NHH

# Flexibility in the local grid: distributed generation, storage and demand response


Endre Bjørndal
Mette Bjørndal

NHH Norwegian School of Economics
Department of Business and Management Science


Distributed Energy Resources Workshop, Auckland NZ
13 Jan 2018

# Outline

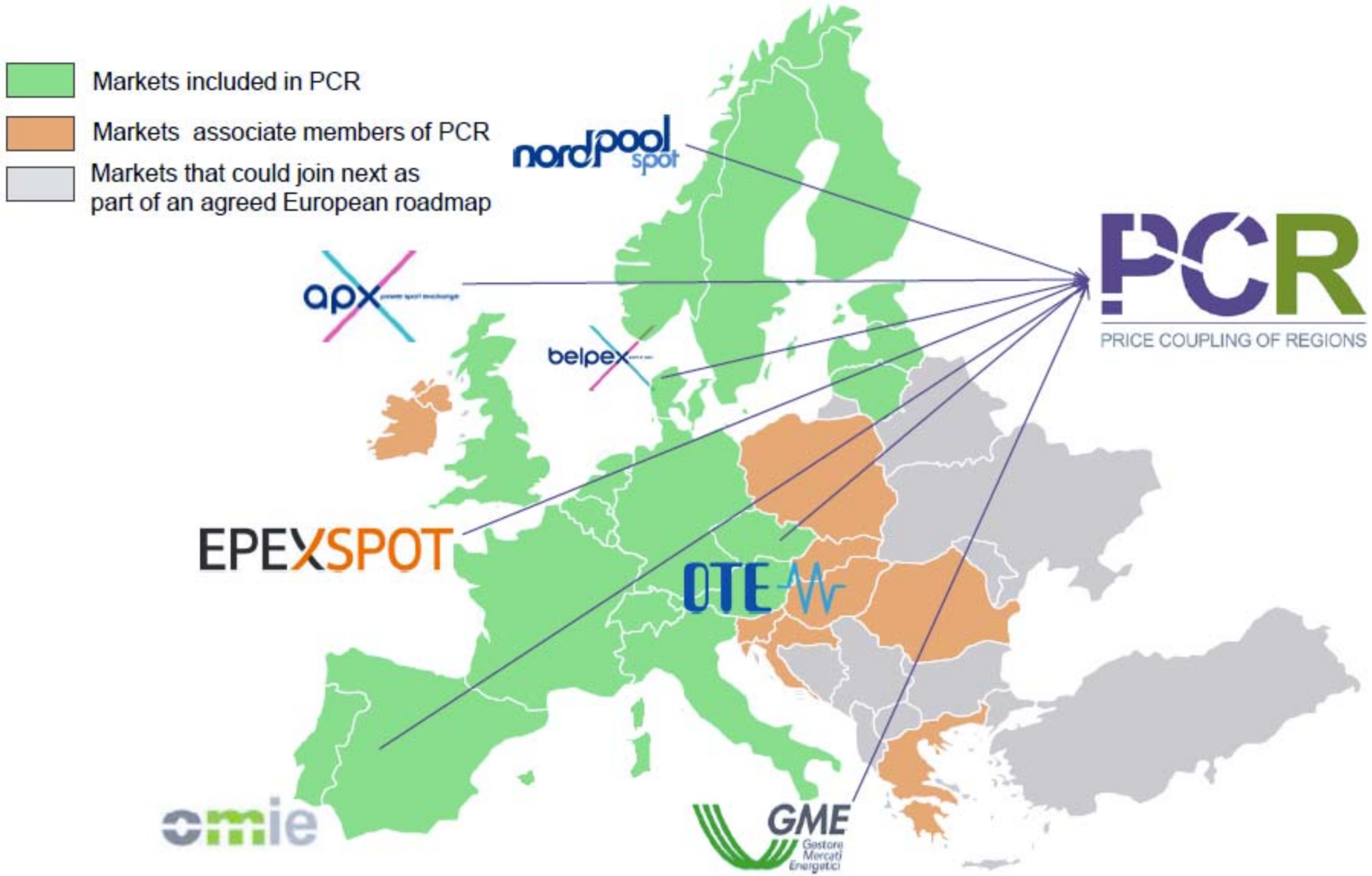
- European market developments
- Norwegian regulatory model
- Case studies
  - Distributed generation / prosumers
  - Storage
  - Demand response
- Conclusions

# Developments of the European power market

- Target model
  - Integrated energy only day-ahead market with market coupling / zonal pricing
    - Available Transfer Capacity (ATC) model
    - Flow-based Market Coupling (FBMC) model
- More renewables imply a need for more flexibility
  - Integration of Intraday markets: XBID from Q1 2018
    - Based on zonal pricing
  - Balancing markets / special regulation mostly national

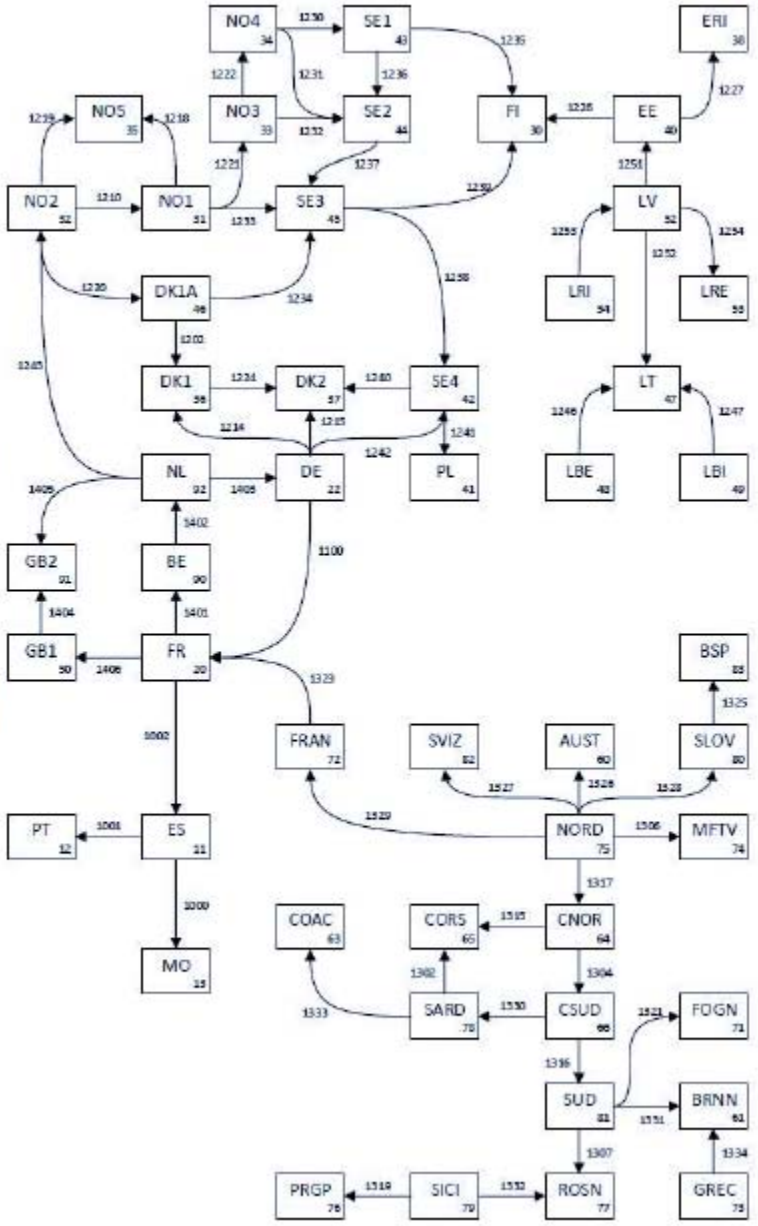
=> Wholesale prices are uniform across large areas

# European day-ahead market
## (Price Coupling og Regions (PCR), EUPHEMIA algorithm)



# MARKET DATA

- Each PX (Market) operates several bidding areas
- All bidding areas are matched at the same time
- A different price can be obtained for each bidding area
- The price for the bidding area must respect maximum and minimum price market boundaries



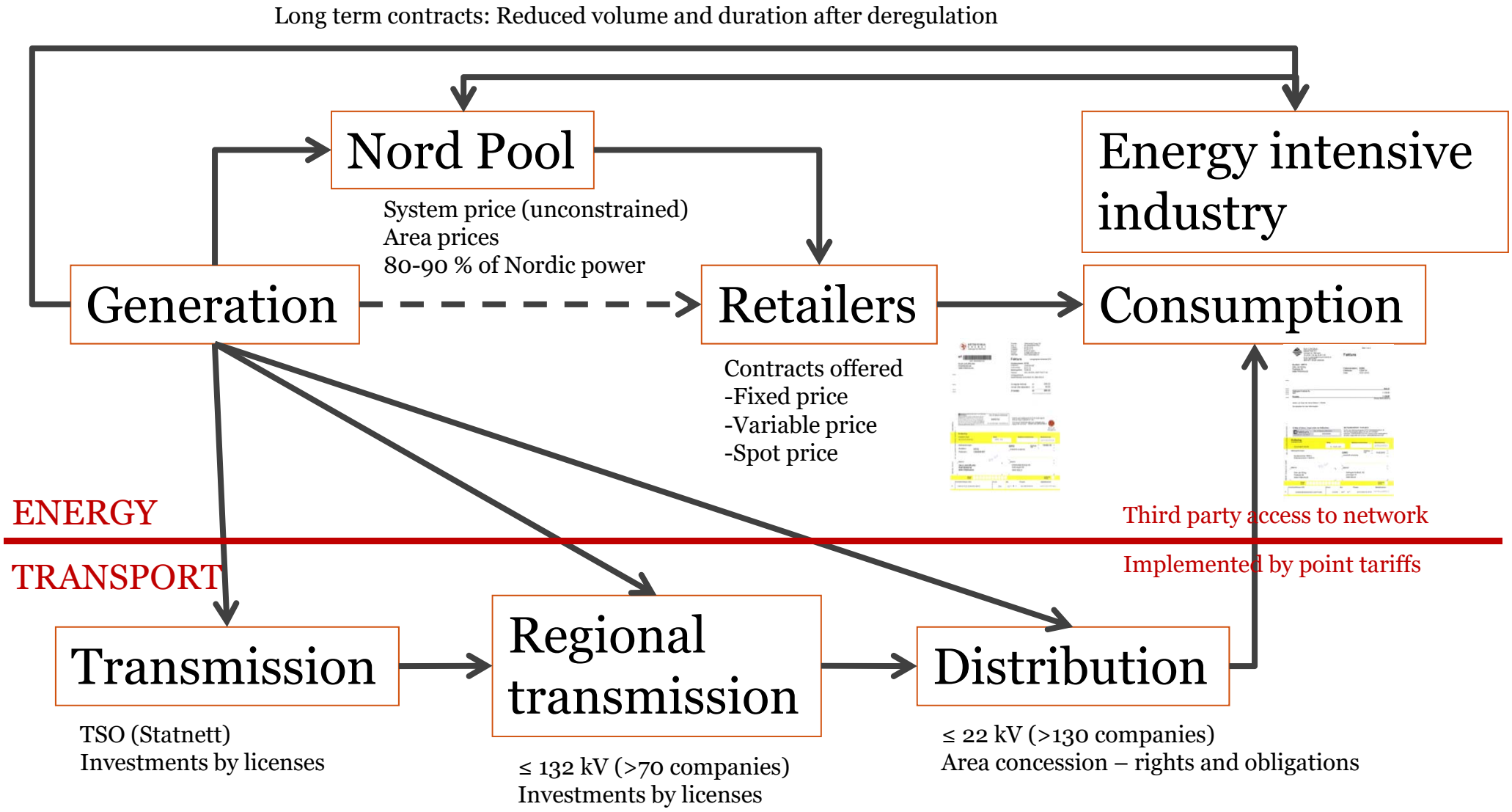
# Flexibility in the local grid

- New technology on the supply and demand side is causing more variation in capacity utilization in the local grids
- New technology in metering, controls and batteries provides the means for dealing with this
- Considerable interest in Norway during the last 5-6 years in using price differentiation in the local grids
  - In order to avoid investments in lines or transformers

# Norwegian and Nordic electricity market

- One of the first deregulated electricity markets in the world
  - Nordic countries (excl. Iceland): 400 TWh / population 25 mill.
- Energy is traded in the Nordic market
  - Power Exchange: Nord Pool / Part of European market coupling
  - Financial Market: NASDAQ OMX Commodities (from 2010)
- Vertical separation of transmission/distribution and generation
- Competitive supply and demand for power
  - Customers choose energy supplier
  - No price caps (not even for households)
- Transmission and distribution are regulated
  - RoR regulation from 1993
  - Incentive regulation from 1997

# Unbundling / Vertical separation is a cornerstone of the Norwegian and Nordic electricity market

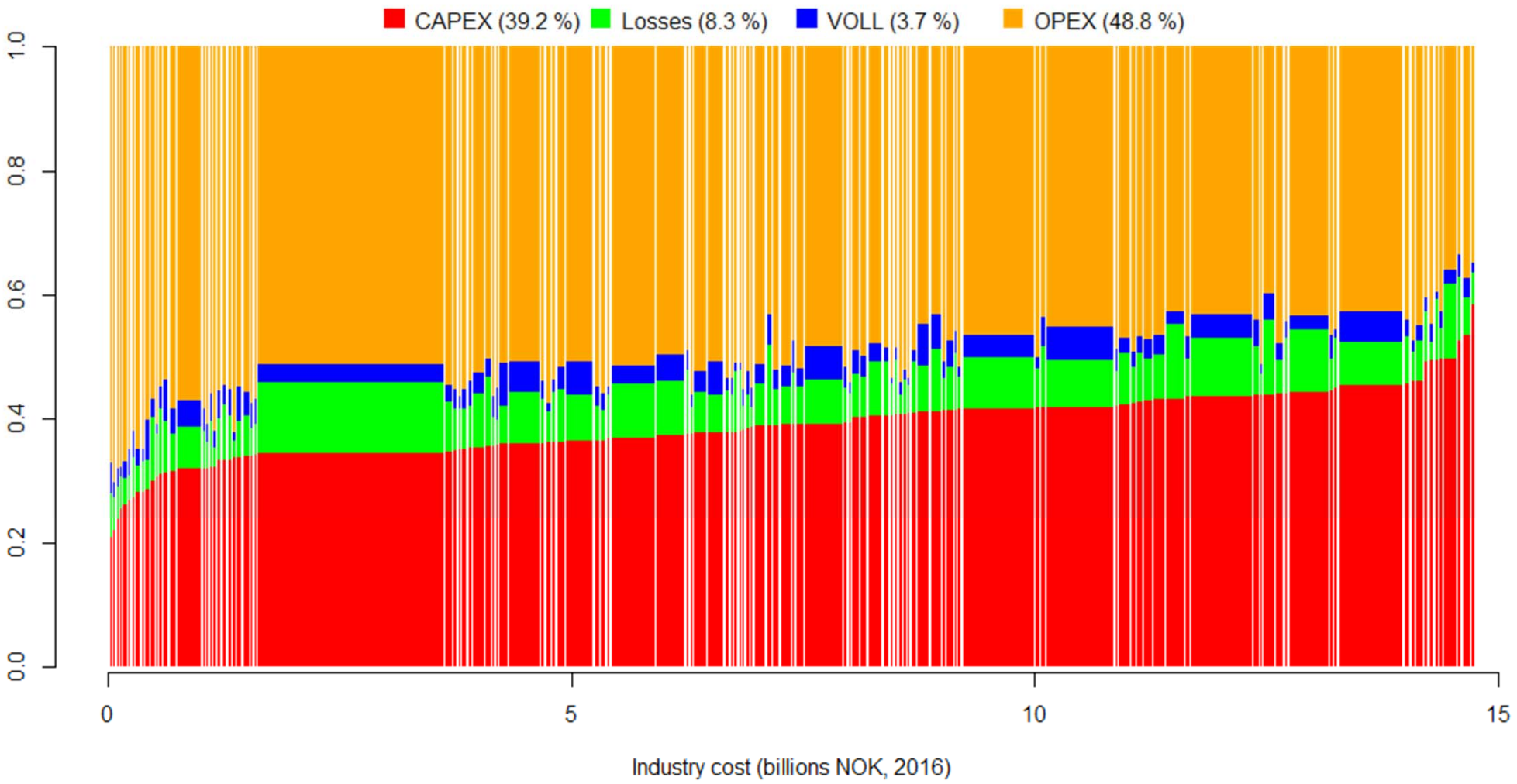


# Yardstick regulation model from 2007

- RCap = 0.6 · C* + 0.4 · C
- Annual updates of C and C*
- Ex ante forecast based on data for year t-2, final decision is made ex post
- C based on accounting values
  - Including capital costs
- C* based on benchmarking analysis: C* = E · C
  - DEA-based cost efficiency with total accounting costs as only input
  - Separate models for distribution and transmission
  - ΣC* calibrated to let averagely efficient companies earn normal rate of return
- Guaranteed minimum return on capital of 0 %

# Cost groups – distribution companies

(119 companies, 2007-2014 average)



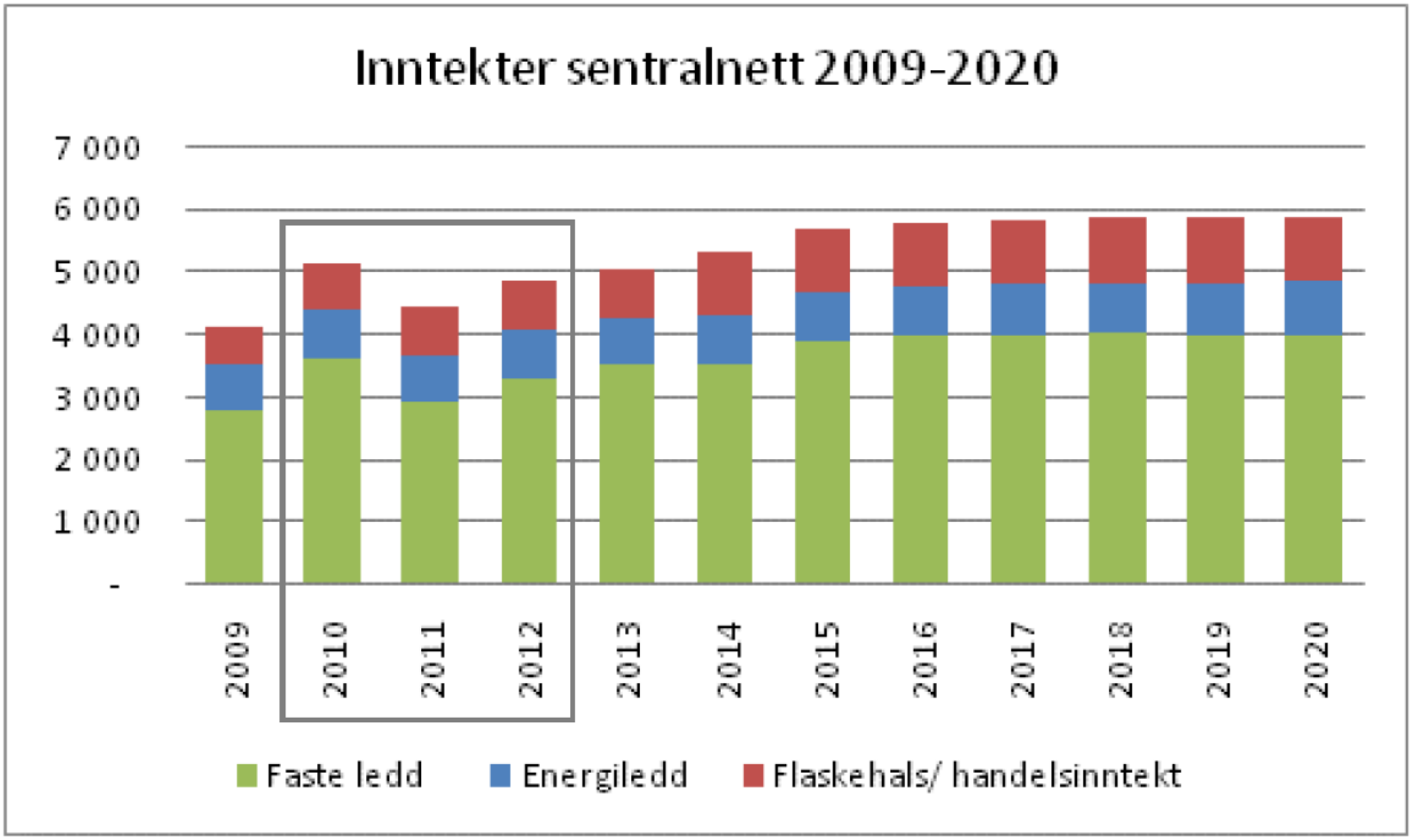
# Output and environmental variables for distribution networks

| Output variable | Unit of measurement | Regulation period | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1997-2001 | 2002-2006 | 2007-2009 | 2010-2012 | 2013-2015 | 2016- |
| Delivered energy | MWh | X | X | X | X | | |
| Customers | No. of customers | X | X | | | X | X |
| Customers, except cottages | No. of customers | | | X | X | | |
| Customers, cottages | No. of customers | | | X | X | | |
| HV lines | Kilometers | X | X | X | X | X | X |
| LV lines | Kilometers | X | X | | | | |
| Sea cables | Kilometers | X | | | | | |
| Expected VOLL | NOK | | X | | | | |
| Network stations | No. of stations | | | X | X | X | X |
| Interface | Weighted measure | | | X | Step 2 | | |
| Forest | Forest index × HV overhead lines | | | X | X | | |
| Snow | Snow index × HV overhead lines | | | X | X | | |
| Coast | Coast index × HV overhead lines | | | X | X | | |
| Small scale hydro power | Installed effect in concession area | | | | Step 2 | | |
| Islands | Number of islands w/o road connection | | | | Step 2 | | |
| Underground cables | Share of total length high-voltage lines | | | | | Step 2 | Step 2 |
| Forest | Share of total length high-voltage lines affected | | | | | Step 2 | Step 2 |
| Distance to road | Meters | | | | | Step 2 | |
| Geo1 | Index = f(steepness, small scale hydro, deciduous forest) | | | | | Step 2 | Step 2 |
| Geo2 | Index = f(wind/distance to coast, islands, sea cables) | | | | | Step 2 | Step 2 |
| Geo3 | Index = f(snow, darkness, ice, temperature) | | | | | | Step 2 |

# Tariffs

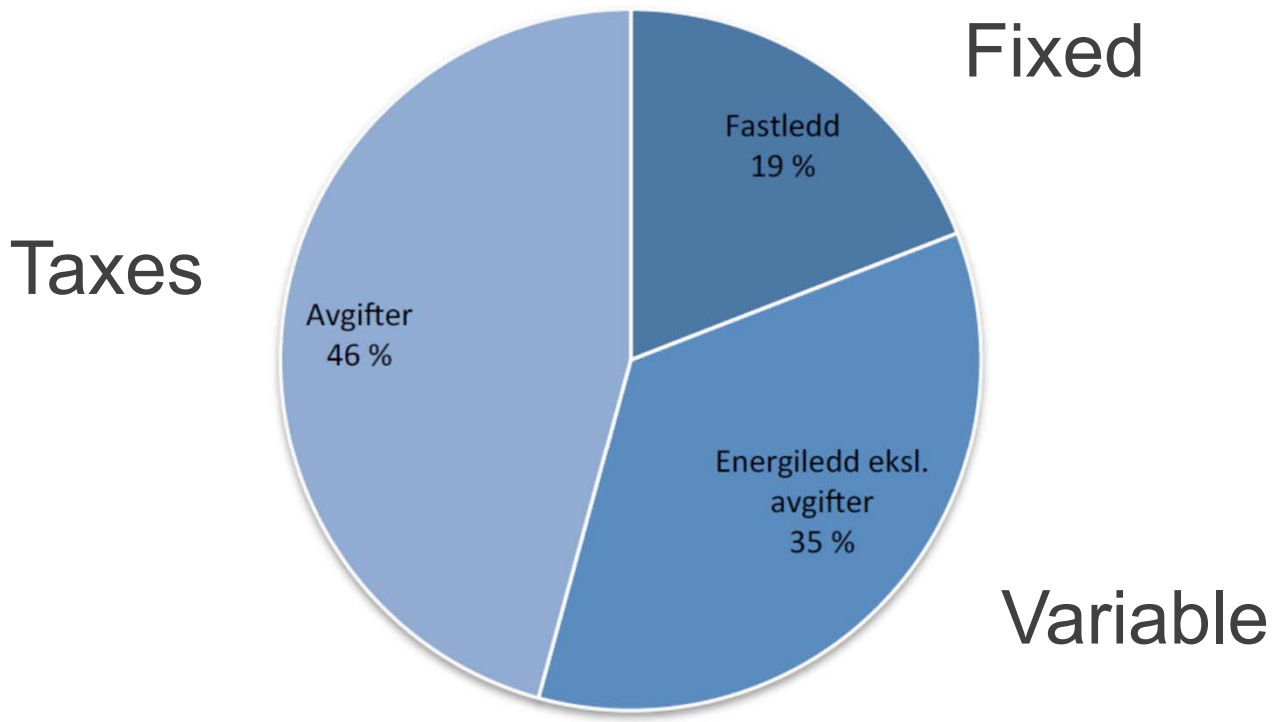
- The revenue cap is collected by means of a two-part tariff
  - Per-unit (variable) fee
    - To give signals for using the grid
    - «Usage-dependent» tariff
    - To reflect marginal cost such as losses
  - Fixed fees
    - Make up for the rest
    - Ideally a «Usage-independent» tariff
- Structure is given by regulation
  - Considerable freedom in determining the parts

# Statnett revenue forecast (2009-2020)




*Figur 1: Inntektsfordelingen i sentralnettet i perioden 2009-2020 (prognose)*

# Local grid company (Agder Energi), 2017




**Figur 1: Kostnadsstruktur for nettleie i 2017 ved forbruk på 20.000 kWh (Agder Energi Nett, 2017)**

# Prosumers / «Plus-customers»
## (Dvergsnes & Vestby)

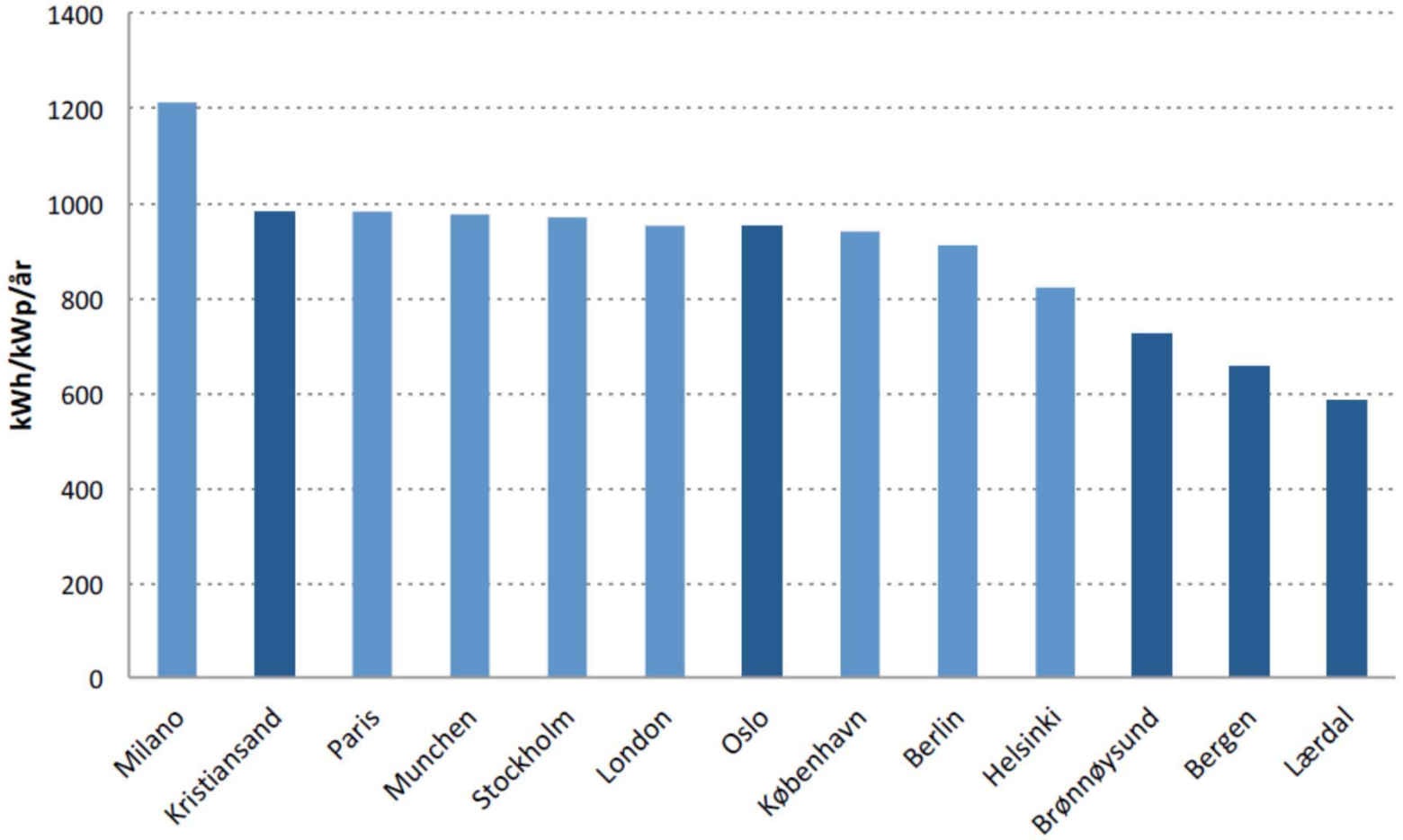
NHH

- What is the socioeconomic value of having more prosumers in Norway, what can we expect about the development in the number of prosumers in the future, and what are the regulatory implications?
- The short answer:
  - Not so beneficial
  - They are here to stay
  - Should reconsider subsidies and grid tariffs, and possibly the benchmarking model

# Prosumers / «Plus-customers»
## (Dvergsnes & Vestby)

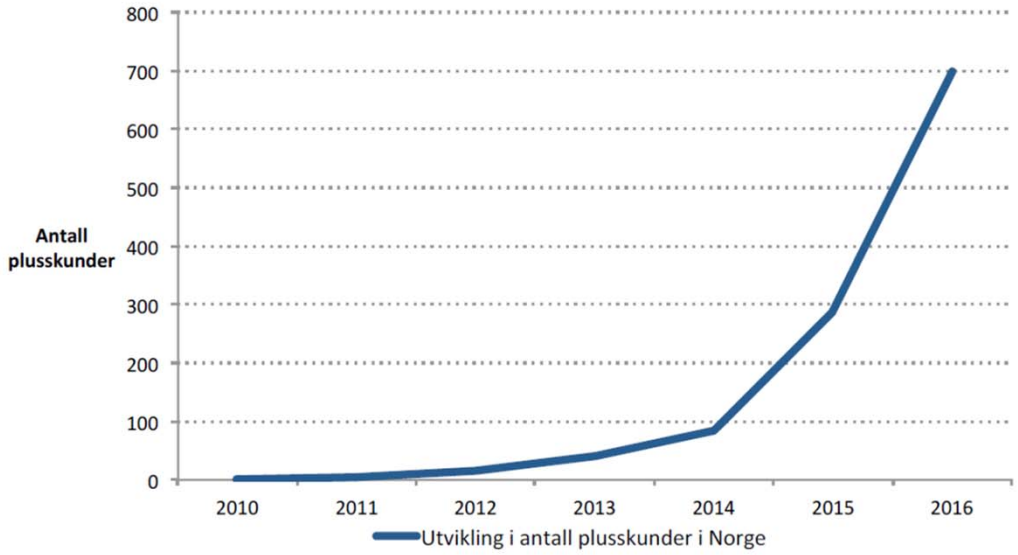
- Present regulation and support mechanisms
  - Direct subsidies (Enova)
    - Enova goals: To reduce greenhouse gas emissions, foster innovation, and improve security of supply
  - Simplified tariffs and rules
    - Do not pay injection tariffs or taxes like other generators
    - Variable injection tariff is often negative (reduced losses)
    - No need for concession or balancing agreement with SO
    - (As consumers: like the others, i.e. fixed + variable tariffs)

# Solar resources



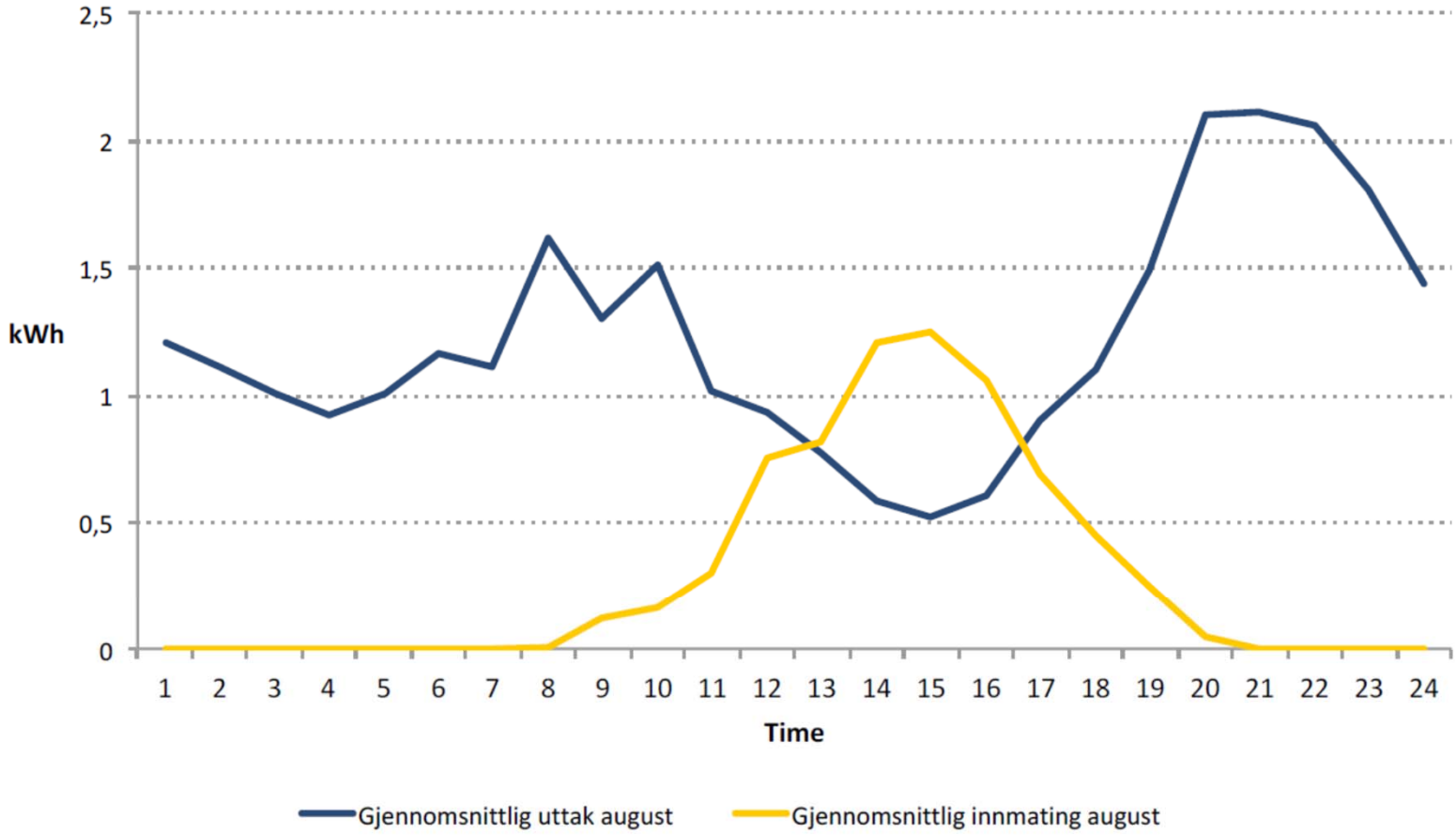

**Figur 3: Estimert årlig produksjon fra et solcellesystem i utvalgte europeiske byer (vedlegg 1)**

# Development so far…




**Figur 2: Utvikling i antall plusskunder i Norge (Arnslett, 2017)**

- Due to reduced investment cost, improved availability and information, increases in grid tariffs and taxes
- But also non-economic reasons




**Figur 6: Gjennomsnittlig uttak og innmating for en plusskunde i Norge i løpet av et døgn i august, basert på virkeli tall fra et titalls plusskunder (data fra Adapt Consulting)**

# Socioeconomic value

NHH

- General benefits
  - Reduced prices
  - Reduced losses
  - Deferred or avoided investment in network capacity
  - Improved recovery time after major outages
  - Improved energy efficiency
  - Improved competition
  - Reduced emissions
- Potential disadvantages
  - Financial challenges for the grid companies
  - Financial risk to other consumers
  - More volatile power prices
  - Challenge for established power producers
  - Voltage fluctuations in the network
  - Bottleneck problems created by surplus power
  - Reduced energy efficiency

- Some of the benefits seen elsewhere are less important in Norway
- Changing tariffs from variable to fixed seems reasonable, but will reduce profitability of prosumers
- If higher cost in distribution company due to prosumers, may have to make changes to benchmarking model

# Storage
## (Miftari & Schiøtz)

NHH

- Can local storage improve company profits and welfare to society, including improved quality and security of supply? What are the implications for regulation?
- The short answer:
  - It can be better to invest in batteries than in new lines
  - Whether profitable depends on who bears the extra cost
  - Should grid companies be allowed to own batteries?

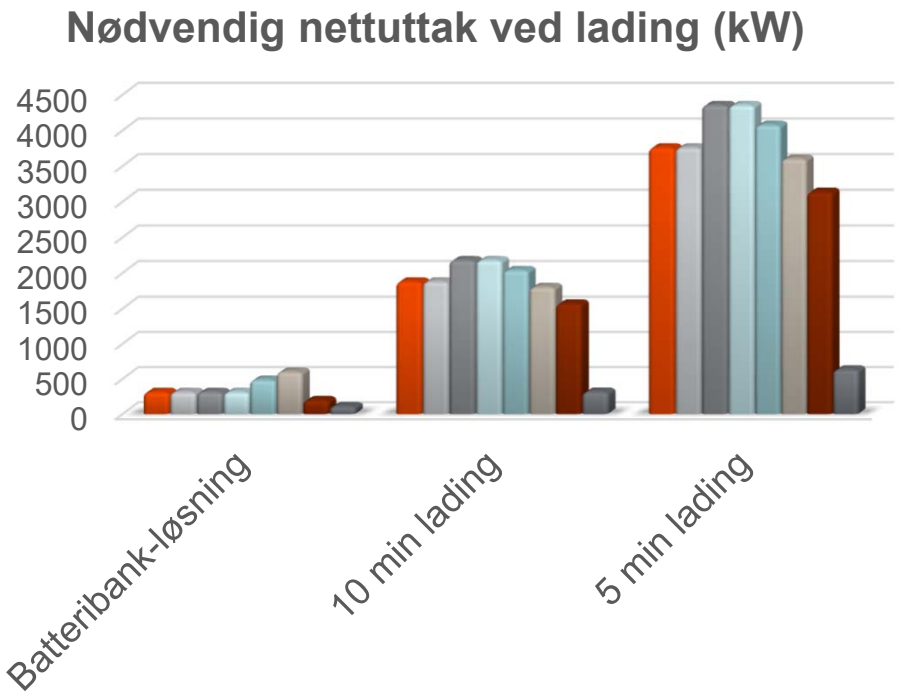
NHH

# Storage facilities for electric ferries

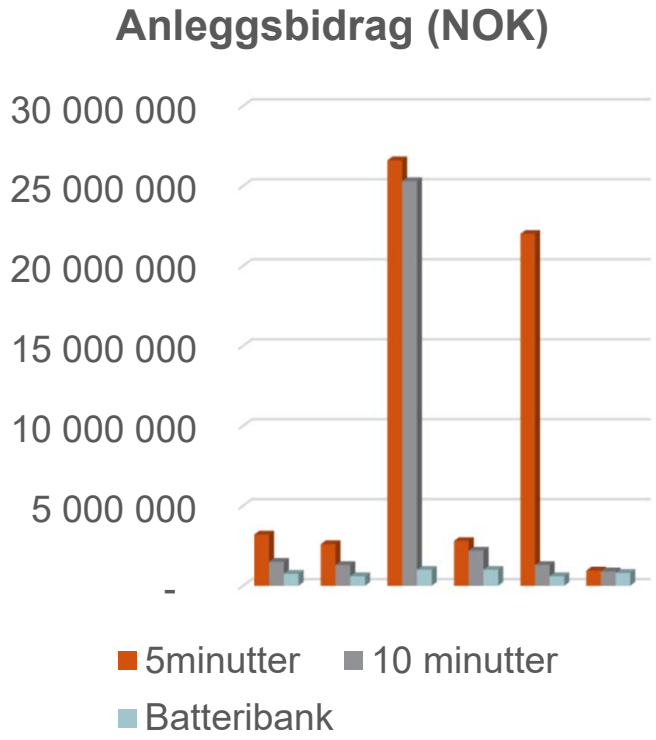

The electric ferry Ampere (Norled)

NORWEGIAN SCHOOL OF ECONOMICS

# Load




# Investment contribution



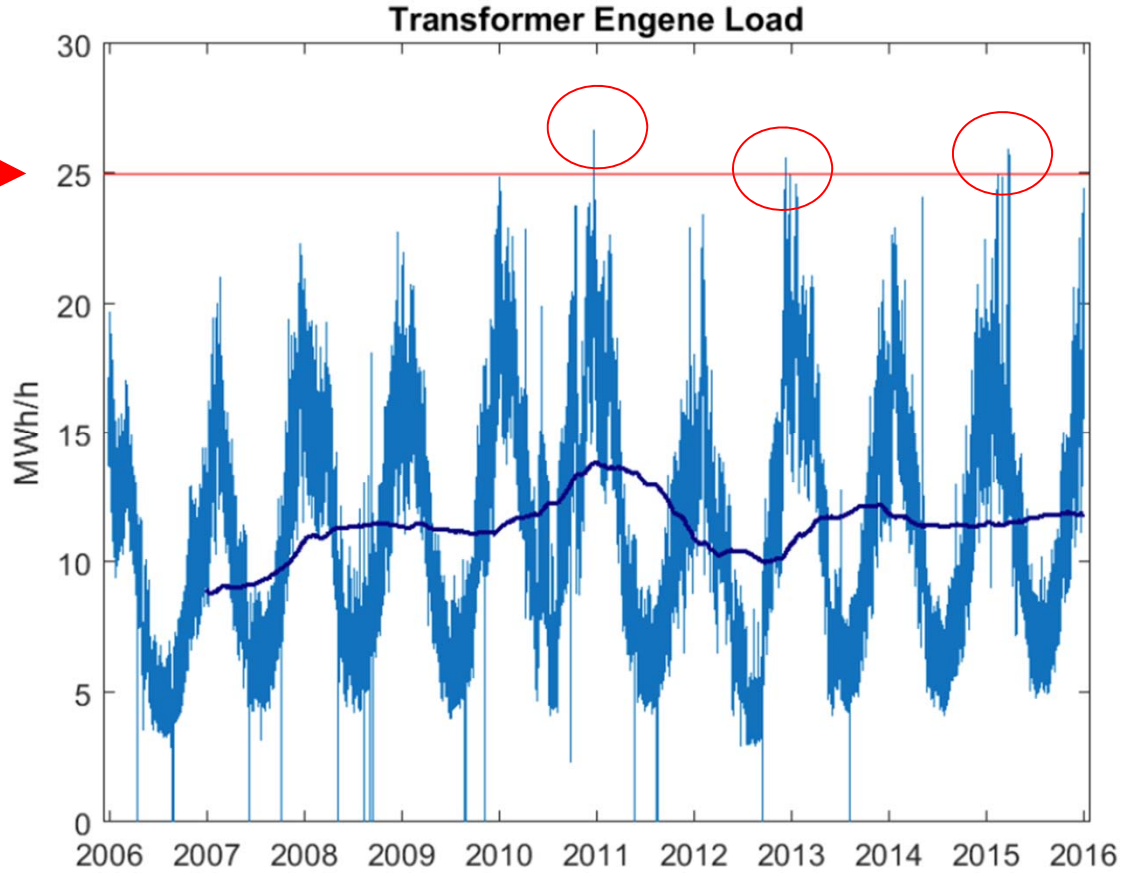

Kilde: BKK

- If total cost of batteries are lower than the cost of a new line, then the battery solution should be chosen
- Complicating issues: Who may own the batteries? Can the grid company charge investment contribution? How easy will it be to buy battery services in a market?

# Demand response
## (Funk & Wood)

NHH

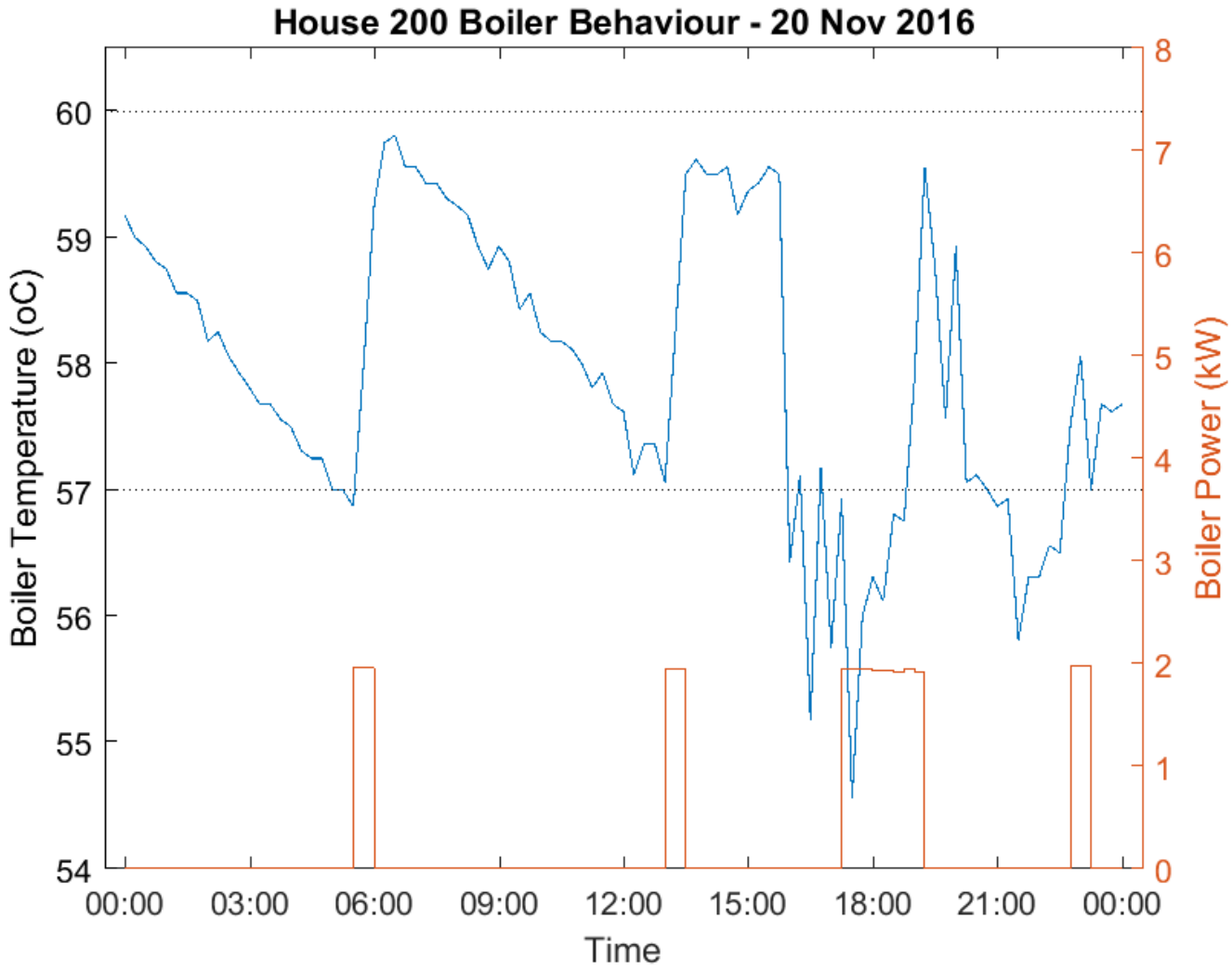
*Max load: 25MW*


*Data source: Agder Energi Nett*

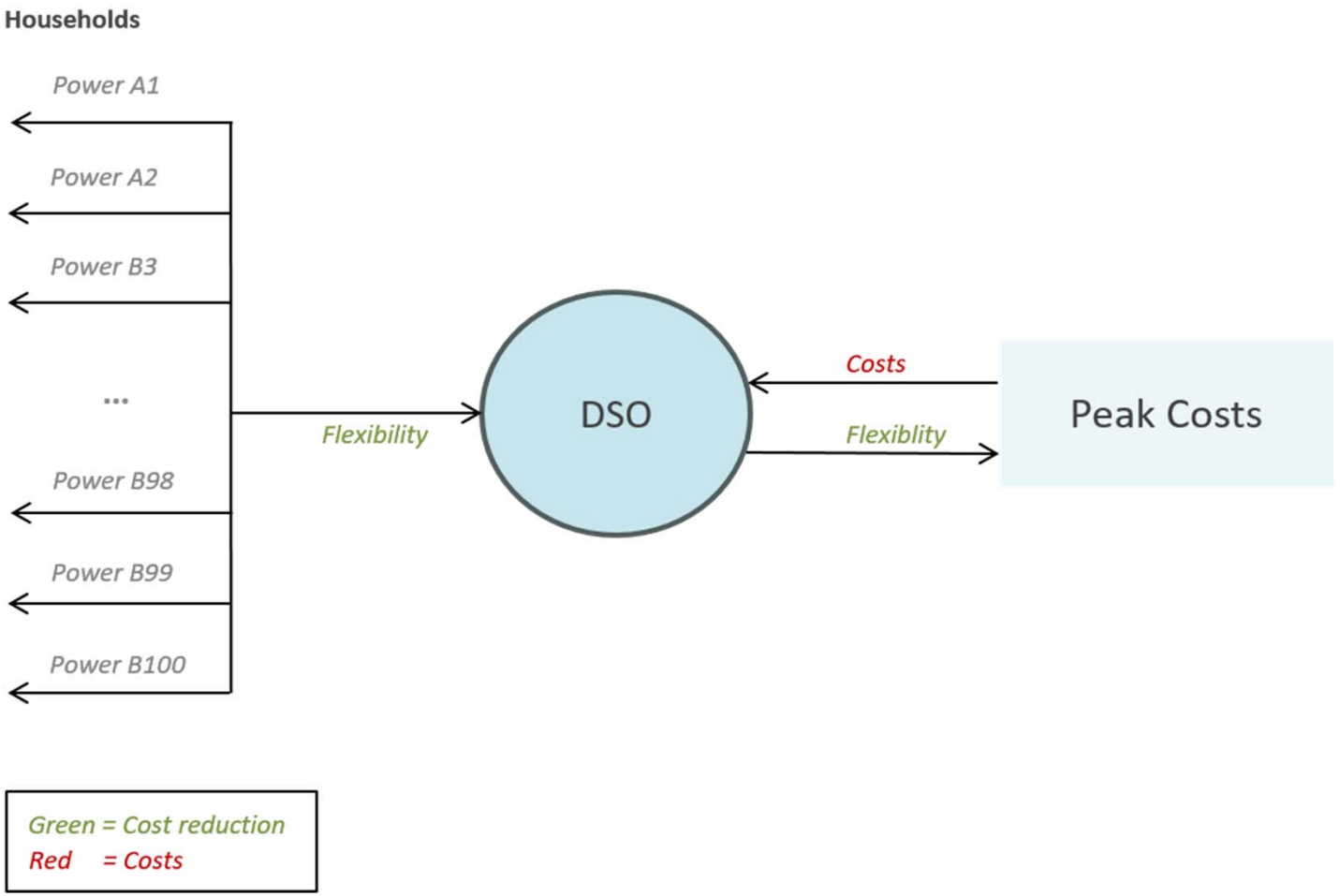
The Problem: Engene Transformer, Agder Energi Nett

# Boiler Behaviour

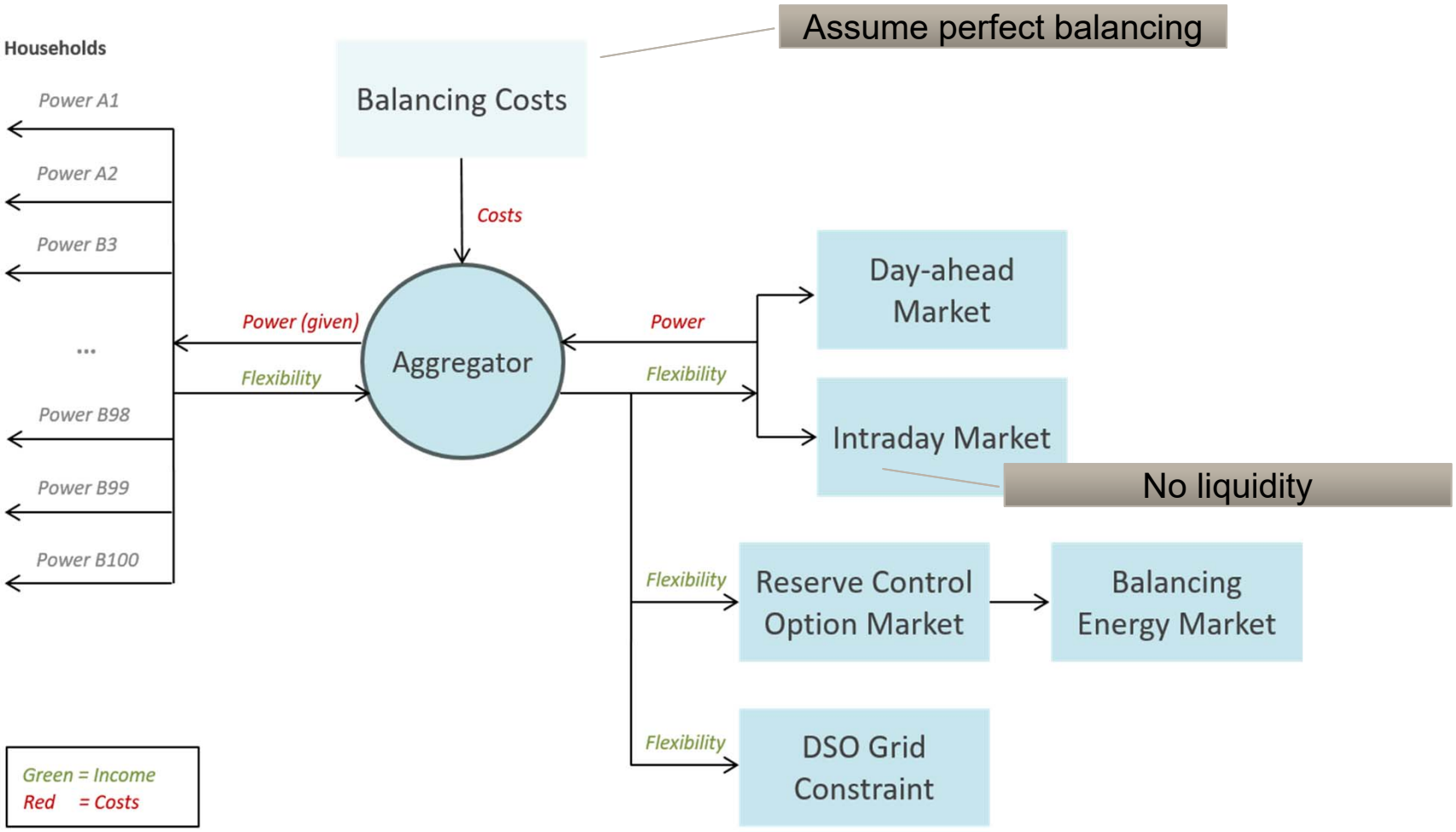



*Data Source: SEMIAH Pilot*

# Optimisation A: DSO Peak Shaving



# Optimisation B: Aggregator as a supplier



# Limitations of approach

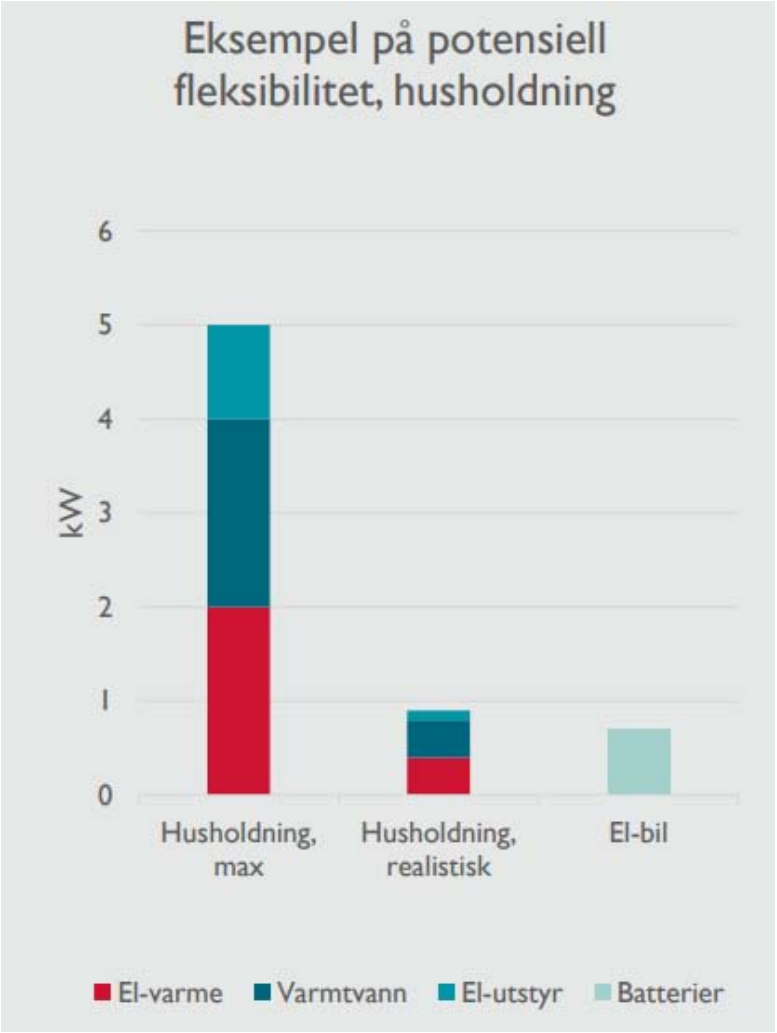
- Data for only 22 households available – quality issues
- Boiler water temperature could not be modelled
- Ex-post optimisation using observed consumption and prices
- Only boiler appliance considered
- Intraday market could not be modelled

# Findings

- DSO only results encouraging but installation costs too high
- Aggregator could bare installation costs and charge DSO a fee
- Revenues from day-ahead and reserve option market optimization limited for aggregator with only boilers
- Aggregator should charge DSO fee for peak shaving
- Peak shaving, including more than only boiler (e.g. EVs), interesting and feasible
- Regulatory framework to set incentives and define roles is missing
- Future price volatility and level are crucial for the value of flexibility

# End-user flexibility and investment deferment
## (Buvik & Børke)

- Skagerak Nett
- Alternative 1: Invest in distribution network capacity now
  - Costly
  - Takes time to plan and build
  - Low capacity utilization (built for redundancy)
  - Environmental issues
- Alternative 2: Invest in end-user flexibility to defer the capacity investment
  - Less costly
  - Load shifting
  - Accommodate distributed renewable generation
  - Storage / batteries




Kilde: NVE

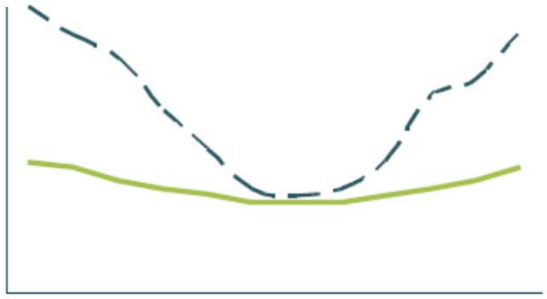
# Compensation schemes

1. Tariff rebate
    - Redistribution of tariffs from flexible customers to inflexible customers
2. Flexibility providers are paid directly, and flexibility payments are added to the regulatory cost base
    - 40 % can be recovered directly from customers
    - The remaining amount can only be recovered if it is offset by increased revenues (improvements in measured efficiency) or by other cost reductions (deferred investments, reduced network losses, reduced O&M)

# Scenarios (THEMA Consulting)

**SELVFORSYNING AV VARME JEVNER UT FORBRUKET**

Maks. last (MW)

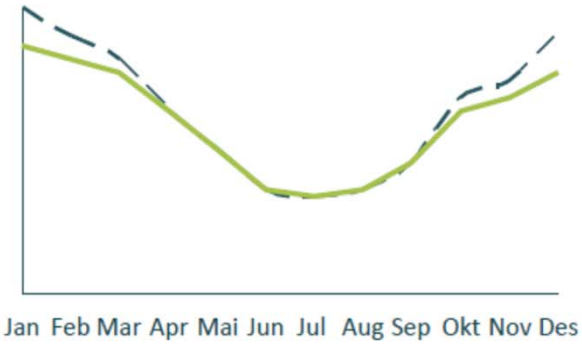



**«RUSHTIDSKUNDER» FORSTERKER DAGENS FORBRUKSPROFILER**

Maks. last (MW)


**FORBRUKSFLEKSIBILITET REDUSERER MAKSIMALT FORBRUK NOE**

Maks. last (MW)




**«NETTET SOM BACK-UP» GIR UFORUTSIGBART BRUK, MEN LAVERE EFFEKTUTTAK OG LAVERE BRUKSTID ENN I DAG**

Maks. last (MW)