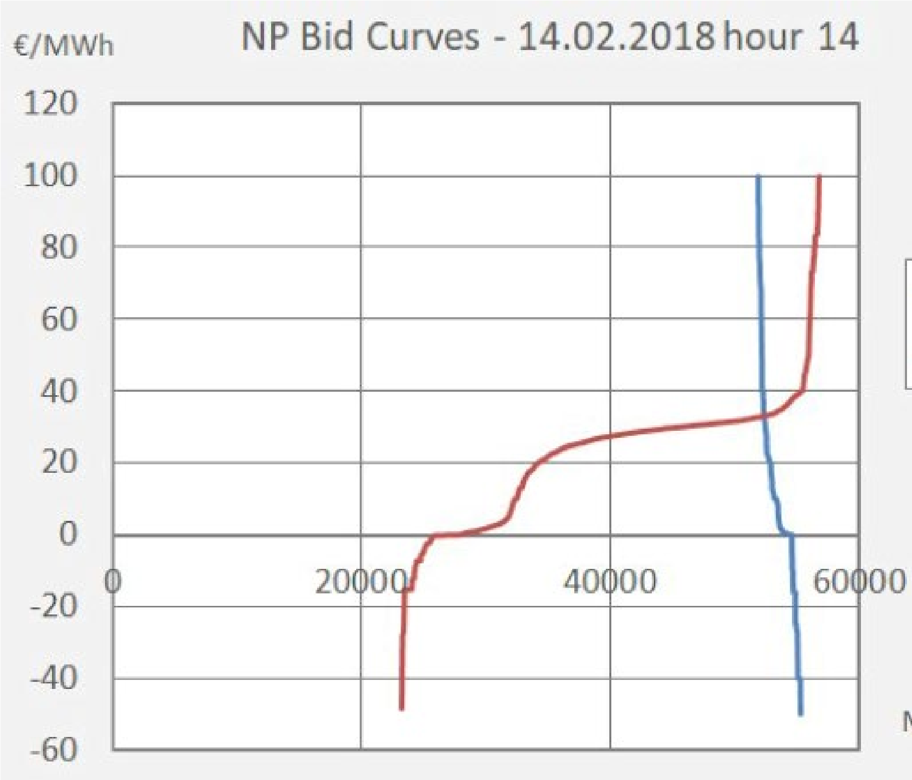
Price formation

- Electricity production is offered with price little bit higher than operational costs
- Everyone who’s offer is accepted will get/pay the same price
- Wind power has very low operational costs → Profitable to sell all available power → Supply curve will shift to right
- Hydro power with reservoirs is able to optimize production schedule to moments when the water value is the highest (typically during high demand and low wind)
- **What is the impacts of electrolysis, EV charging and electrification in heating?**

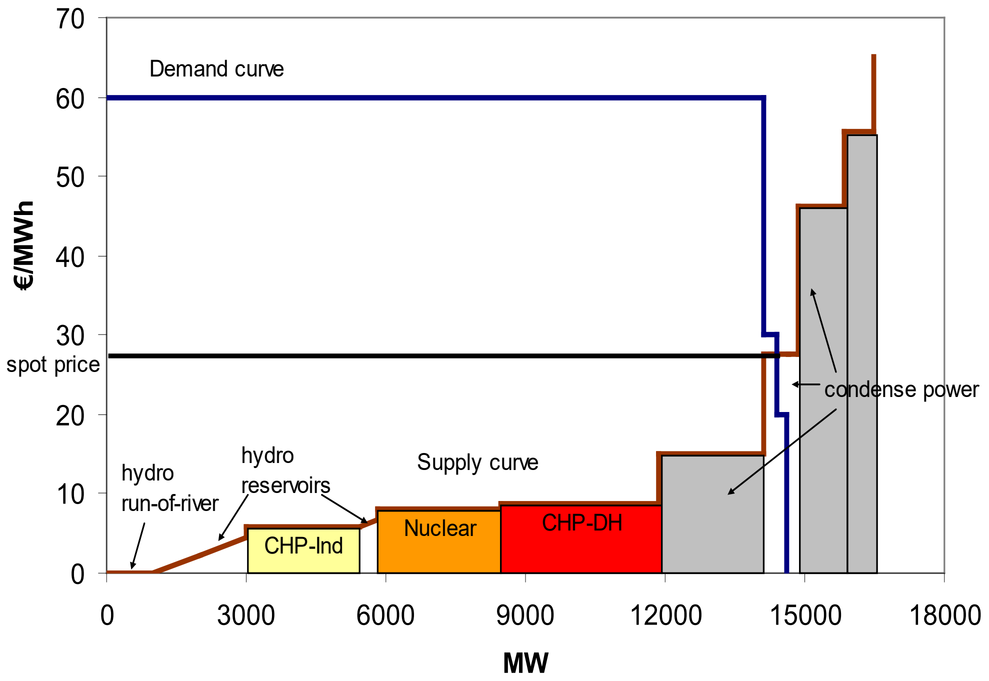


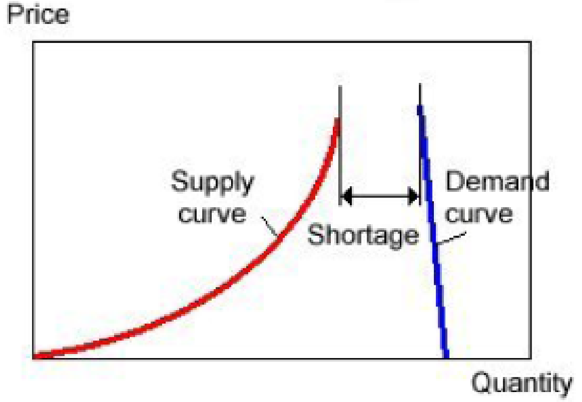
Market impacts

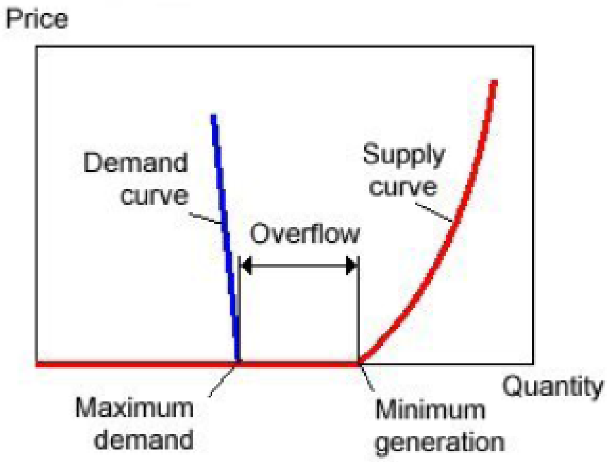
- **Market prices are defined by wind variations and strategic bidding**
  - Hydrogen storage and demand response is a risk management tool
  - Wind power PPA does not guarantee continuous flow of electricity
- **Reserves and balancing**
  - Electrolysis with production following
  - Wind and solar power together
  - Electrolysis is excellent resource for reserve and balancing services



Market for the production of zero marginal cost

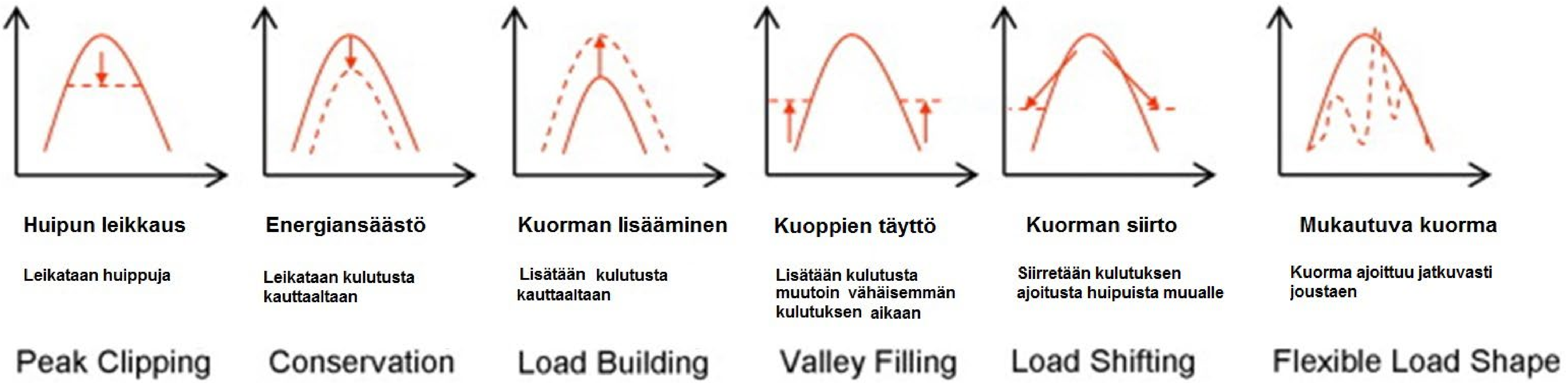






- Transmission capacity to exchange power and larger market areas
- Flexible demand and supply
- Energy market → Power market

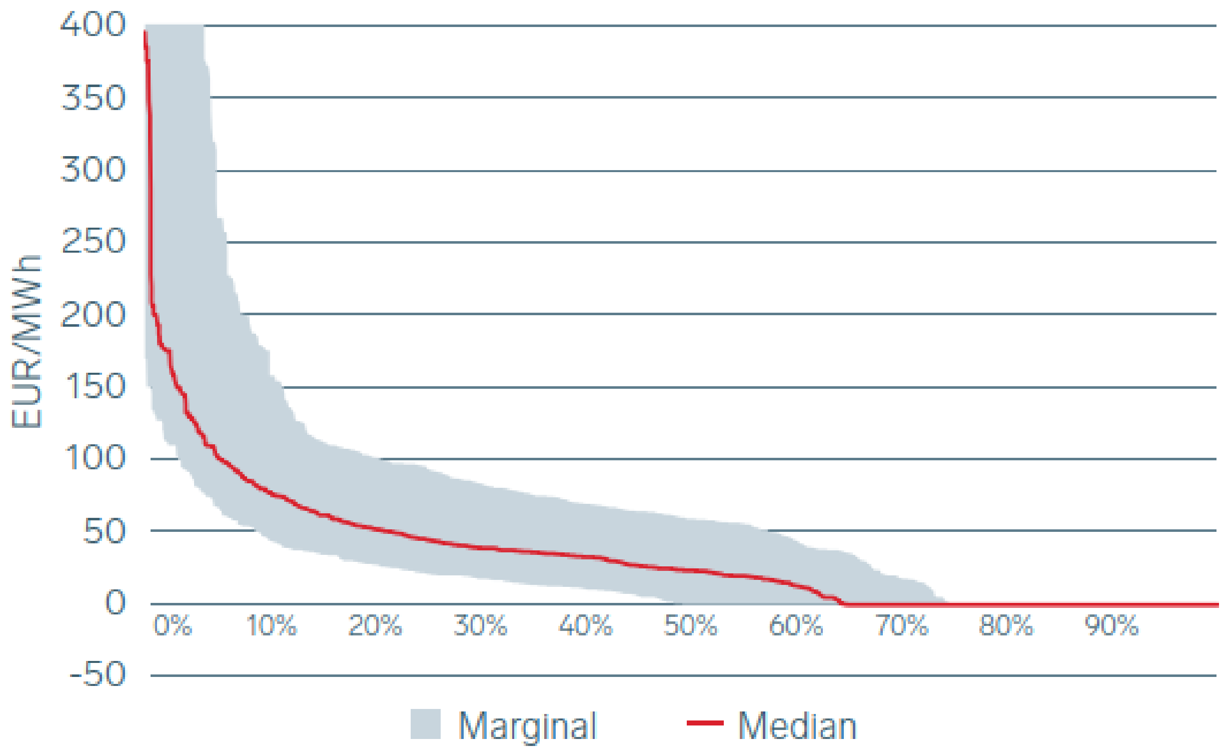
Demand response methods



Market risk management

- **Shortage of energy**
  - Peak clipping
  - Load shifting to realize production following → energy storage becomes essential asset to avoid price risk
- **Excess energy**
  - Load shifting from high to low price hours → energy storage provides opportunity to make profit
  - Demand response is making price profile more flat as well (profitability erosion)

Figure 10 Duration of electricity price in the scenario Power to products in 2035. The y-axis of the figure is cut for readability, the maximum of the range is multiple times higher.



Energy vs. power storage

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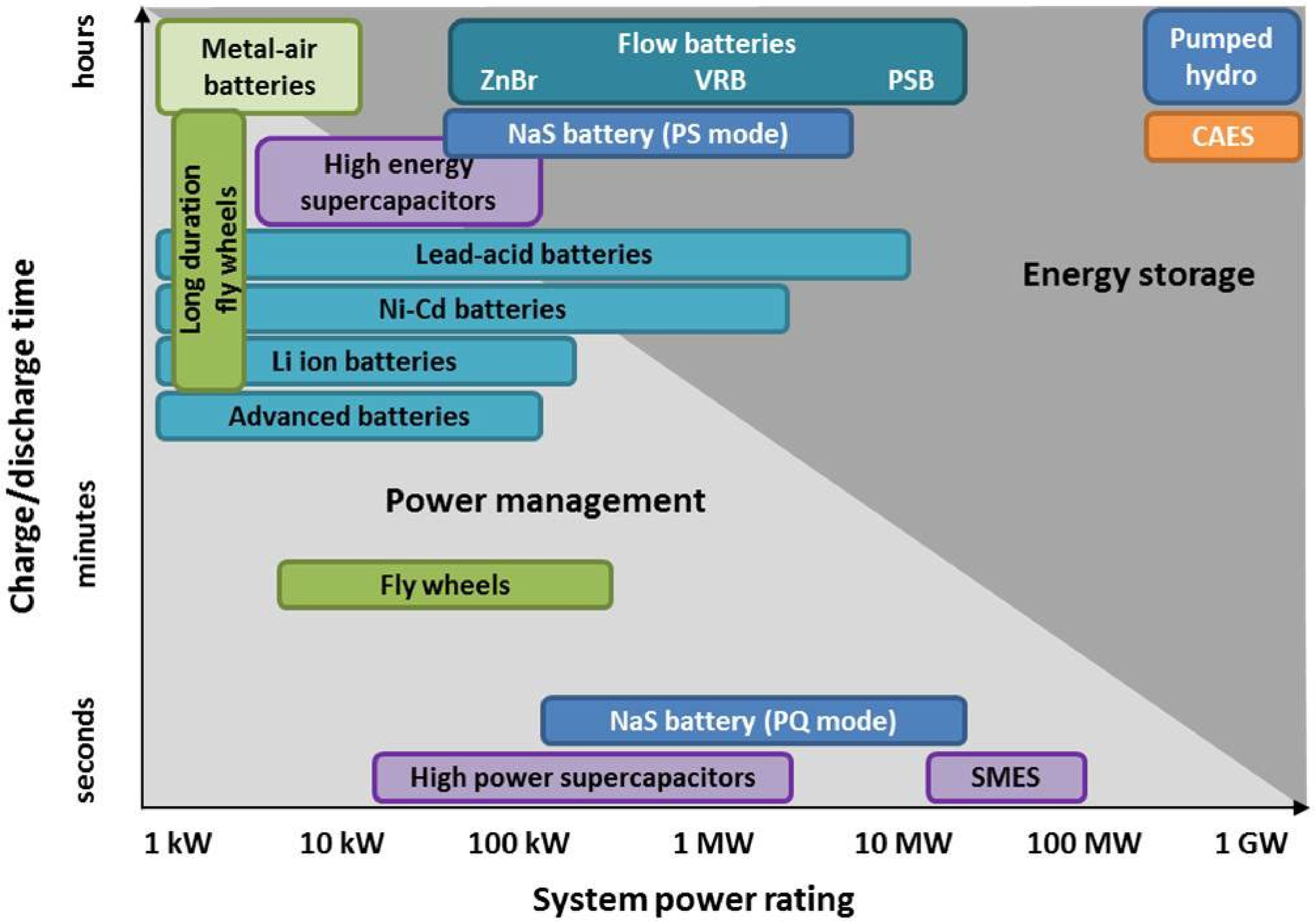
Where are:

- Data centres
- Traditional industry
  - Pulp & paper
  - Chemical
  - Metal
- Electric vehicles
- Heat storage (electric and heat pumps)
  - Domestic
  - District heating
- Electrolysis + H2 storage



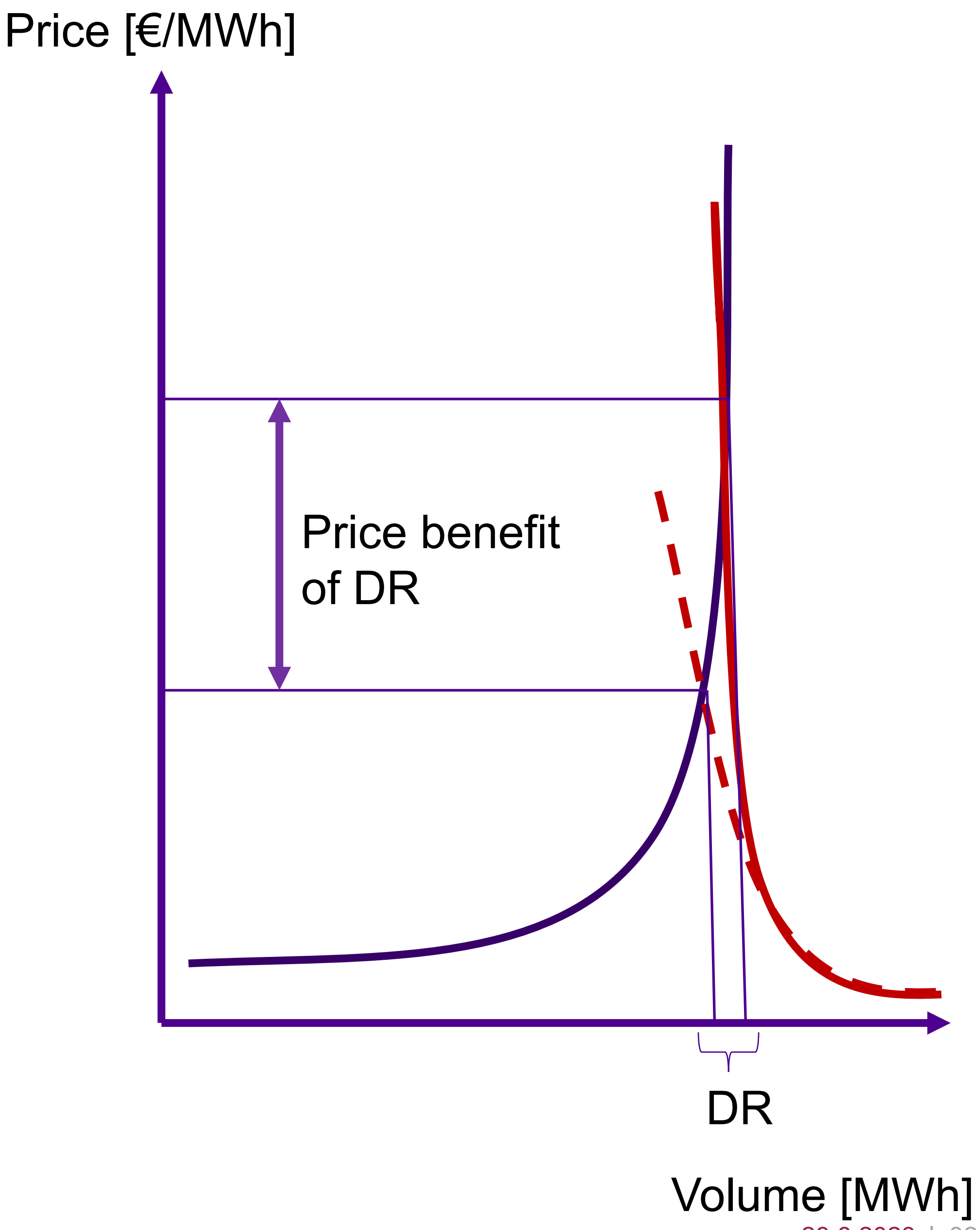
CAES = Compressed Air Energy Storage
SMES = Superconducting magnetic energy storage

Possible solutions

- **Market risk management**
  - Storage siting and sizing
  - Understand of hydrogen storage and demand response as a risk management tool
  - What if Finland is divided to two or more price areas?

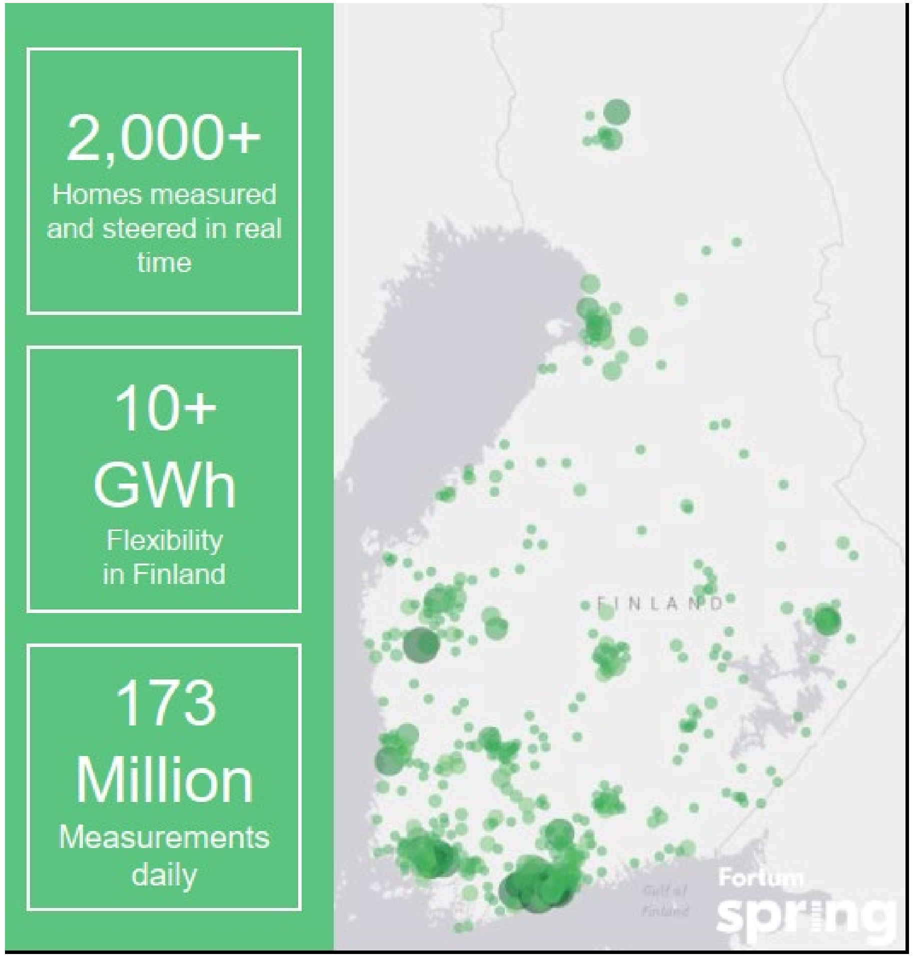
Energy arbitrage

- Operation on energy market
  - Load shifting included as a part of economic dispatch
  - Price maker
  - Correction of prediction errors
  - Allocation between day-ahead and intra-day markets
  - Generation start-up and shut-down costs in unit commitment



Energy cost saving

- Active participation on energy and flexibility markets
  - Participation to day-ahead market via retail tariff based on day-ahead market price
  - Pre- or (post-)charging of storage (e.g. temperature in buildings)
  - Possibility to manage the peak power (benefit if your grid tariff has a power component in addition to energy component)
- Additional benefits
  - Real-time consumption data available
  - Remote control of home appliances
- Aggregator benefits
  - Possibility to optimize the energy portfolio at day-ahead market via charging demand predictions and optimal plans (if aggregator is a retailer as well)
  - Sell short-term flexibility to other markets within comfort limits defined in the customer contracts
    - Intra-day energy market (1h), balancing power (15 min), FCR-D (about 15 min), FCR-N (few seconds to one minute)



Prosumer interest for flexibility

- Energy cost savings
  - Optimize the moment when heating/cooling, EV charging, etc. are done
- Self-consumption of PV
  - Maximize the benefit of own generation
  - Energy purchase cost > Energy selling price (situation before 2022)
  - Tax benefit
  - Grid tariff benefit
- Some retailers accept a net metering system where two or more connection points are considered as one customer
  - PV share in a bigger PV plant + consumption at home
  - Net metering is a summation of two measurements

Discussions

- Transmission capacity to exchange power, hydrogen and CO_2
- Flexible demand and supply together with storage
- Energy market → Power market, due to high share of zero marginal cost electricity production