Optimal scheduling of demand side flexible units under uncertainty in SmartGrids

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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

Presentation outline

- Intro – SmartGrids and flexibility
- Optimization model
- Case study
- Future research

SmartGrid intro

- Active interaction between smart prosumers and energy system/market to create benefits in the value chain
- Demand side technologies
- Pricing regimes, business models
- Demand side flexibility

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Increasing need for demand side flexibility

- Integration of renewable generation
  - Intermittent
  - Non dispatchable
  - Difficult to predict

- Integration of electrical vehicles
- In general more dynamics in the distribution grid

- This flexibility exists at distribution level

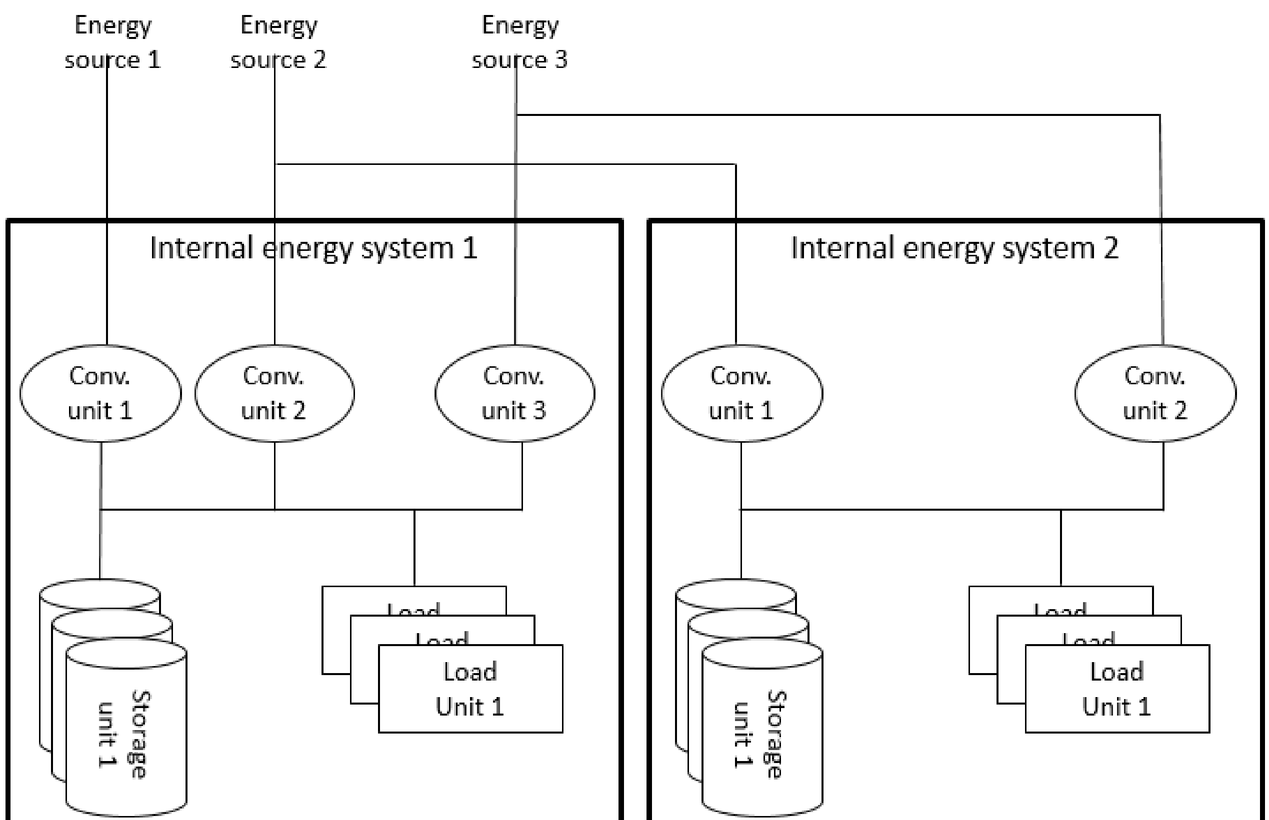
Our problem

- Smart prosumer (building with flexible energy resources (loads, generation/conversion, storage))
- El-prices that vary as a function of time and/or volume
- Participation in the end-user market

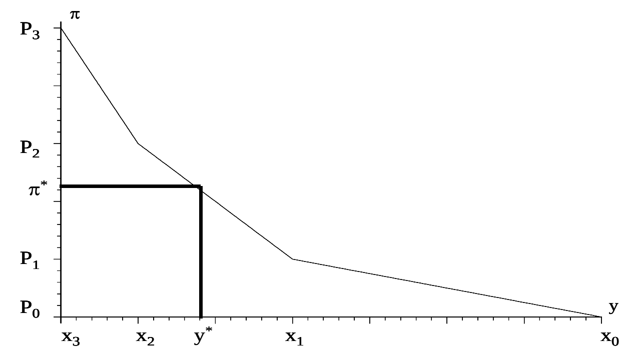
- **How to decide a short term (day ahead) <u>optimal schedule</u> for the flexible resources?**
- Need a general **<u>model</u>** that minimizes total costs with respect to
  - Technical, comfort and economical constraints
  - All information is not known at the decision point

Internal energy systems

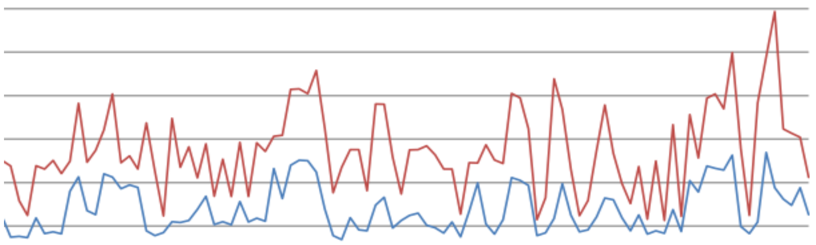
- Incentives from electricity prices
- Flexibility from interaction between electrical and thermal system (needs and appliances)

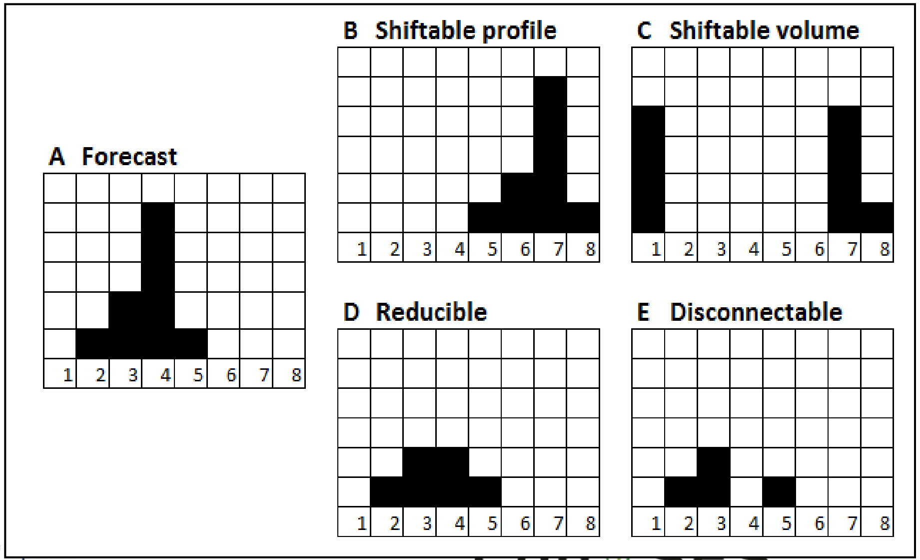


How to model loads?



- Flexibility model must reflect underlying physical system
- Must find an appropriate detail level
- Split into
  - Shiftable
  - Curtailable
  - Inflexible
- Parameters for when, how long, how often….





Optimization model

- Objective: Minimize expected total costs

$$\min z = \sum_{s \in S} R_s \cdot \left[\sum_{a \in A} \sum_{t \in T} P_{a,t,s}^{energy} \chi_{a,t,s}^{net-in} + \sum_{a \in A} P_a^{cap} \chi_{a,s}^{cap} + \sum_{y \in Y} \sum_{o \in O} \sum_{t \in T} \alpha_{o,y,t,s}^{start} G_{y,o}^{startup} + \sum_{d \in D^C} \sum_{y \in Y} \sum_{t \in T} X_{d,y} \varphi_{d,y,t,s} - \sum_{a \in A} \sum_{t \in T} P_{a,t}^{sales} \chi_{a,t,s}^{net-out} \right]$$

- Subject to:
  - Energy carrier constraints
  - Converter constraints
  - Storage constraints
  - Load constraints
  - Energy system balances
- Stochastisk mixed integer problem (SMIP)

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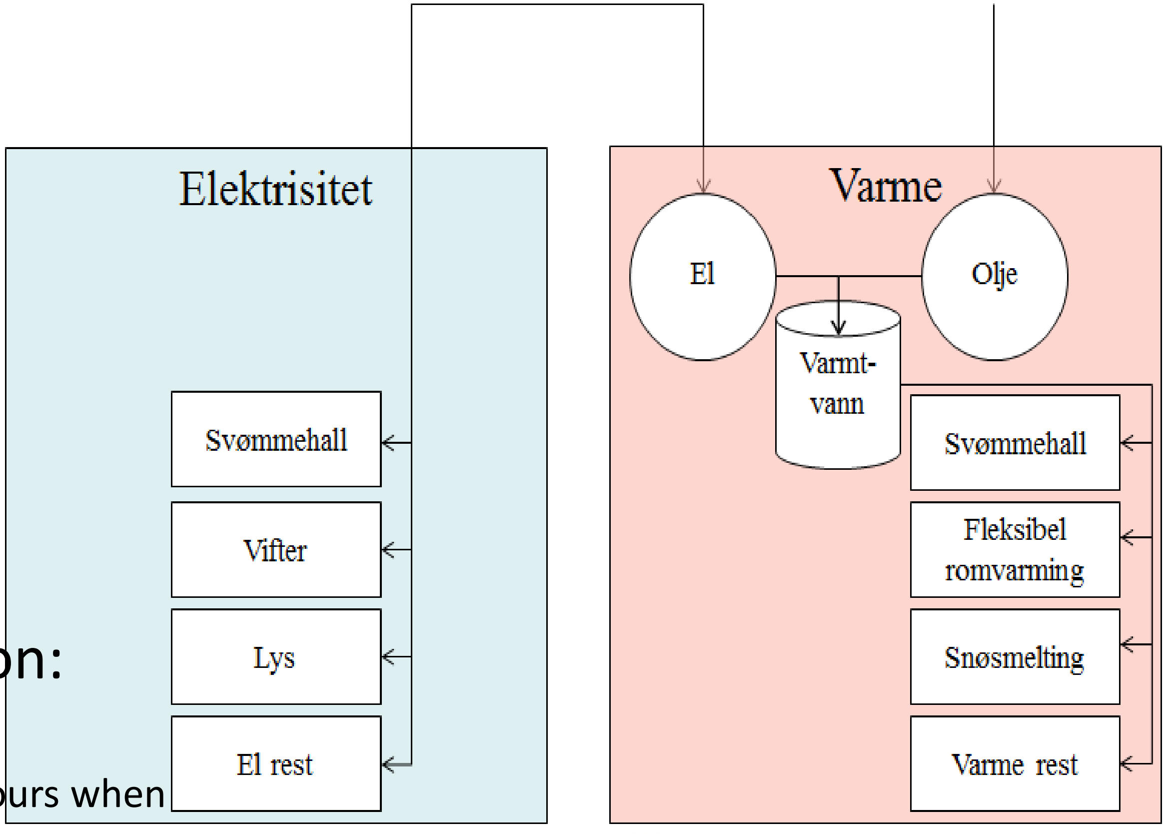
Case-study

- Matematical model defined and implemented in Xpress
- Case-study performed based on university college building in Halden – in close cooperation with Statsbygg

Energy system model

- Flexible loads:
  - Shiftable volume
    - Swin area: whole day
    - Room: 2 and 2 hours
  - Shiftable profile
    - Snow melting (4 hours)
  - Curtailable
    - Lights. 20% dimmed
- Heat storage:
    - 37 kWh, maks 10 kW
- Energy carrier substitution:
    - Can change any time
    - Must run for minimum 4 hours when started
    - Small startup-cost



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Load forecasting model

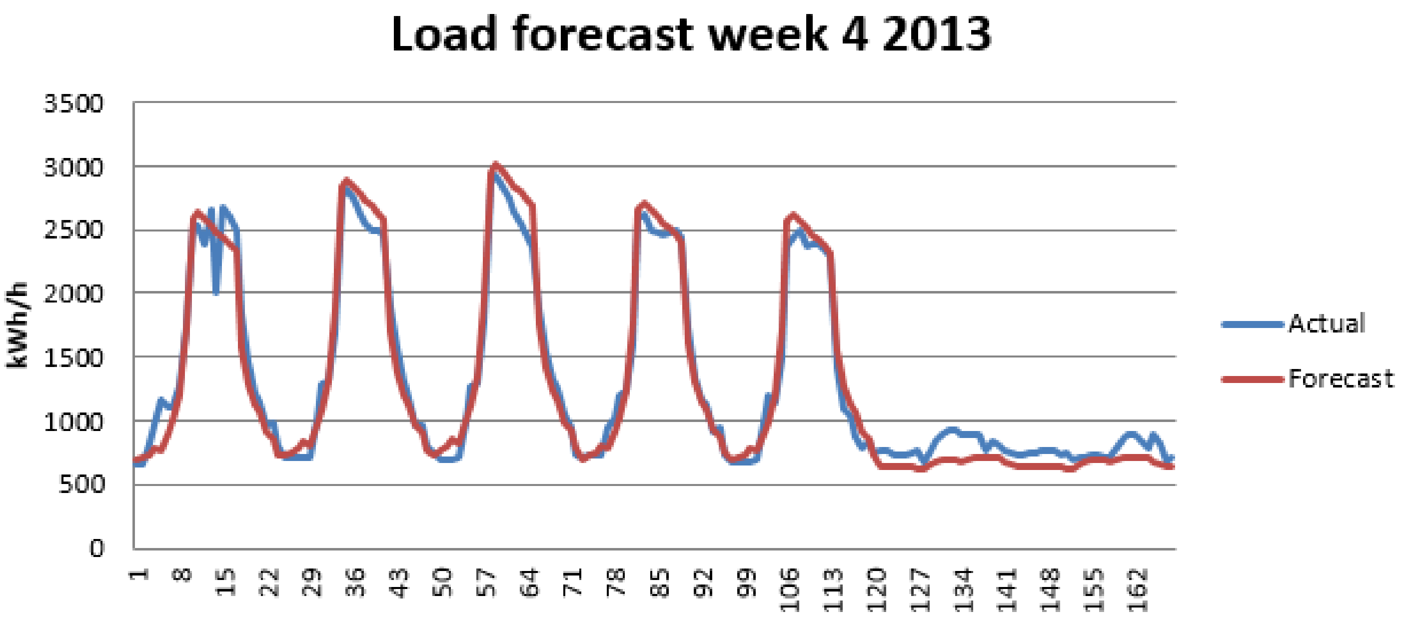
- At decision time load is not known - need a load forecast
- Model based on multiple linear regression with exogenous explanatory variables
- Load can be explained by hour of the day, whether workday or not, out-door temperature and month

$$L_t = \mu + \sum_{h=1}^{24} \alpha_h^{workday} D_{t,h}^{hour} D_t^{workday} + \sum_{h=1}^{24} \beta_h^{workday} D_{t,h}^{hour} D_t^{workday} \tau_t + \sum_{h=1}^{24} \alpha_h^{nonworkday} D_{t,h}^{hour} D_t^{nonworkday} +$$

$$\sum_{h=1}^{24} \beta_h^{nonworkday} D_{t,h}^{hour} D_t^{nonworkday} \tau_t + \sum_{m=1}^{12} \gamma_m D_{t,m}^{month} + \varepsilon_t \qquad \forall t \in T$$

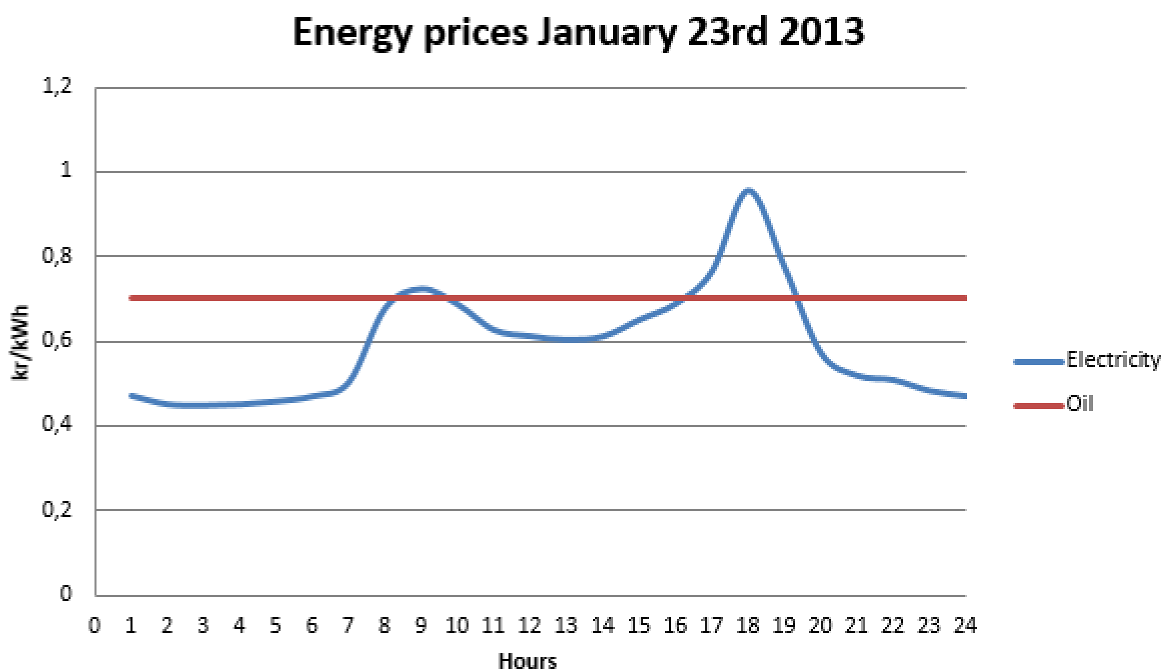
Load forecasting

- Model calibrated (least squares) based on historic load (8 months 2012)
- R^2 = 0,94, mean residual = 0 each month
- Load forecast generated for scheduling day



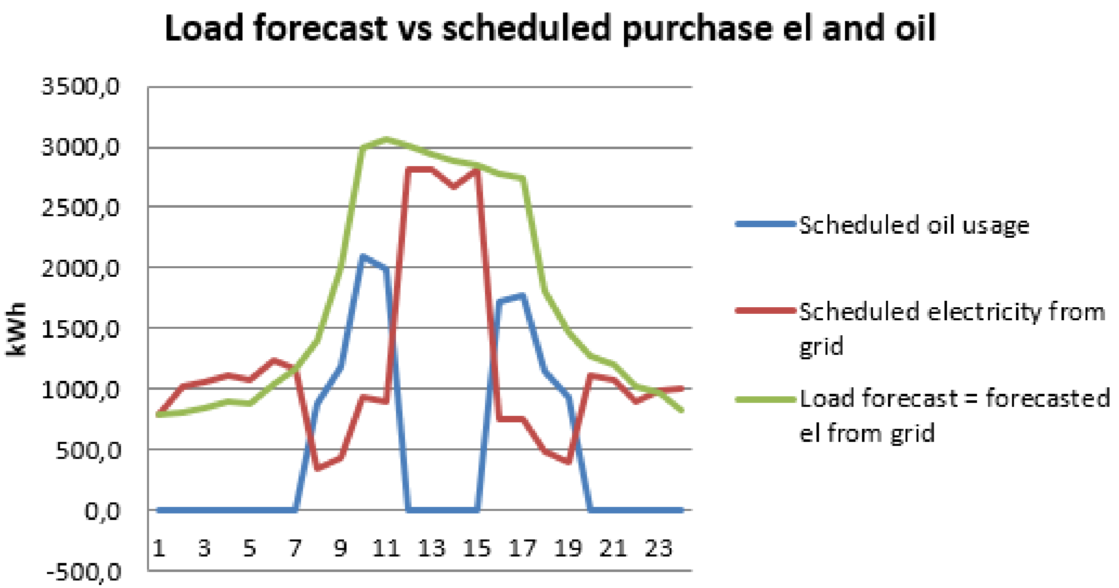
Day, contracts and prices

- Case run for a cold winter day: January 23rd 2013
- El supply contract based on elspot price hour by hour
- Grid contract based on DSO Fortum standard contract: 18,51 øre/kWh, 57 kr/kW/month
- Peak el up to Jan 22nd: 2.821 kW



Case study main results

- Target: Decide schedule for all flexible units (el/oil converter, storage, shiftable/curtailable load units)
- Flexibility used to exploit:
  - El-price variations during the day
  - Price variations between el and oil
  - To reduce peak electricity



- Net cost saving compared to no flexibility:
  - 1.000 kr energy
  - 11.000 kr peak

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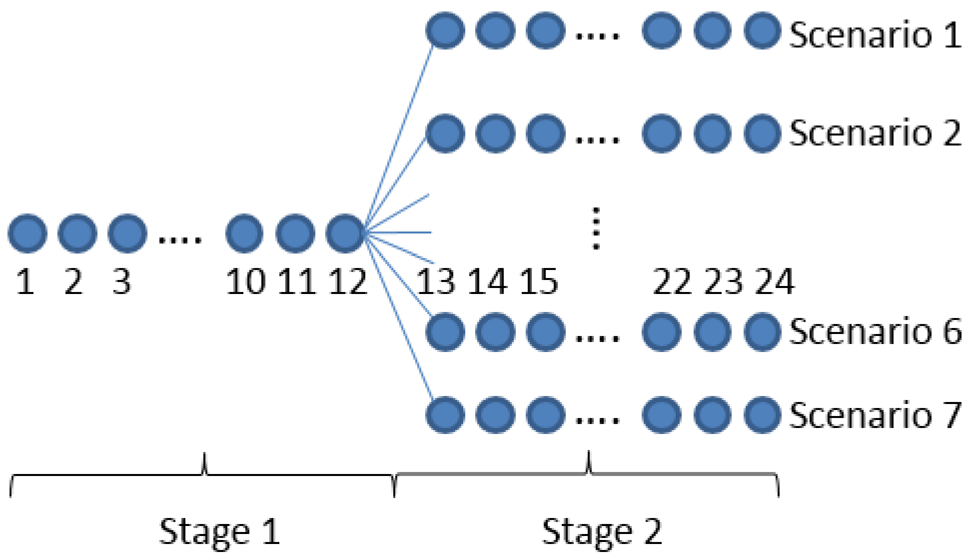
Uncertainty

- Have assumed all parameters known with certainty
- Real load in not known until end of each hour.
- Becomes more certain the closer we get
- Simplification
  - Assume everything certain for first half day
  - In the end of hour 12 real load becomes known for the rest (hour 13 – 24)



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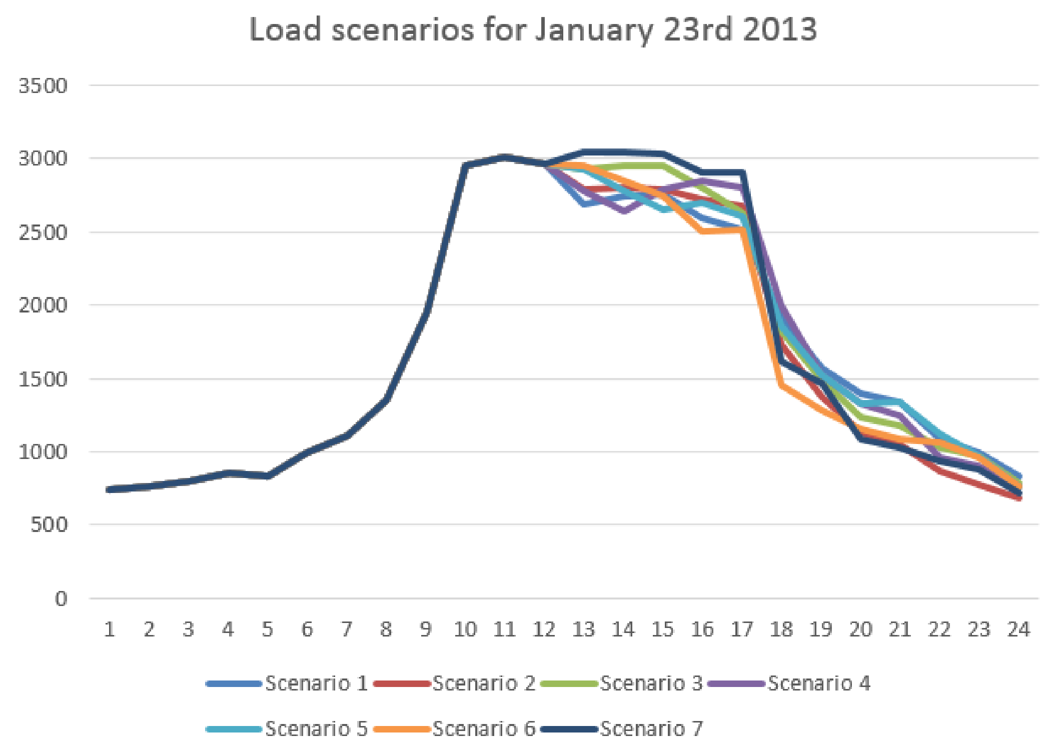
Scenario generation

- 7 load scenarios based on load forecast for actual day + sampled residuals
- Residuals strongly auto correlated – sample day randomly and take whole series (hour 13 – 24)
- Repeat until mean residual ≈ 0

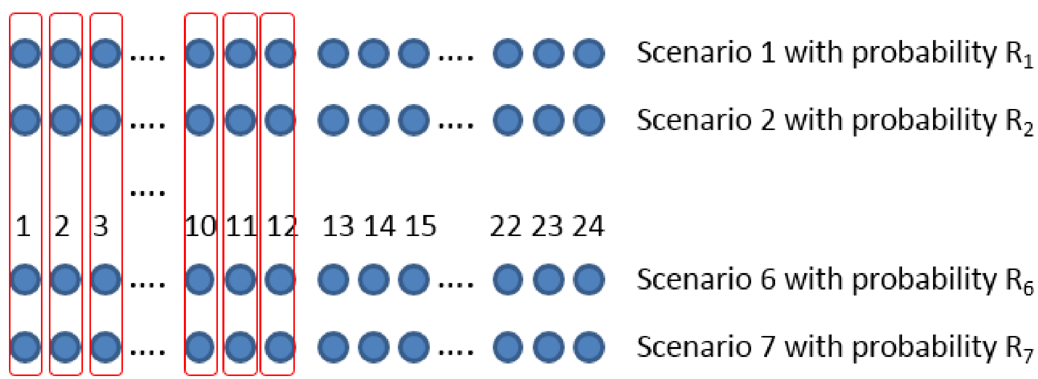


2-stage model with recourse

- Minimize expected total costs
- 1st stage decision: Flexibility schedule for hour 1 – 12
- 2nd stage (recourse) action: Select second stage decision (flexibility schedule) when realized scenario is known

$$
\begin{aligned}
\text{Min} \quad & cx + E[h(x,\tilde{\omega})] \\
\text{s.t.} \quad & Ax \geq b \\
& x \geq 0
\end{aligned}
$$

$$
\text{where} \quad h(x,\omega) = \text{Min} \quad g_\omega y \qquad \text{s.t.} \quad W_\omega y \geq r_\omega - T_\omega x, \quad y \geq 0.
$$



Stochastic solution

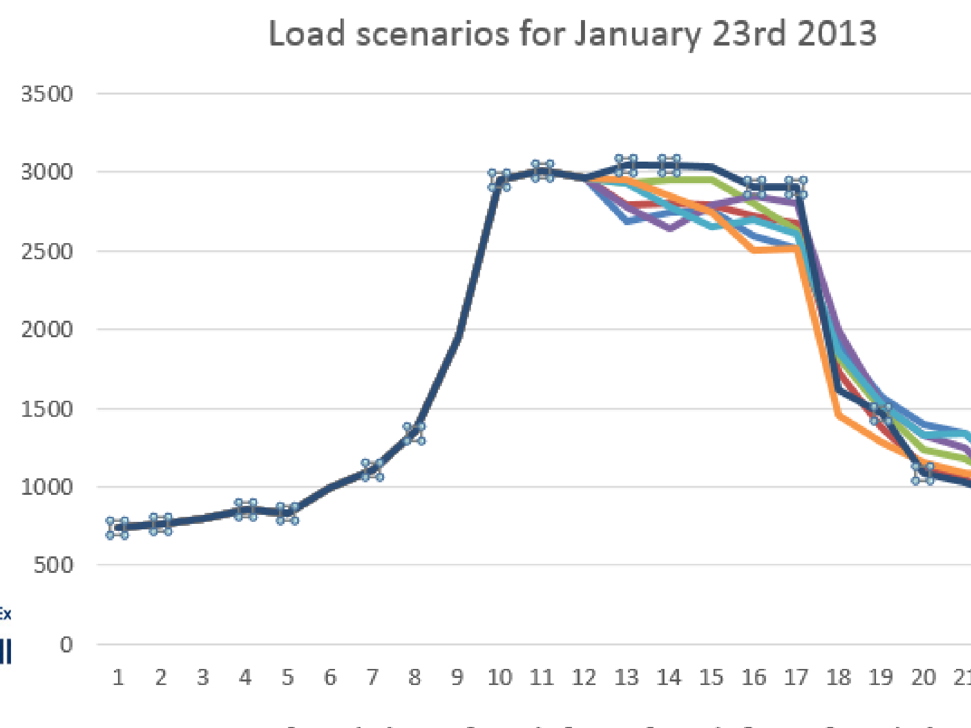
- We get one solution for stage 1 and 7 solutions for stage 2
- Stochastic solution different from deterministic also in stage 1, mainly in the el/oil decision

Type	**Obj. func. value**	**1-7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21-24**
Deterministic	25001	**E**	**O**	**O**	**O**	**O**	**E**	**E**	**E**	**E**	**O**	**O**	**O**	**O**	**E**	**E**
Stochastic	25085	**E**	**E**	**O**	**O**	**O**	**O**	**D**	**D**	**D**	**D**	**O**	**O**	**O**	**O**	**E**

Stochastic vs deterministic solution

Type	Obj. func. value	1-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21-24
Deterministic	25001	E	O	O	O	O	E	E	E	E	O	O	O	O	E	E
Stochastisk	25085	E	E	O	O	O	O	D	D	D	D	O	O	O	O	E

- What if we implement deterministic solution for hours 1 – 12 (1st stage) and then replan?
- Det. decides to startup el-boiler in hour 12 – must run for at least 4 hours
- Earliest next startup for oil is hour 16
- Scenario 7 has new max load in 13, 14 and 15



What if we implement deterministic solution in stage 1?

- In stage 2 we can not start up oil converter in 13, 14 or 15 – have lost flexibility in the decision process
- Scenario 7 will give new peak = 2.917 kW
- Added cost scenario 7: (2.917 – 2.821)*57 = 5.472 kr
- Expected cost of ignoring uncertainty: 782 kr = Value of stochastic solution (VSS)

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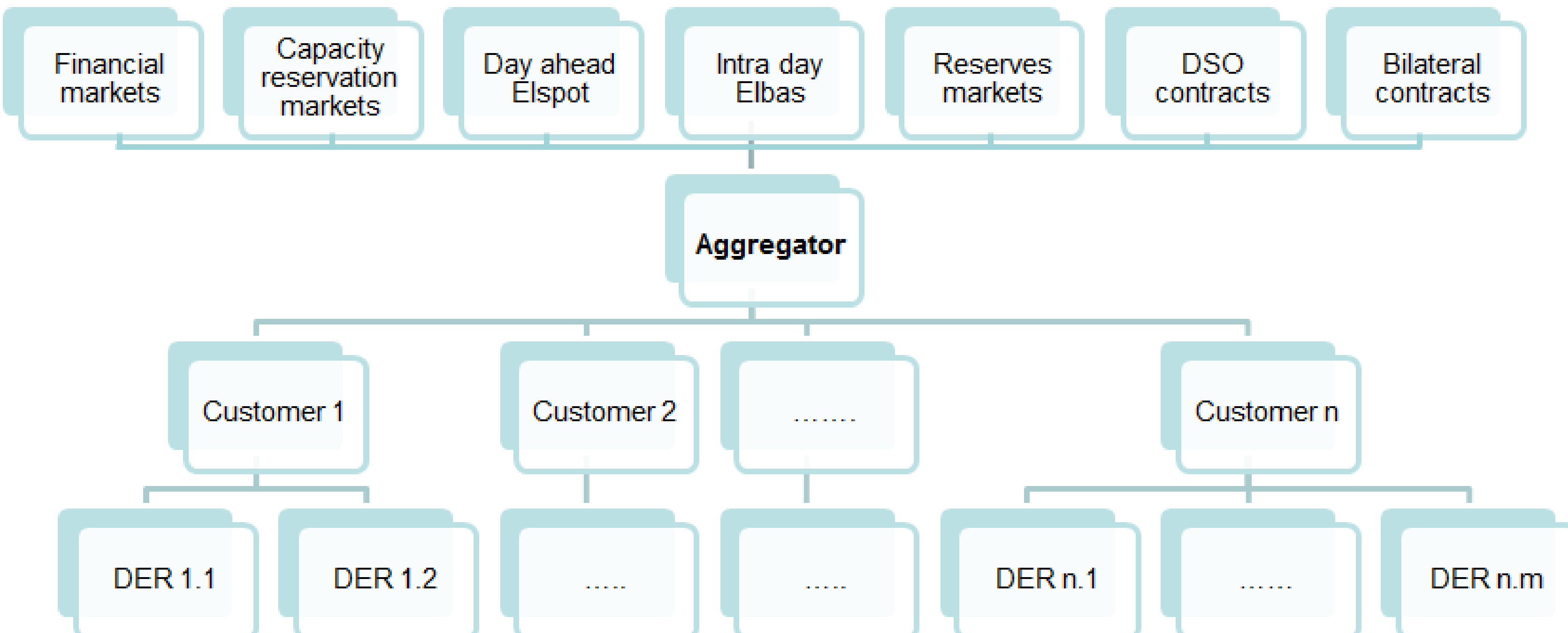
Discussion

- Concept model described
- Quantification of real cost reduction potential:
  - Flexibility parameters must be properly estimated
  - Run model over larger period
  - Rolling planning horizon
  - What happens in real life (none of the scenarios realize)
  - Rather simplified stage model and scenario generation method
- Selected one single day, high load (monthly peak) and large price variations
- Current incentives in Norway weak – stronger in other countries
- Type of contract crucial

Further work

- Aggregation and wholesale market participation
- Optimal bidding and allocation between contracts and markets
- Supply chain optimization and contract design



Thank you for your attention

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