WP 3.2
Control Architecture of Future Power Systems

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CEESA meeting Aalborg January 2010

Centre for Electric Technology

DTU Elektro

Upcoming report:

Toward Control Architecture for 100% Renewable Energy Systems

Introduction and Application of Functional Modeling for Scenario Analysis and Design

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Outline of Report.

1. **Introduction: Scenarios as representations**
2. **Representation in Functional Models**
   1. **Means and Ends**
   2. **Thinking Functional**
   3. **Representing Control Levels (time scales, system topology)**
3. **Adding Wind to the System**
   1. **Option 1 ”just add it”**
   2. **Option 2, etc, local balancing, coupled balancing, common market**
4. **Formulating Requirements from Functional Models**
5. **Conclusions**
   (implications for scenario development)

Technical Feasibility as a design question

(1) “Can it be done?”

requires to answer:

(2) “How would it be done?”

a) as we always did? → go, simulate!

b) Different? Well then - how?

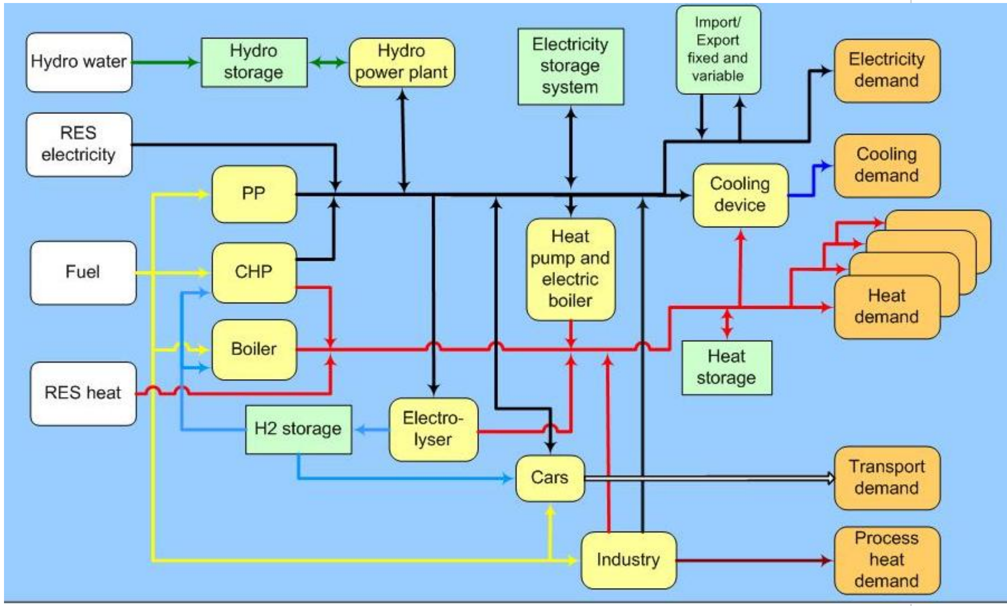
In other words:

Technical feasibility is first of all
a question of technical design.

!

Representation in Scenario Models

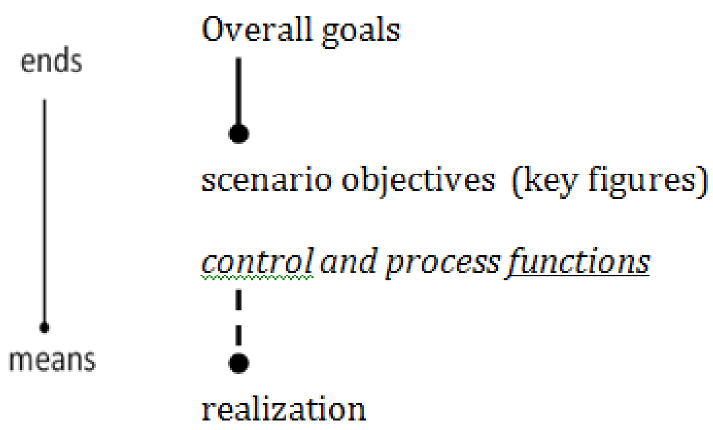
- A scenario model is based on *implicit representations* of functions (operational principles and practices)
- The use of physical units (energy, power) does not mean that we are just representing ”physics”
  → energy flow *functions*

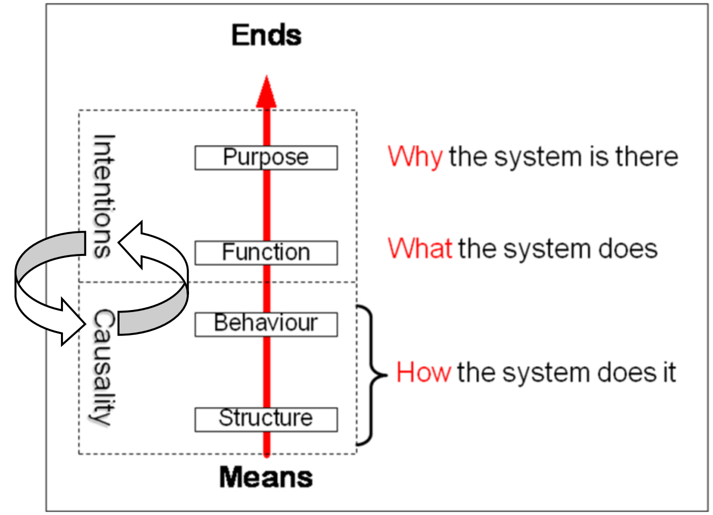


EnergyPlan scenario tool overview.
http://energy.plan.aau.dk/

- Control functions are often overlooked, or assumed to be ”the equations” (and yes, that is where they are *hiding*! ☺)

Means-Ends and Functions in Scenarios





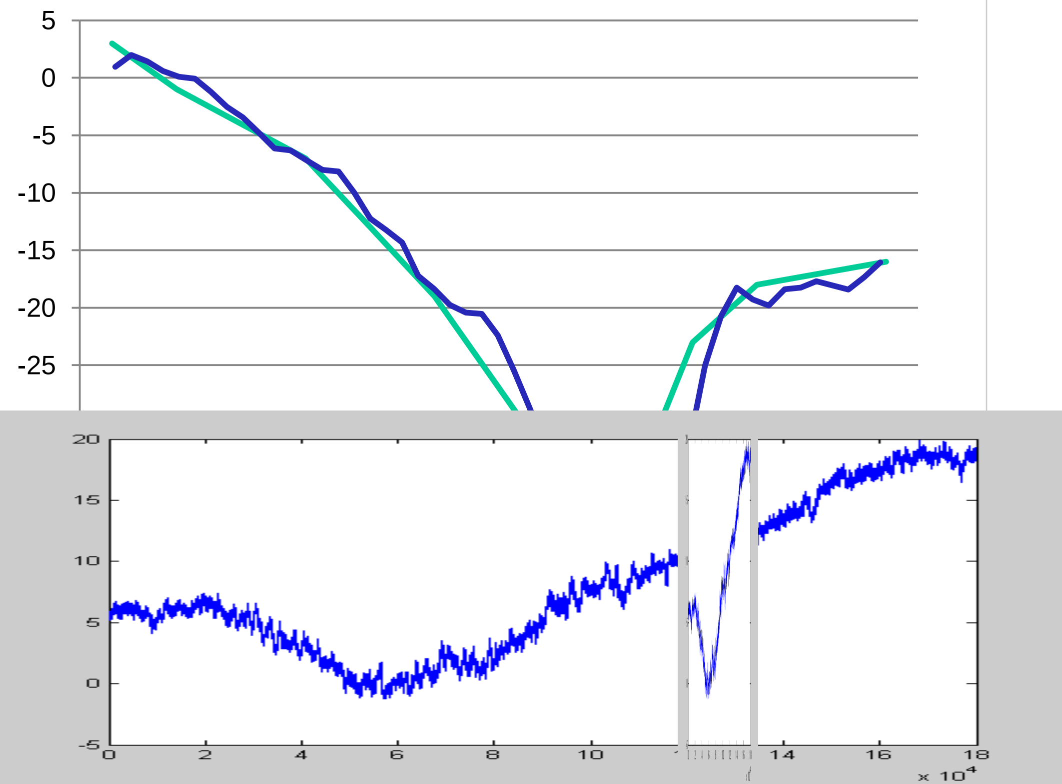
- Instead of talking about ”the physical system”, talk about the ***system-in-view***
- the *system-in view* is (multi-layered): different behavioural and functional models apply for each layer.

Reminder:
– ”What happens within the hour?”

- 12hours:
  - 1h vs 15min

- 1h with higher resolution

  ... As the output of a larger windfarm



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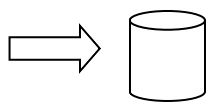
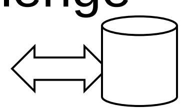
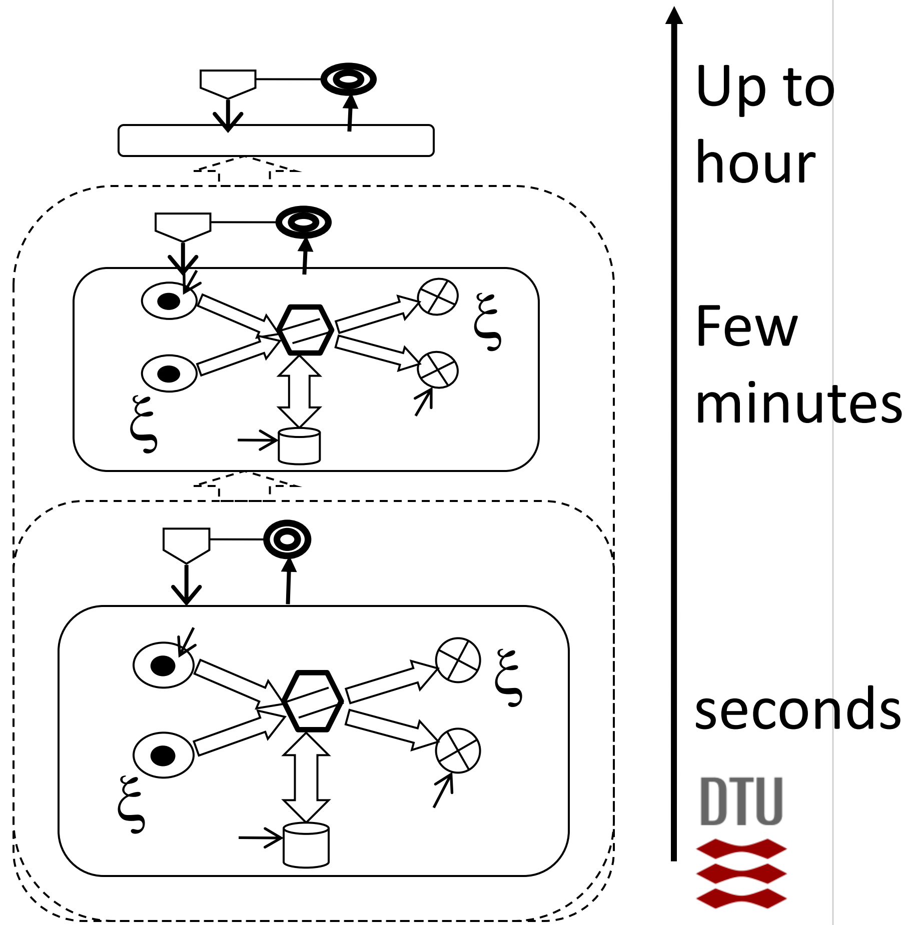
Storage and Fluctuation :
Control-Agents,Counter-Agents, Time Scales

- Uncertainty and variatbility (ξ) are controlled, and thus encapsulated, control layer by control layer
- The means used by control systems needs to be considered in two dimensions: *power* and *energy* (per time scale)



- How to utilize Energy storage is the architecure challenge





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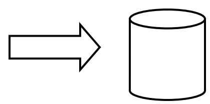

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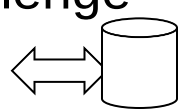

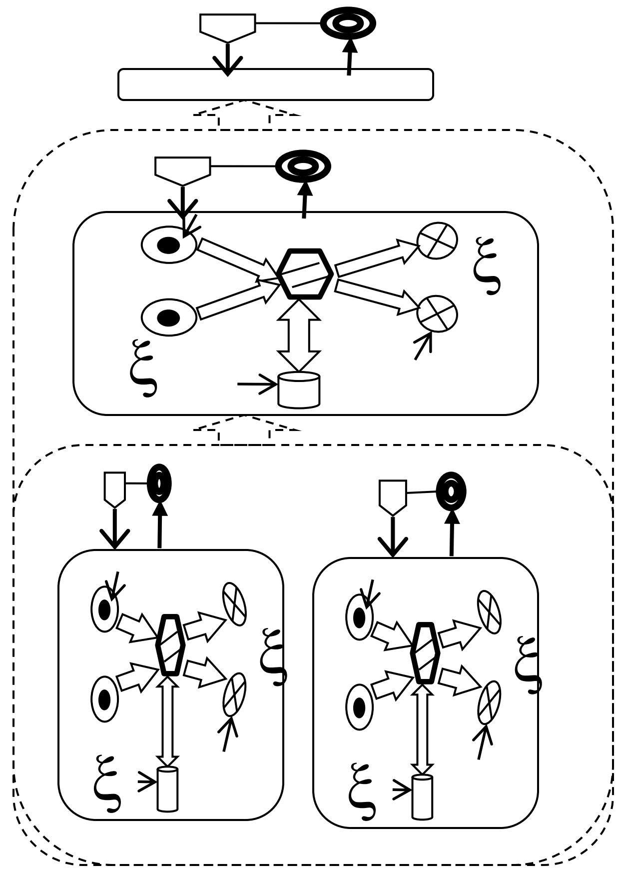

Up to hour

Few minutes

seconds

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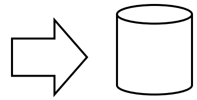

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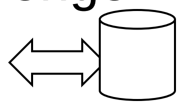

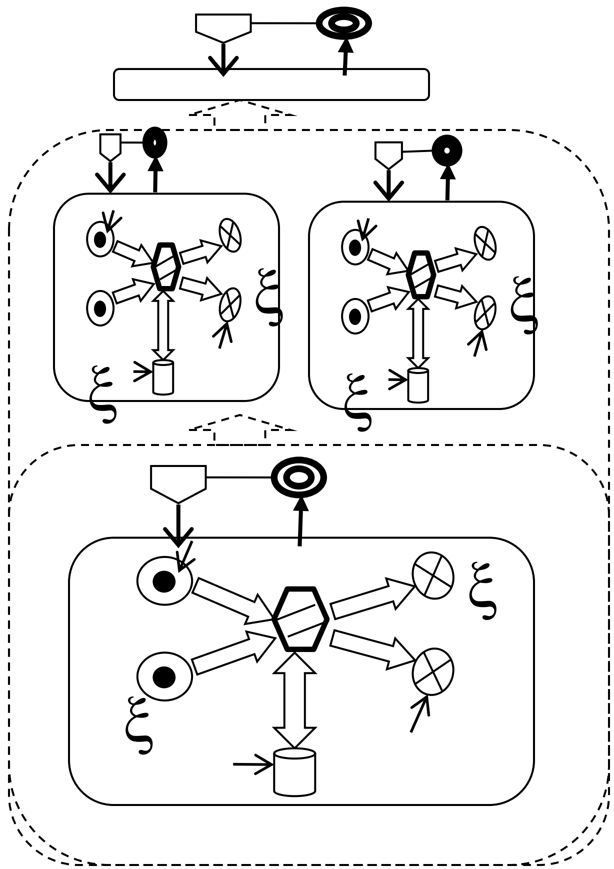

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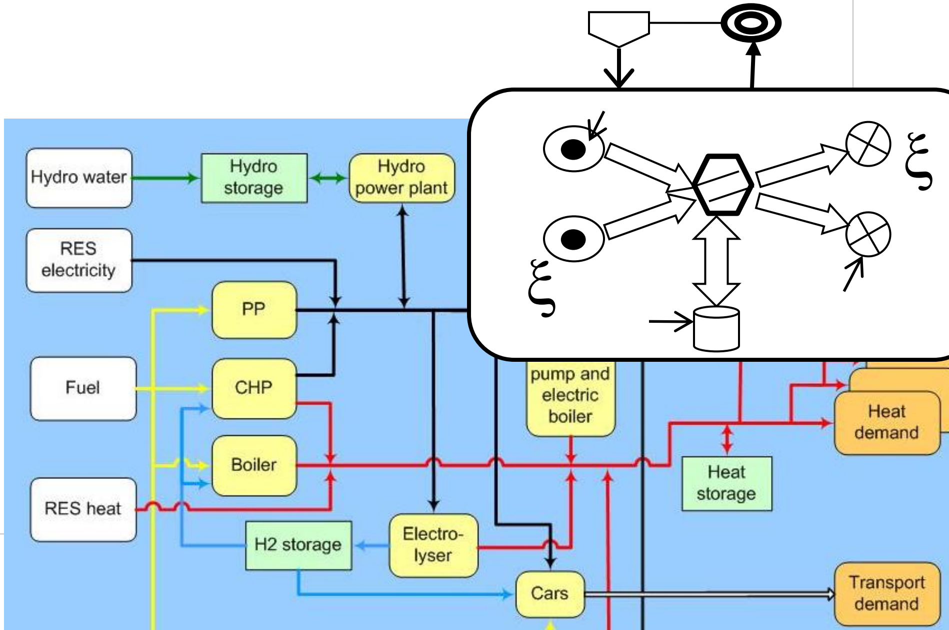
Feasible Scenarios
– contribution to scenario modeling

- Scenarios are modeled on understanding of current energy systems
- Granularity of scenarios makes then reasonably accurate
- Regulation options can be structured and control features integrated with technology options
- Possible suggestions for careful revision of control models

- ...later.



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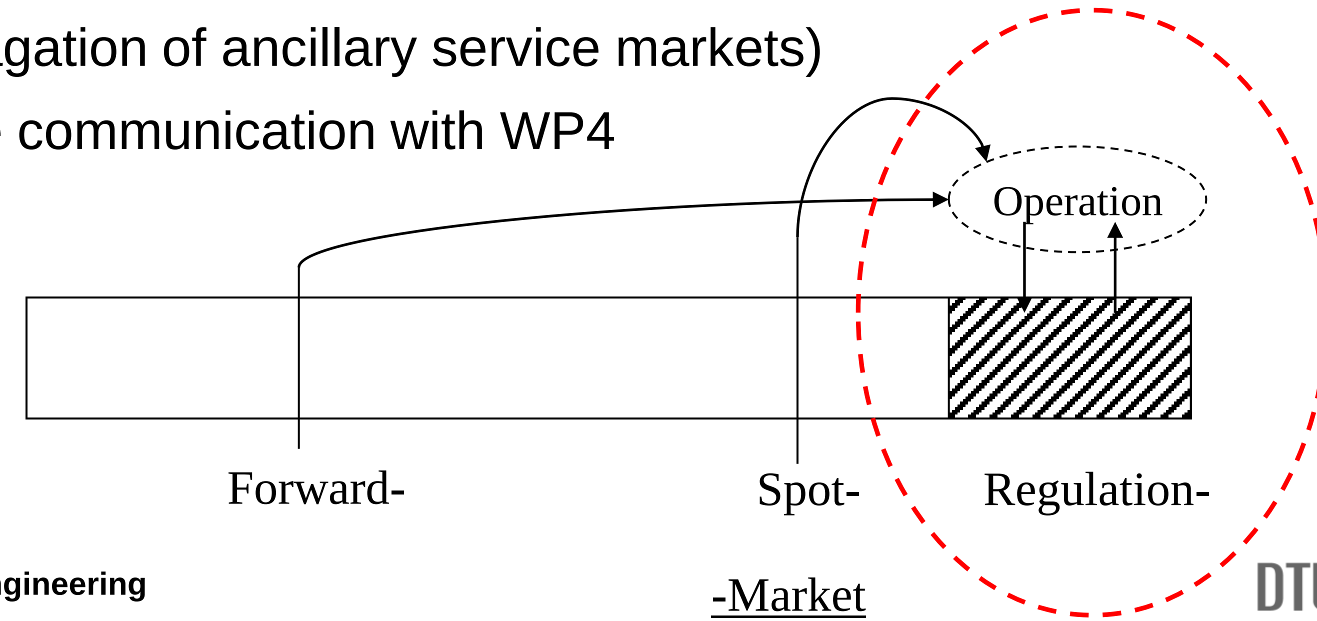
Other research outputs:
Connecting to Value-exchange (markets)

- Next stay abroad: research in modelling service exchange for household appliances control.
- Connection of control models with service models.
- (Investiagation of ancillary service markets)
- Possible communication with WP4



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Thanks for your Attention!

Questions? Welcome!

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Planned CEESA related output (decided after meeting)

- *Articles*
  - <u>Study on Electric Vehicle contribution to system stability</u>
    - WP 3.1 & 3.2 joint article
    - ”Electrical Island mode”
      - Bornholm as example
    - ”Interconnected mode”
      - West-Denmark as example
      - Setpoints with and without market schedule (*maybe*)
  - <u>Functional Modeling for Scenario Analysis </u>(based on report presented)
  - (<u>Study case on altenative control architectures. </u>)
- Recommendations/requirements to WP 4.

Backup-slides

ANALYSIS
(PRESENTED IN VEJLE)

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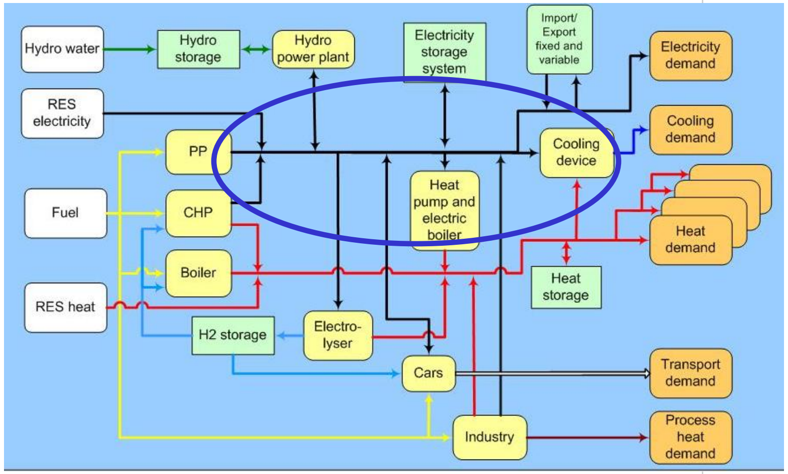
Three (Electrical) “Blind Spots”

- Time Resolution
  - ”What happens within the hour?”
  - → Fluctuations and balancing
- Granulation & spatial distribution
  - Big central or distributed generation?
  - Placement
  - → transmission capacities
- The future is uncertain! How to prepare?
  - E.g. Uncertainty of wind power prediction
  - → Market Design
  - → Control Architecture



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(1) Time Resolution
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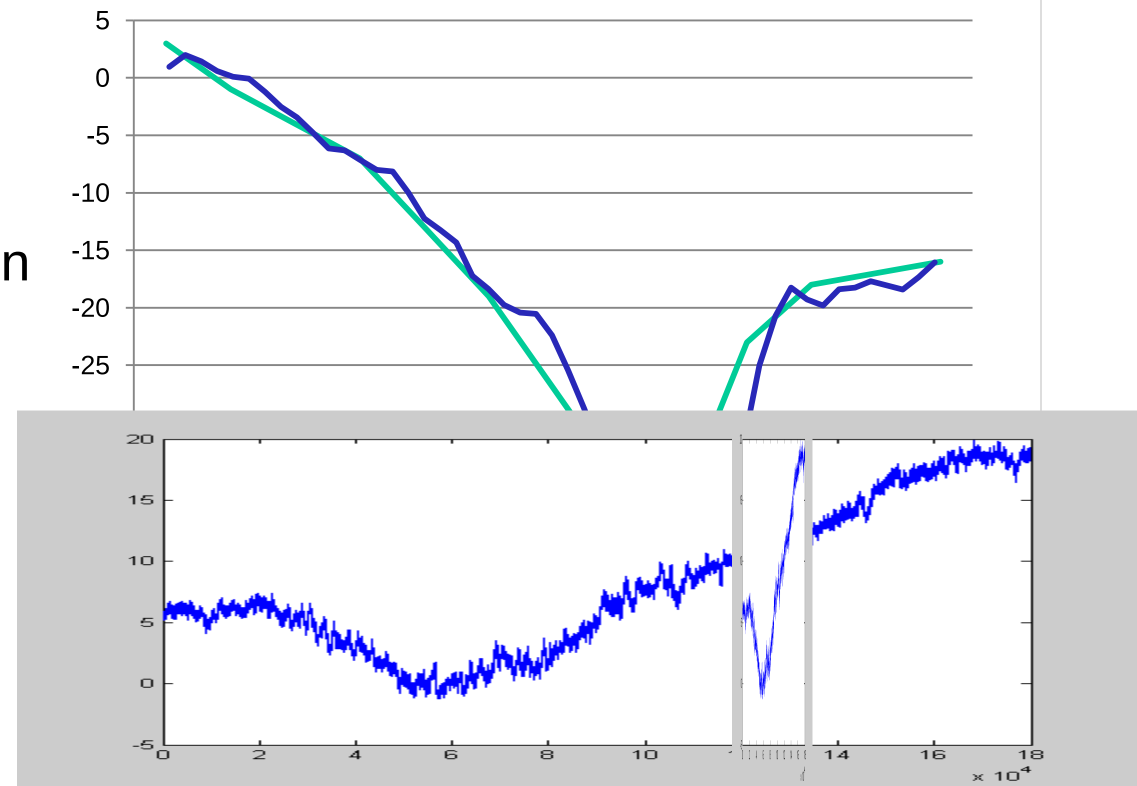
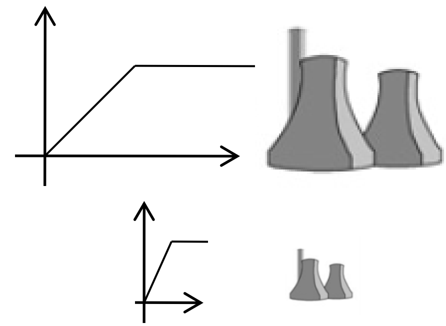


(2) Granulation & spatial resolution

- The ramping capability of a generation unit is proportional to its size
  - Big units with inertia make ”friendly” (slow, controllable)
  - Small units make it more flexible but difficult to control



- Big central or distributed generation?
  → Ramping / Flexibility
- But also: Location
  - Will you balance wind power locally?

  → transmission capacities

(3) Dealing with uncertain future ...

- Next *day / hour / minute / second*
- ”benefit -of-hindsight” used in EnergyPlan
  - Yearly distribution is optimally utilized with storage

- Following a plan under uncertainty when operating
  - <u>Uncertainty of forecast cannot be eliminated!</u>
  - prepare for the uncertain.

→What Can be known? (Theoretical limits?)
→ Allocation of balancing resources (Markets)
→ Connection of control architecture and short-term markets

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***Addendum*:**

dialogue *hypothetical & from the minutes*

Slide presented at Ballerup meeting:

System Analyst: Here's the Scenario. Is it feasible?

Engineer: Looks difficult --- Let me try! ...
... Hmmm, not with given technology

SA: It's ok, you don't have to invent the whole system. I just want to know if it *would* be feasible.

E: (puzzled) What do you mean? I mean, how can I simulate a system that I don't know.

<u>In Engineering, system design comes before feasibility.</u>

From the minutes of Ballerup meeting:

- **Henrik Lund:** We need to know from the WP if it can be done?
- **Kai Heussen:** It probably can be done.
- **Henrik Lund:** Can you be certain it can be done?
- **Poul Erik Morthorst:** We should state what is required in order for the system to work.
- **Henrik Wenzel:** Different percentage numbers between minimum and maximum should be included
- <u>Main conclusion:</u>
  Electric vehicles are important for our scenarios.

section II

ACTIVITIES IN WP3(.2)

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What is in the scenarios? (IDA 2030 / *2050*)

A. Central Generation

- Replace future power […] by fuel cell CHP plants, equal to 35-40 per cent of total power plants in 2030, (individual house heating →district heating CHP)
- Introduce 450 MWe large heat pumps
- *Replace all CHP and power plants by fuel cell-based or biogas or biomass gasification*

B. Renewable Electricity (uncontrolled)

- Increase wind power
  3000 MW to 6000 MW in 2030
  onshore@3000MW, 3000MW offshore)
- 500 MW wave; 700 MW PV
- *Increase wave power to 1000 MW*
- *Wind power (all offshore)*
  IDA2050: 7000MW //
  IDA2050Biomass: 3000MW //
  IDA2050Wind: 12000MW

C. (controllable) Distributed Generation

- Replace natural gas boilers by microCHP, ~10 per cent of house heating
- *Convert micro CHP systems from natural gas to hydrogen*

D. Electricity Demand Reduction

- … by 50 per cent in private households
- …by 30 per cent in industry

E. (controllable) Demand flexibility

- Flexible electricity demand in order to integrate wind power and CHP better in the energy system. (quantification?)
- *3TWh of industrial heat from heat pumps*

F. Transportation – V2G

- 20 per cent of fuel for road transportation by electricity (and 20 per cent by biofuels)
- *Stabilise the transportation demand at the 2030 level*

Initial comments / Apparent challenges

- The fundamental (frequency-forming) unit of power systems is the *synchronous generator*.
  Introduction of *fuel-cell CHP plants* means to remove stabilizing system inertia.

  →complete replacement of CHP plants by fuel cells seems most radical system change

- All measures are stated with reference to Ref2030 scenario*
  →scenario descriptions are only relative changes.
  A "business as usual" power system model does not exist.
  Further, a power system for the whole of Denmark is not available for us, neither tractable.

Mapping to Electricity perspective

1. Generation Units ← *more renewables, less inertia?*
2. Grid Design ← *transmission network, components?*
3. Balancing Control ← *Intermittency*
    1. Controllability issues
    2. Balancing resources (time scales/ volume)
4. Network Control (Operational stability) ← *Changing flows*
    1. Voltage Control
    2. Distributed inputs
    3. Reactive flows and congestion management
5. (Protection Systems)

Measures / Tech. Areas	A. Central Generation	B. renewable Electricity	C. Distributed Generation	D. Demand reduction	E. Demand Flexibility	F. Transportation	WP3.1	WP3.2
I.	X	x		-	-	-	?	?
i.	X	x	x	?				
II.	X	X		x	X	X	X	X
i.	x	X		?	X	X	X	X
ii.		X	X		X	X		X
III.		x	X	-	X	?	X	x?
i.		x			X		?	x
ii.			X		X		X	x
iii.	X				x	x	x	
IV.	?	?		-	?		X?	?

X – major, x – minor, ? – unclear, - – none

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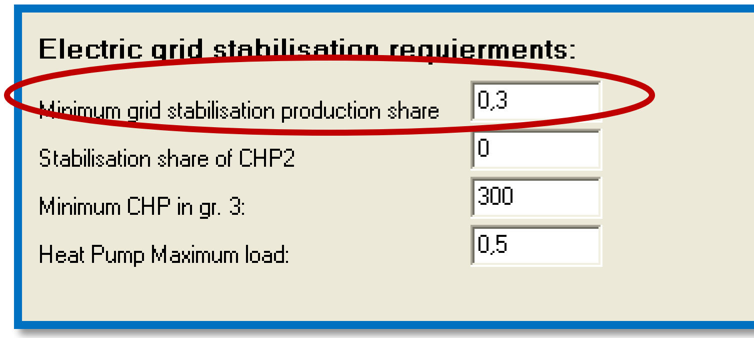
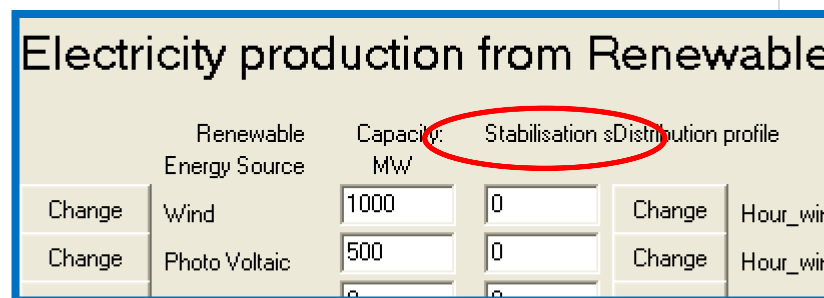
Integration with WP 1 / EnergyPlan

- EnergyPlan adresses some grid requiremnts
- Required *”stabilization share”* (connected large synchronous generation):
  - Estimated 30% according to experience from system operators
  - CEESA calcualtes with 0%
  - *Theoretical minimum* unknown
- stabilizing contribution from renewable energies
  - Possible, to be investigated...





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