Techno-economic models in SmartGrids

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NCE Smart Energy Markets

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SINTEF · NTNU Det skapende universitet · IFE Institutt for energiteknikk · NHH 2011 75 år · HØGSKULEN i SOGN OG FJORDANE · VESTLANDSFORSKING · UiO : Universitetet i Oslo · SNF Et selskap i NHH-miljøet

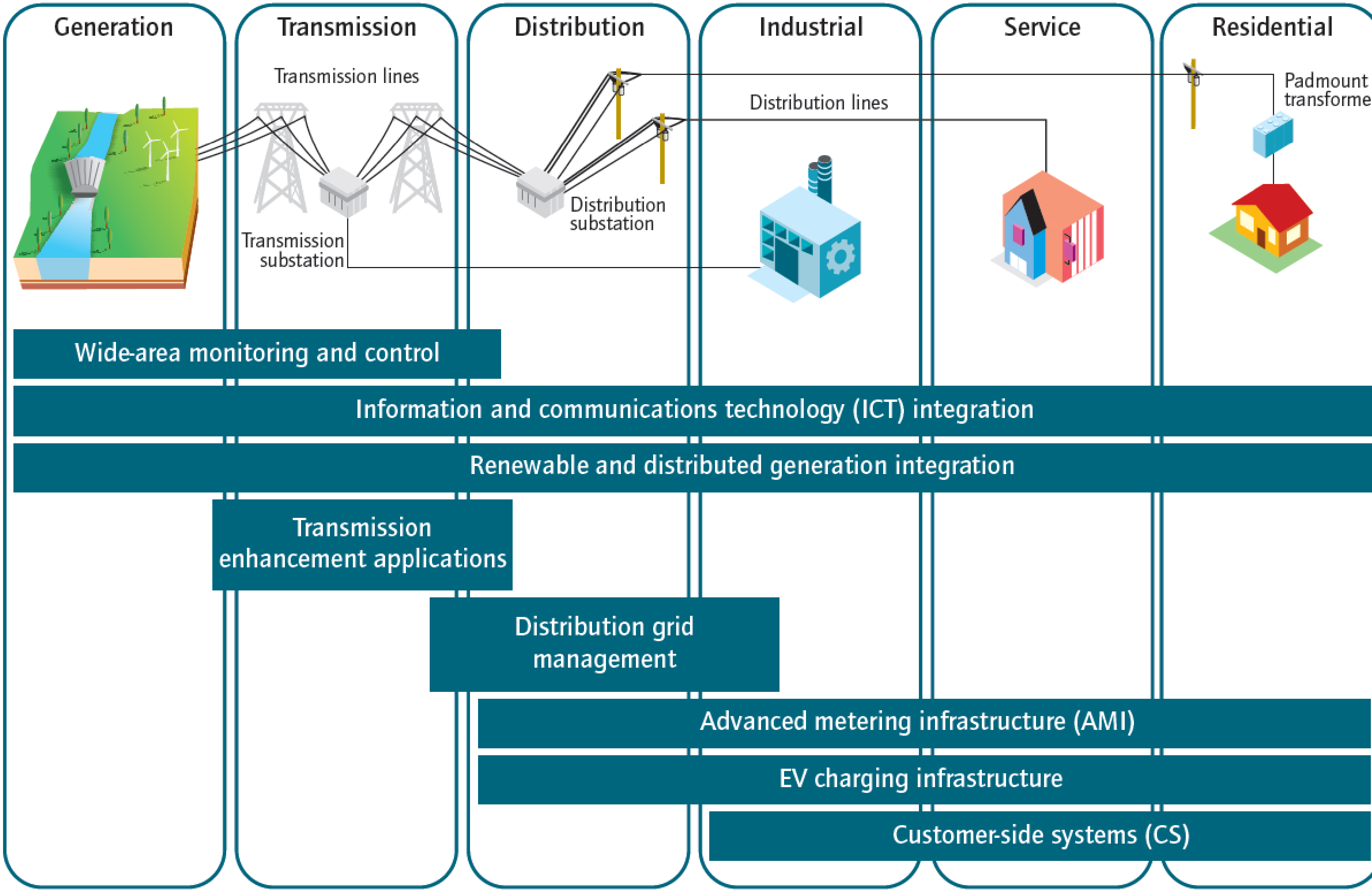
- PhD student at NTNU Industrial Economics
- PhD financed through an innovation research project «Manage Smart in SmartGrids»
- Project funded by
  - The research council (RENERGI)
  - Industry partners in the project

Presentation outline

- SmartGrid intro
  - Technologies and features
  - Potential benefits
  - Incentives
- Current research – A scheduling model
- Future research

What is the SmartGrid?

International Energy Agency



Overview – SmartGrid technology at demand side

Figure A.33 (left): 6.4kW modules
Figure A.34 (right): 100-kW, 15-kWh Li-ion batteries for UPS

Source: Hokuriku Electric Power Co., 2008. Source: Electricity Storage Association 2009.

Electrical vehicles

Distributed storage

AMI:

1. Infrastructure DSO-consumer

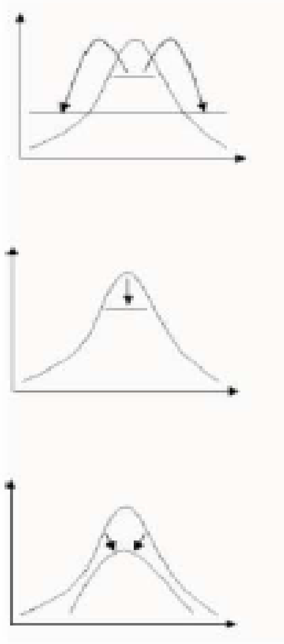
2. Smart meters

Home automation / Smart appliances

Distributed generation

Key feature – Added flexibility and at demand side

- Response based on
  - Demand flexibility
  - Distributed generation flexibility
  - Distributed storage flexibility
- Estimated potential for DR in Norway:
  - 4.700 MW (Sintef Energy)
  - Peak load: app. 24.000 MW



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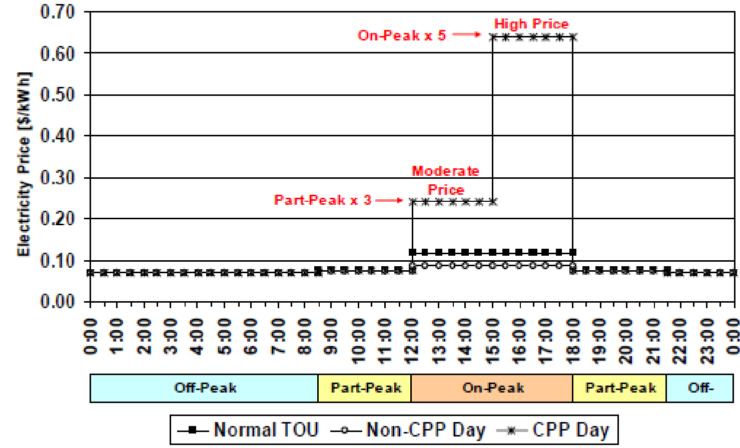
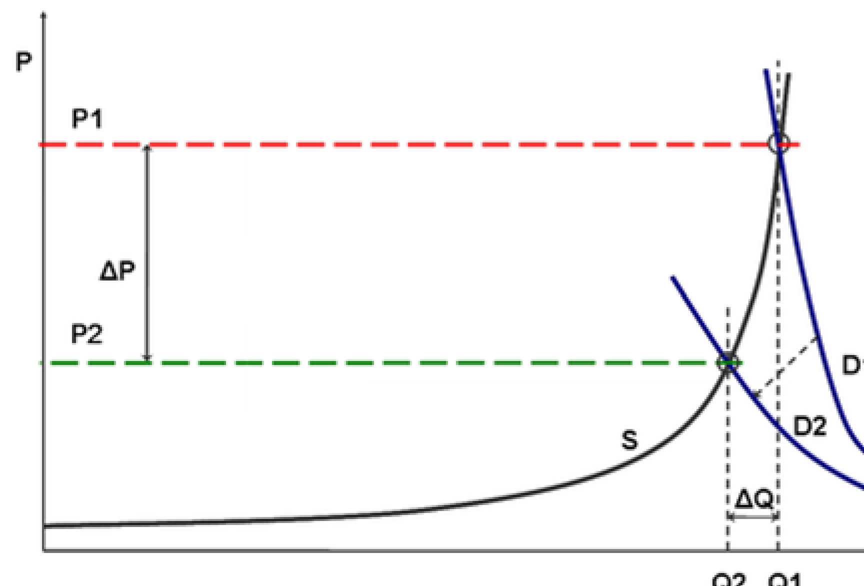
Potential benefits 1 - for the power system

- Delayed investments (gen. and grid)
- Better control of operational situation
- Increased reliability/reduced black-outs
- Reduced need for peak generation and reserves
- Reduced environmental/climate impact
- Increased ability to integrate intermittent renewable generation

Potential benefits 2 – for the power markets



- Introduction of dynamic price regimes
- Increased demand elasticity/ reduced risk for extreme prices
- Increased number of market participants/ volumes



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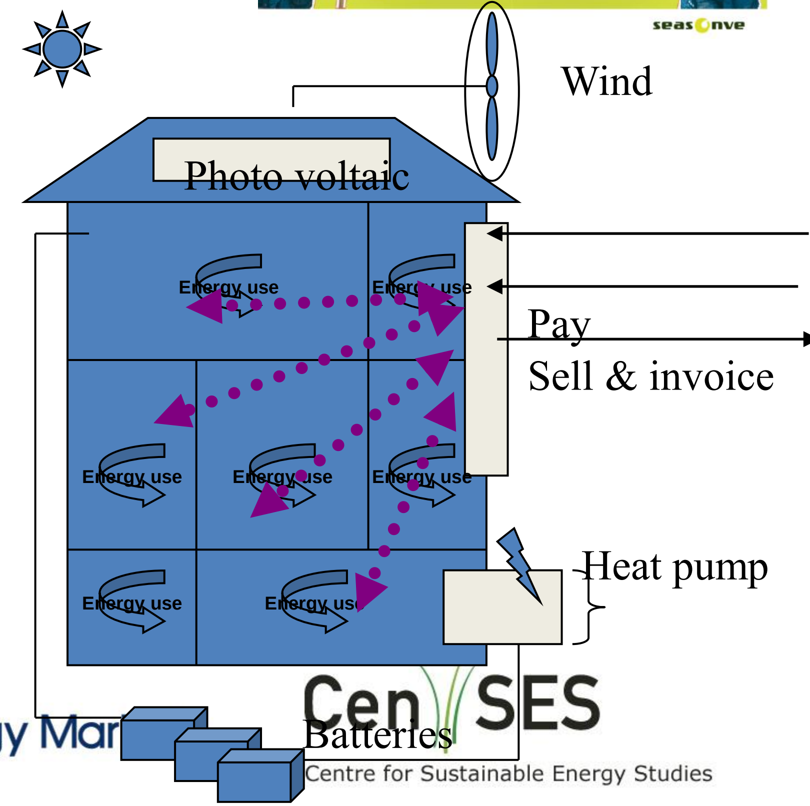
Potential benefits 3 – for the consumers

- Cost savings
- Being environmentally friendly
- Being in front technologically
- Involvement and active participation
  => prosumer



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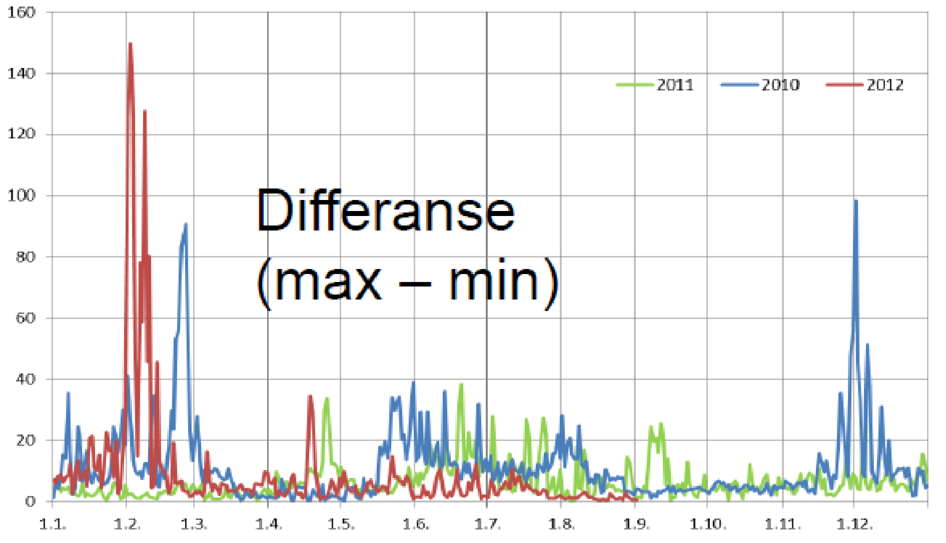
Current incentives for demand side flexibility in Norway

- Without hourly metering: No incentive
- With hourly metering:
  - Power market: Small price differences
  - Grid tariff large consumers: Capacity fee based on actual max kWh/h per month

=> Weak incentives



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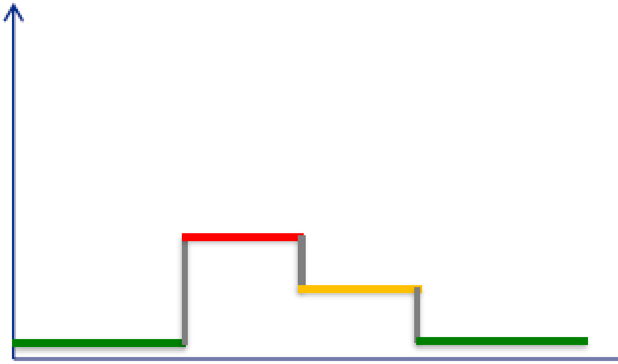
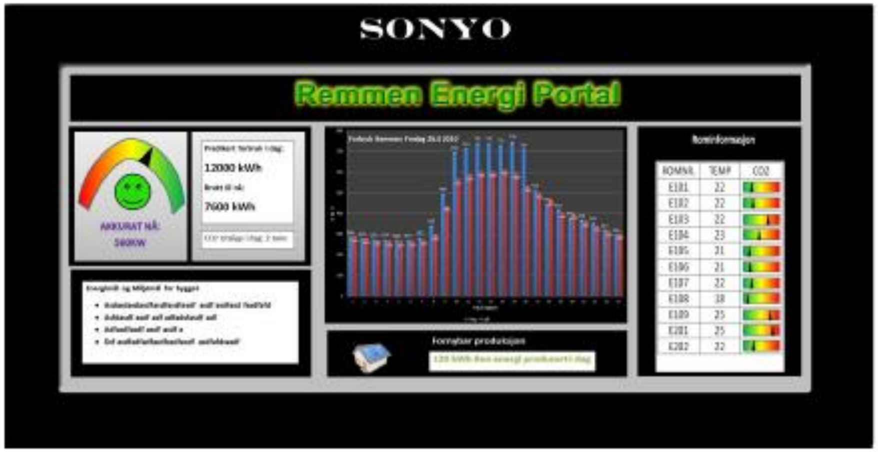
Future incentives

- How will the price variability in the power market develop?
- Introduction of dynamic grid tariffs?
  - Time of use, predefined price levels and periods
  - Time dynamic, predefined price levels, but periods based on real situation in the grid



Future incentives – introduction of new market roles – Service providers

- Service providers:
  - ESCo – Energy Service Company
  - SESP – Smart Energy Service Provider
- Scheduling and dispatching appliances
- Additional services
  - Energy efficiency advice
  - Technology packages
  - Financial arrangements



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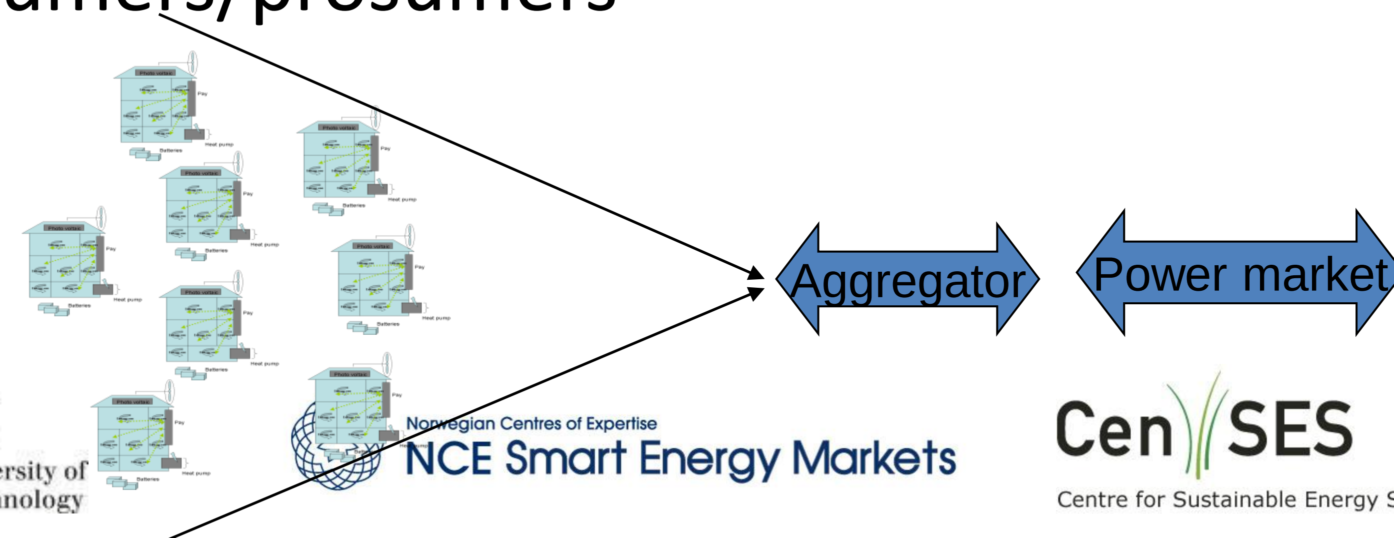
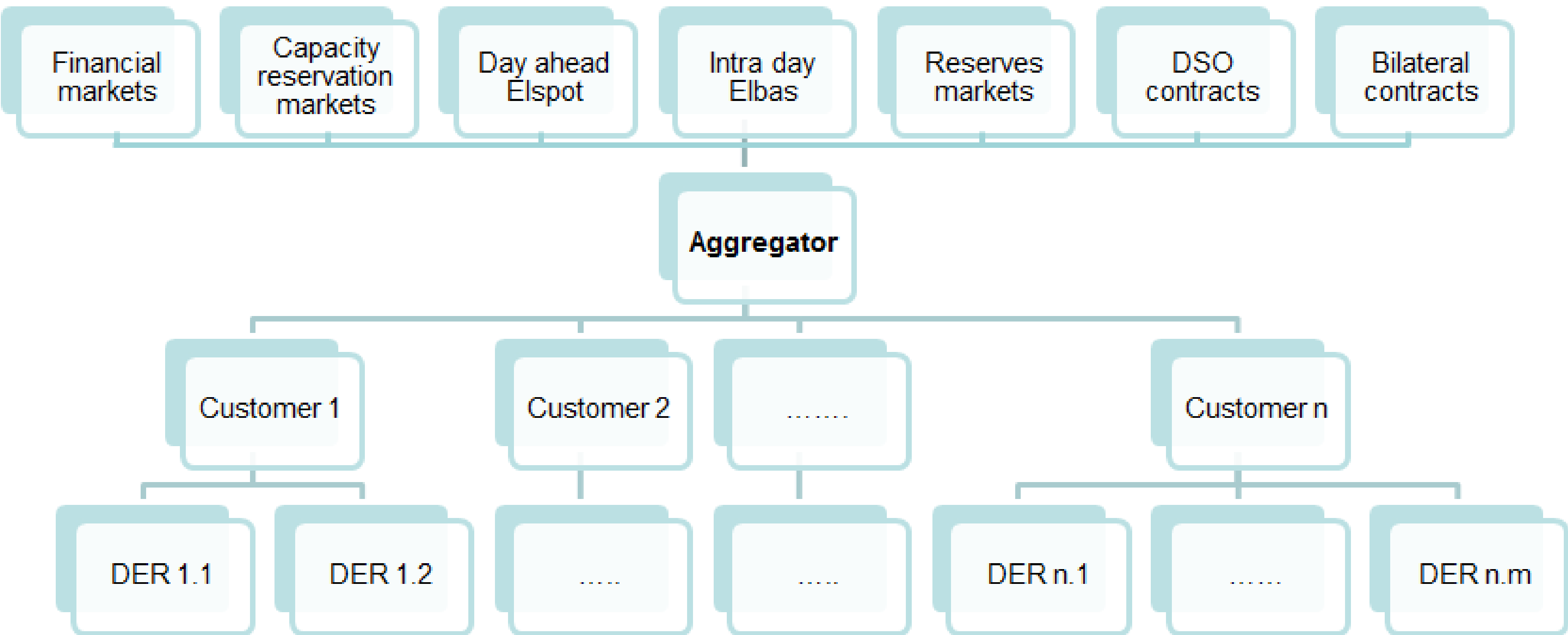
Future incentives – introduction of new market roles – VPP/Aggregator

- May provide the same services as ESCo/SESP
- + Aggregating (flexibility) volumes - selling in markets – virtual power plant
- Creates market access to new markets for the consumers/prosumers



New market opportunities for demand side flexibility

- Trading in existing (and future) organized market places
- Selling flexibility as a service to the DSO or other companies



Future incentives – new business models

- Energy as a service (not as a pure commodity – parallel to telecom)
- Bundling with other services (financing, health, security, entertainment…)
- Need to think out of the silos and have a holistic approach


Illustrasjonsbilde Foto: Think

Kjøp leilighet - få elbil med på kjøpet

Etter at markedsføringslovens regler om tilgift ble fjernet dukker det stadig opp nye kreative pakkeløsninger

DN.no
Publisert 23.01.2010 - 11:29 Oppdatert 23.01.2010 - 11:40


STAVANGER

Eldreomsorg

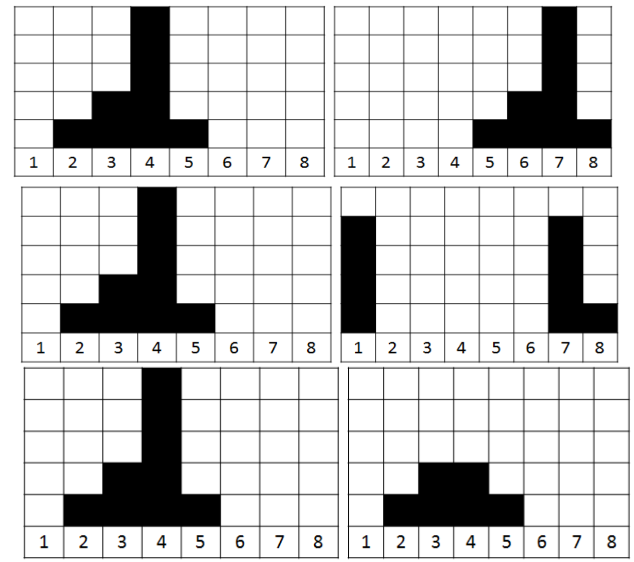
– Vi føler oss tryggere

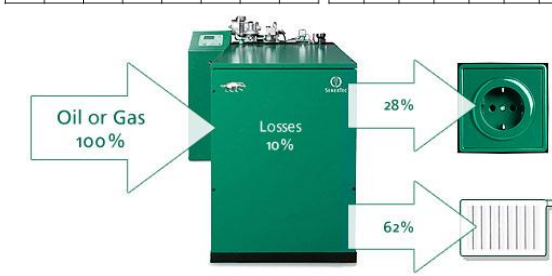
Research focus 1 An optimization model for prosumers' scheduling problem

- Pre-requisites:
  - A building with energy units with operational flexibility
  - Dynamic electricity prices
  - We want a general model that can be applicable
- Assumptions:
  - Direct/automatic control
  - Participation at retail side in electricity market

How to model flexibility?

- Flexibility classes:
  - Load shifting profile
  - Load shifting volume
  - Load reduction
  - Generation dispatching
  - Energy carrier substitution
  - Storage dispatching





- Maximization of flexibility in electricity – must look at total energy system in the building

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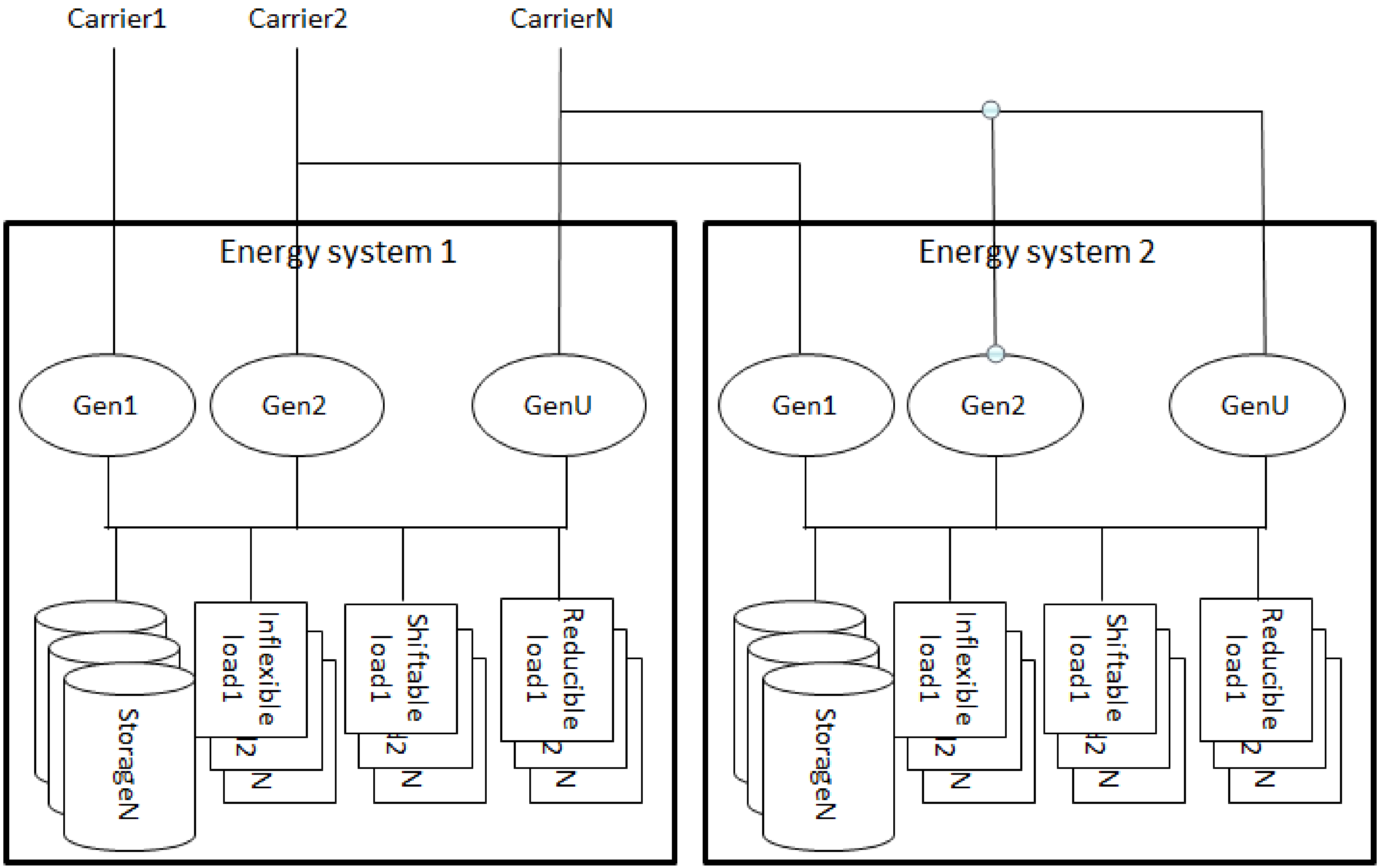
The total internal energy system



Mathematical model: objective function

$$\min z = \sum_{s\in S} R_s \cdot \left[\begin{aligned} &\sum_{a\in A}\sum_{t\in T}\left(P^{var}_{a,t,s}\cdot \chi^{net-in}_{a,t,s}\right) + \sum_{a\in A}\left(P^{cap}_{a}\cdot \chi^{max}_{a,s}\right) + \\ &\sum_{d\in D^R}\sum_{y\in Y}\left(X_{d,y}\cdot \sum_{t\in T}\varphi_{d,y,t,s}\right) - \sum_{a\in A}\sum_{t\in T}\left(P^{sales}_{a,t}\cdot \chi^{net-out}_{a,t,s}\right) \end{aligned} \right]$$

- Cost minimization
- Variable cost (function of kWh)
- Cost for capacity (peak, function of max kW)
- Disutility/dissatisfaction cost (function of kWh reduced)
- Income from sales of surplus energy

Constraints – energy carrier

$$\sum_{y \in Y} \sum_{o \in O} \chi_{a,y,o,t,s} \leq U_a, a \in A, t \in T, s \in S \tag{1.12}$$

$$\chi_{a,t,s}^{net-in} = \max((\sum_{y \in Y} \sum_{o \in O} \chi_{a,y,o,t,s}), 0), \forall a \in A, t \in T, s \in S \tag{1.13}$$

$$\chi_{a,s}^{\max} \geq M_a, a \in A, s \in S \tag{1.14}$$

$$\chi_{a,s}^{\max} \geq \max(\sum_{y \in Y} \sum_{o \in O} \chi_{a,y,o,t,s}), \forall a \in A, s \in S \tag{1.15}$$

$$\chi_{a,t,s}^{net-out} = -\min((\sum_{y \in Y} \sum_{o \in O} \chi_{a,y,o,t,s}), 0), \forall a \in A, t \in T, s \in S \tag{1.16}$$

Constraints – generation and storage

$$\psi_{o,y,t,s} = A_{o,y} \cdot \chi_{a,o,t,s}, \forall o \in O, y \in Y, t \in T, s \in S \qquad (1.17)$$

$$\psi_{o,y,t,s} \leq G_{o,y}^{\max}, \forall o \in O, y \in Y, t \in T, s \in S \qquad (1.18)$$

$$\chi_{a,o,t,s} = I_{o,t}, \forall a = 2, o \in O, t \in T, s \in S \qquad (1.19)$$

$$\sigma_{l,y,t,s}^{soc} = \sigma_{l,y,t-1,s}^{soc} + \sigma_{l,y,t,s}^{in} \cdot A_{l,y}^{in} - \frac{\sigma_{l,y,t,s}^{out}}{A_{l,y}^{in}}, \forall l \in L, y \in Y, t \in T, s \in S \qquad (1.20)$$

$$\sigma_{l,y,t,s}^{soc} \leq O_{l,y}^{\max}, \forall l \in L, y \in Y, t \in T, s \in S \qquad (1.21)$$

$$\sigma_{l,y,t,s}^{soc} \geq O_{l,y}^{\min}, \forall l \in L, y \in Y, t \in T, s \in S \qquad (1.22)$$

$$\sigma_{l,y,t,s}^{in} \leq Q_{l,y}^{in}, l \in L, y \in Y, t \in T, s \in S \qquad (1.23)$$

$$\sigma_{l,y,t,s}^{out} \leq Q_{l,y}^{out}, l \in L, y \in Y, t \in T, s \in S \qquad (1.24)$$

$$\sigma_{l,y,t,s}^{soc} \geq H_{l,y}, l \in L, y \in Y, t = T, s \in S \qquad (1.25)$$

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Constraints – loads

- Reducible
- Shiftable volume
- Shiftable profile

$$\delta^{run}_{d,y,t,s} + \delta^{end}_{d,y,t,s} = 0, \forall d \in D, y \in Y, t = 1, s \in S \qquad (1.26)$$

$$\delta^{start}_{d,y,t-1,s} + \delta^{run}_{d,y,t-1,s} = \delta^{run}_{d,y,t,s} + \delta^{end}_{d,y,t,s}, \forall d \in D^R, y \in Y, t \in Z, s \in S \qquad (1.27)$$

$$\delta^{start}_{d,y,t,s} + \delta^{run}_{d,y,t,s} \leq 1, \forall d \in D^R, y \in Y, t \in Z, s \in S \qquad (1.28)$$

$$\delta^{run}_{d,y,t,s} + \delta^{end}_{d,y,t,s} \leq 1, \forall d \in D^R, y \in Y, t \in Z, s \in S \qquad (1.29)$$

$$\sum_{\tau=t+1}^{t+D^{max}_{f,y}} \delta^{end}_{d,y,t,s} \geq \delta^{start}_{d,y,t,s}, \forall d \in D^R, y \in Y, t \in Z, s \in S \qquad (1.30)$$

$$\sum_{t \in T} \delta^{start}_{d,y,t,s} \leq B^{max}_{d,y}, \forall d \in D^R, y \in Y, t \in Z, s \in S \qquad (1.31)$$

$$\delta^{end}_{d,y,t} + \sum_{\tau=t}^{t+D^{min}_{d,y}} \delta^{start}_{d,y,t} \leq 1, \forall d \in D^R, y \in Y, t \in Z \qquad (1.32)$$

$$_{,t,s} \leq U^{max}_{d,y} \cdot P_{d,y,t} \cdot (\delta^{start}_{d,y,t,s} + \delta^{run}_{d,y,t,s} + \delta^{end}_{d,y,t,s}), \forall d \in D, y \in Y, t \in Z, s \in S \qquad (1.33)$$

$$\sum_{T^{start}_{d,y,g,s}}^{T^{end}_{d,y,g,s}} \omega_{d,y,t,s} = Y_{d,y,t}, \forall d \in D^S, y \in Y, t \in T, g \in G, s \in S \qquad (1.34)$$

$$\omega_{d,y,t,s} \leq E^{max}_{d,y}, \forall d \in D, y \in Y, t \in T, s \in S \qquad (1.35)$$

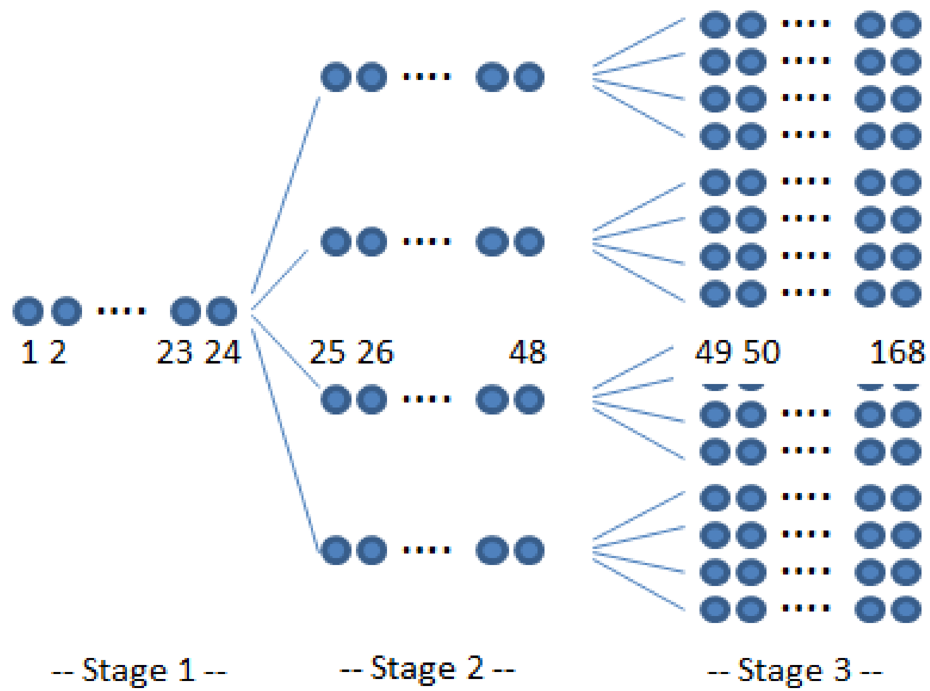
$$\omega_{d,y,t,s} \geq E^{min}_{d,y,t}, \forall d \in D, y \in Y, t \in T, s \in S \qquad (1.36)$$

$$\sum_{\tau=T^{start}-t^{start}}^{T^{end}-t^{end}} \gamma_{d,y,g,\tau,s} = 1, \forall d \in D^{SP}, y \in Y, g \in G, s \in S \qquad (1.40)$$

$$w_{d,y,t,s} = \sum_{i=0}^{T^{end}-T^{start}} (\gamma_{d,y,g,(t-T^{start}-i),s} \cdot W_{(T^{start}+i)}), \forall s \in D^{SP}, y \in Y, t \in \{T^{start}, T^{end}\}, s \in S \qquad (1.41)$$

Uncertainty

- Uncertain parameters: Prices, loads, wind speed, solar radiation
- Uncertainty handled by stochastic programming
- Uncertain parameters handled through scenario trees



Status and next steps

- Mathematical model is implemented in FICO Mosel Xpress optimization suite – now in test
- Case study will be performed based on one of Statsbygg's buildings (college building in Halden)
- To be published in international journal (1st paper in PhD) (hopefully ☺)

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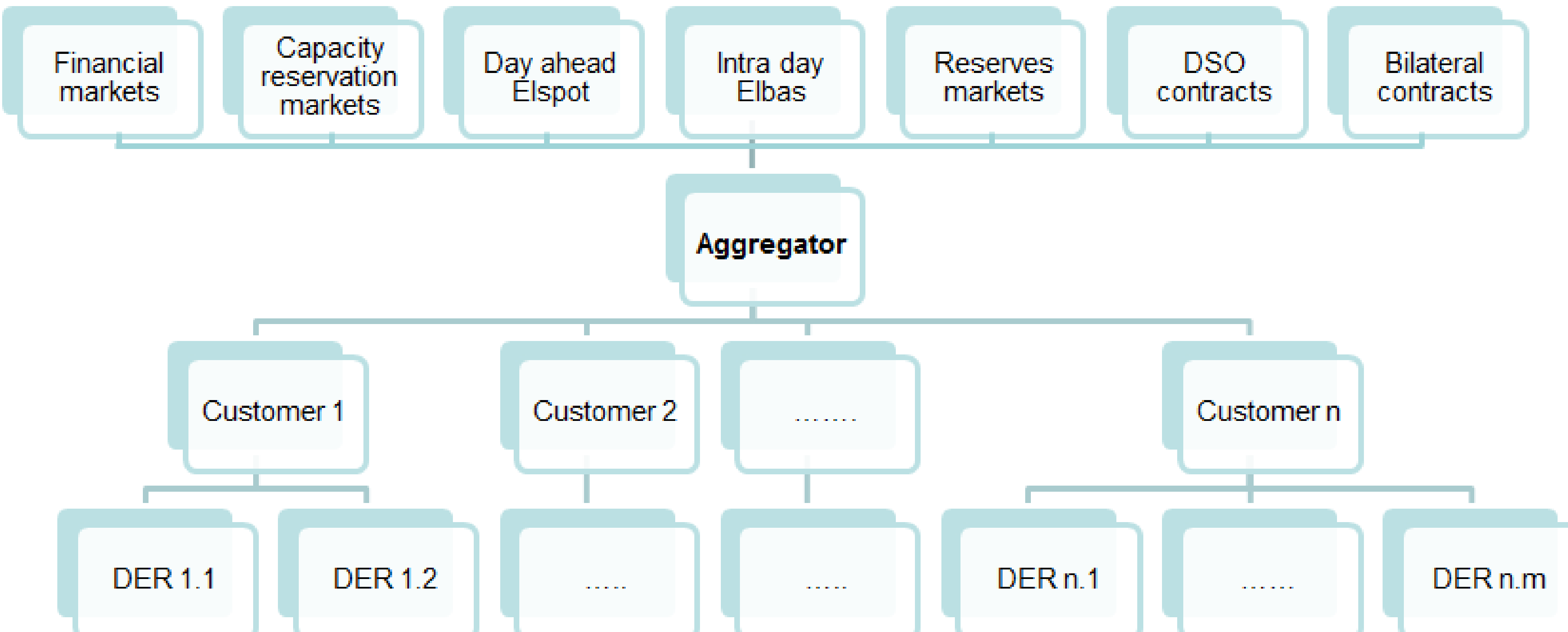
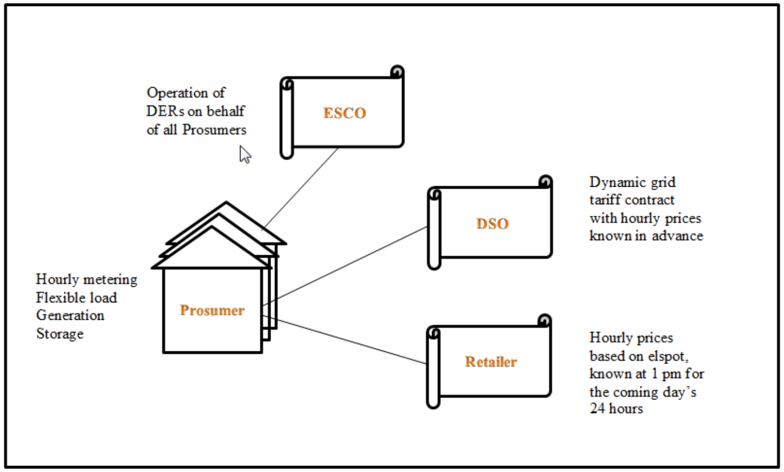
Research focus 2 - The aggregator portfolio management problem

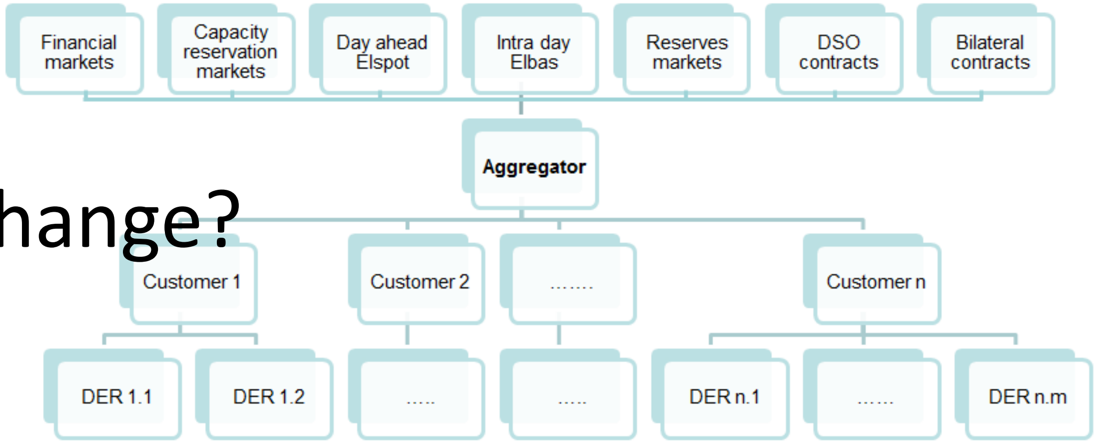
- Active participation in the market (wholesale side)
- Aggregation, shorter term, portfolio optimization



Research focus 3 - Cooperation contracts in the SmartGrid value chain

- Efficient profit and risk sharing between aggregator and prosumers
- Also between aggregator and market
- And between the DSO/ power supplier and prosumer
- Will existing roles change?





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Summary

- SmartGrids contain a lot of technology
- May contribute with benefits to the system, market, actors and consumers
- Existing incentives weak, new innovative offerings (from new market roles) needed
- Holistic and inter-disciplinary thinking needed
- New knowledge and models needed

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Thank you for your attention

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