

## Evolution of the Danish Energy system + Introduction to energy systems analyses

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## Programme of lecture

- Who are we?
- Plan og Miljø
- Danish energy planning (motives, approach, plans and results)
- The Danish energy system
- Integration of renewable energy into the energy system
- The EnergyPLAN model - example of analysis
- Using the EnergyPLAN model
- After the lecture – exercises with the model

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## Research area

- Inter-disciplinary work on energy planning
- Technical energy systems analyses and GIS analyses of energy systems
- Business-economic and socio-economic analyses of energy systems
- Institutional analyses
- Primary focus is on the production of energy

Situation I  
Business Economy I  
Socio-Economy I  
Market Economy I  
Public Regulation I

Situation II  
Business Economy II  
Market Economy II  
Public Regulation II

Production and Demand (MWh)  
Hour (Relative to midnight August 23 2000)

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## Plan & Miljø

(Planning and Environment – Aménagement et Environnement)

- Five year programme in engineering
- Focus on energy planning, the environment and urban planning
- Candidates with a technological, institutional and economic understanding of the energy/environmental and urban systems
- Three masters' level programmes (two last years) taught in English

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## World primary energy consumption

World Primary Energy Consumption

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## Evolution of the Danish energy demand

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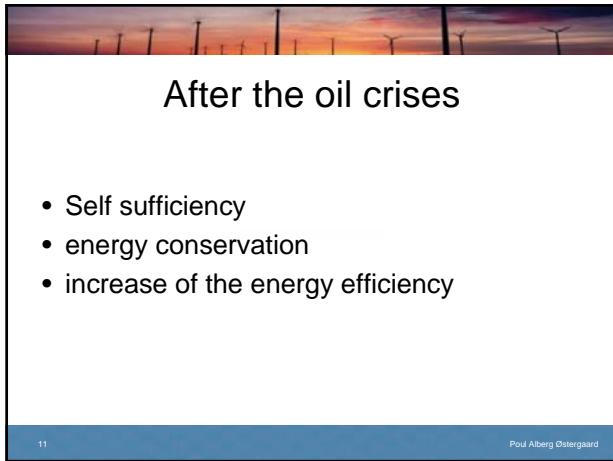
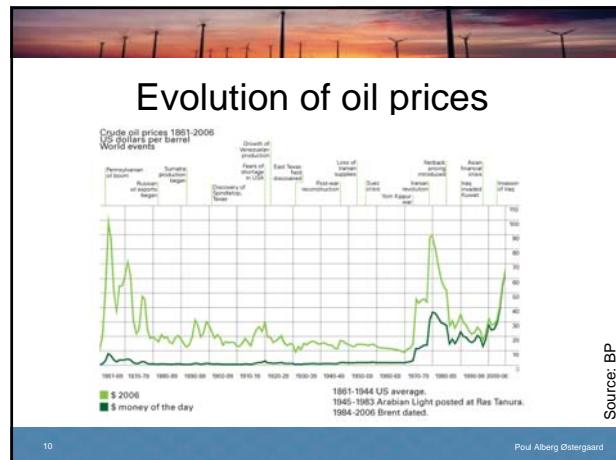


## The happy 1960s

- large increases in the economies
- energy was considered as an important precondition for the increases of the economy
- almost 100% of the energy consumption was based on oil

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- ## New initiatives
- Production of natural gas from the North Sea
  - A natural gas grid was established
  - Heat and electricity planning was carried out for the whole country
  - Energy saving programmes
  - Renewable energy was introduced
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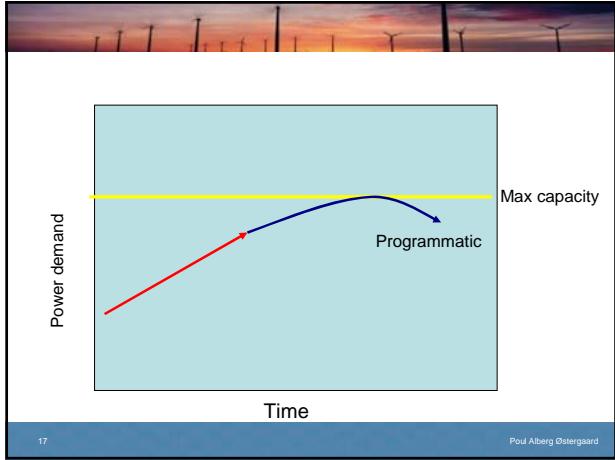
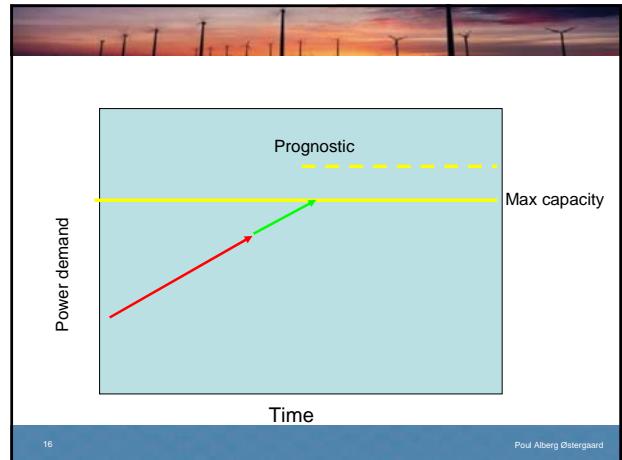
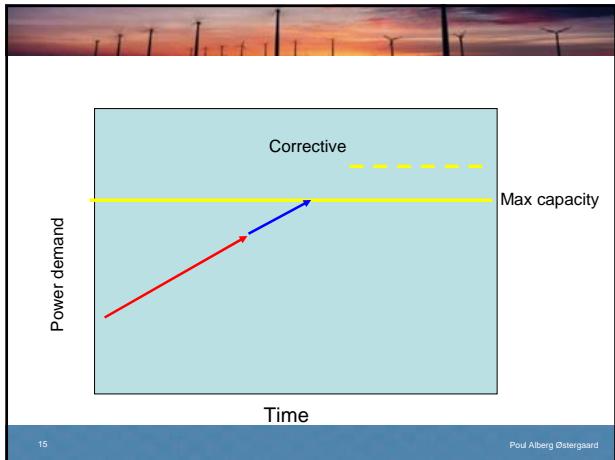
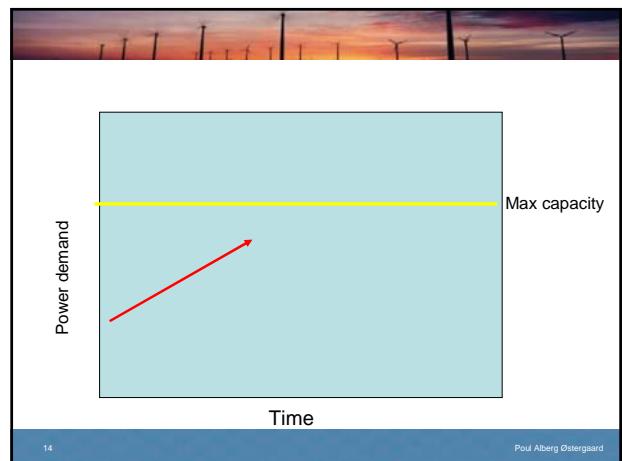
## General planning strategies

(Theodor Geiger, 1948)

- corrective,
- prognostic and
- programmatic planning

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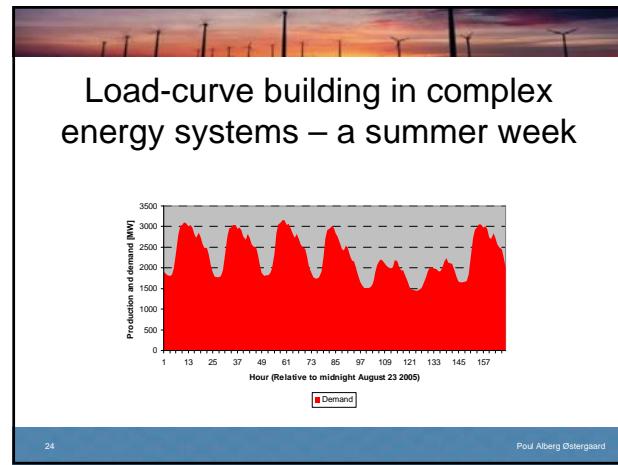
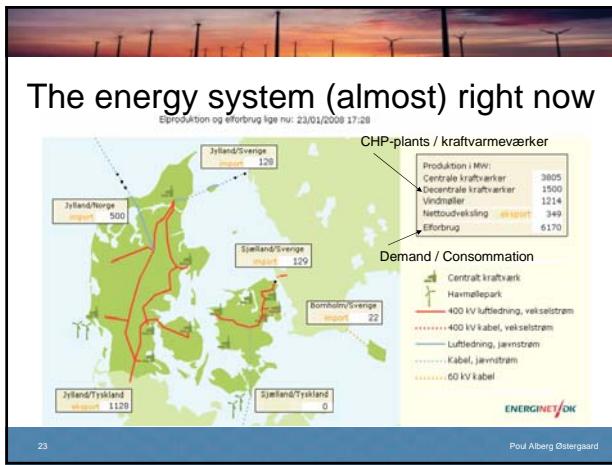
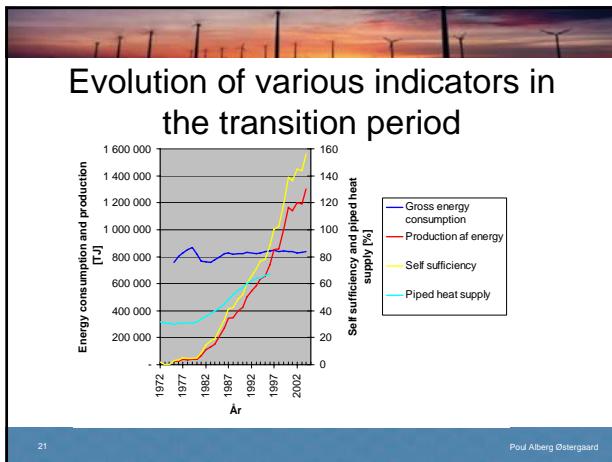
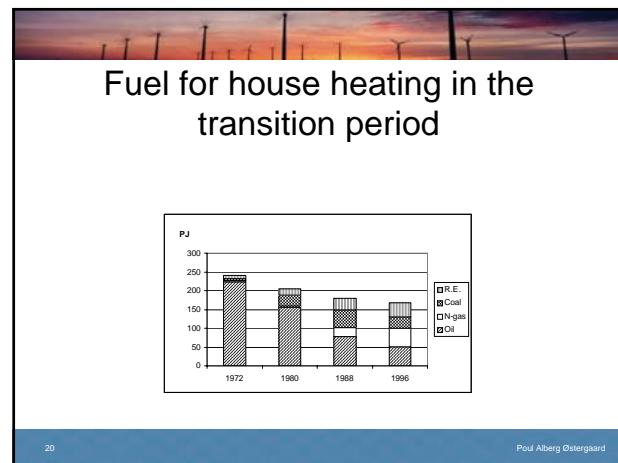
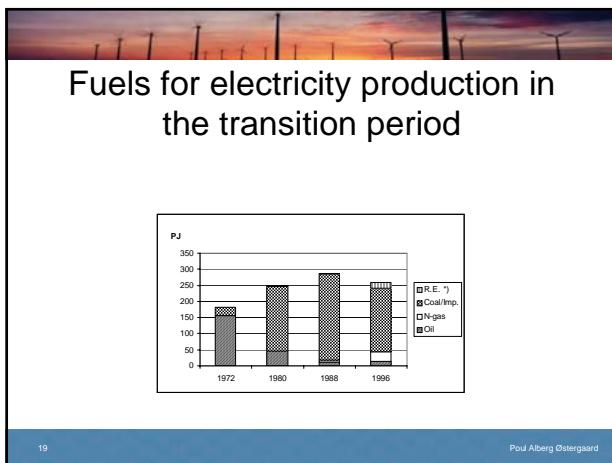


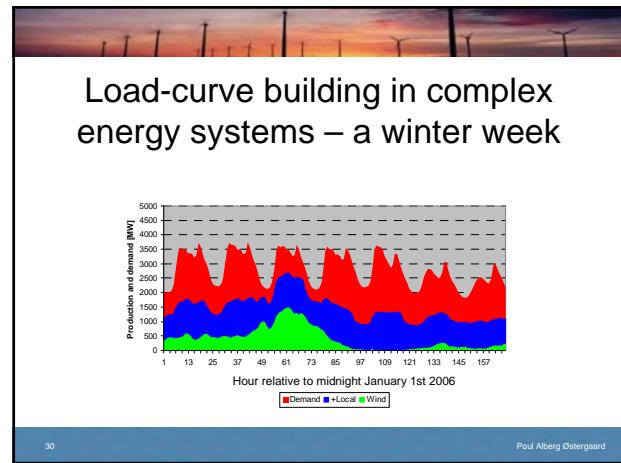
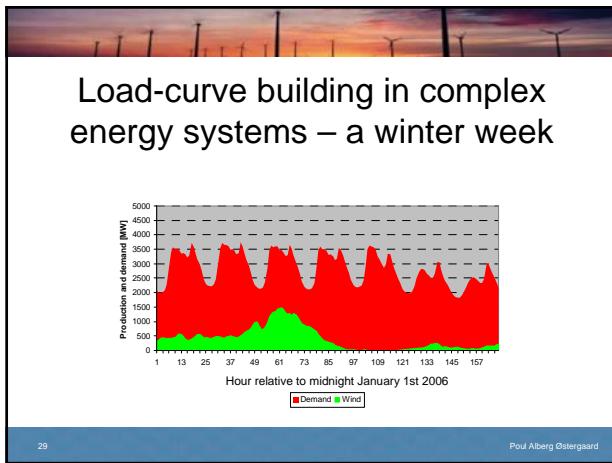
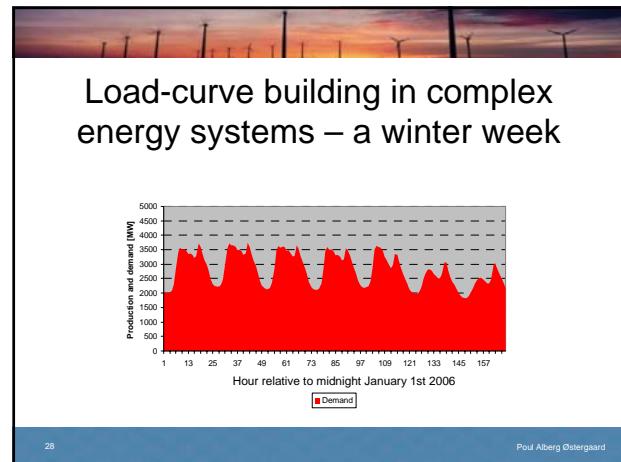
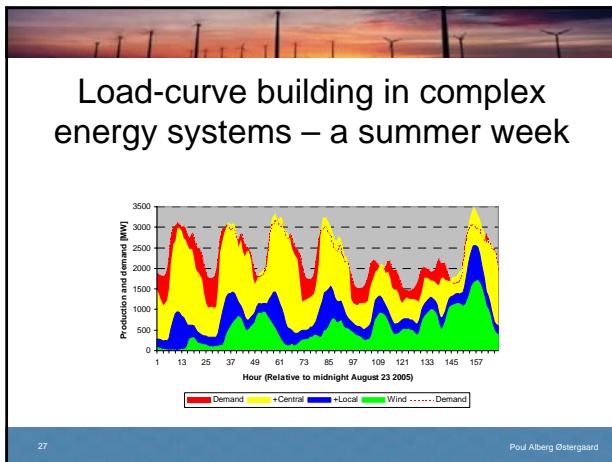
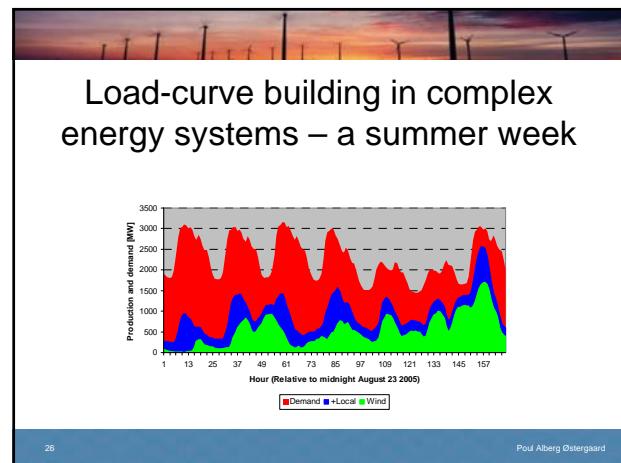
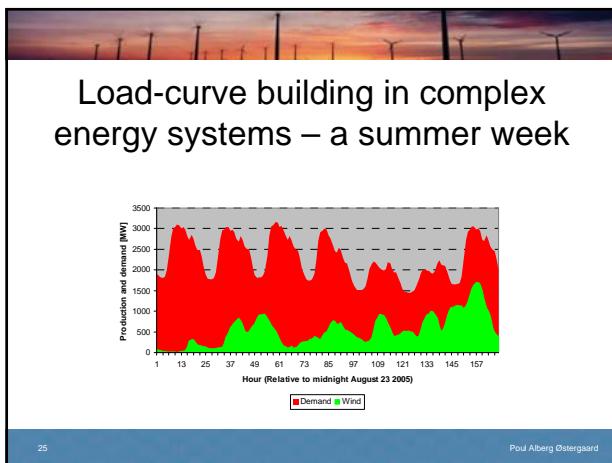
## Danish Energy plans

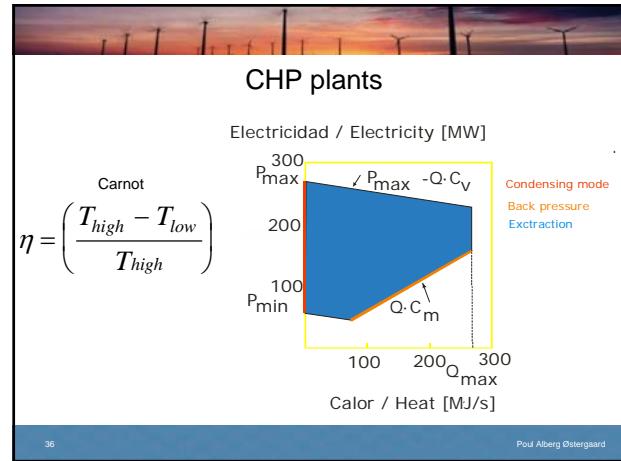
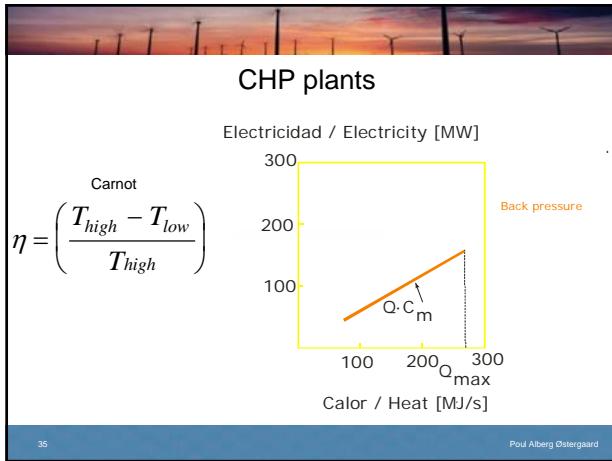
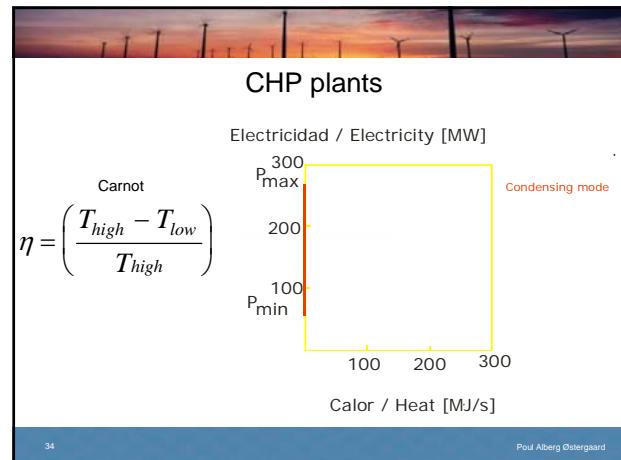
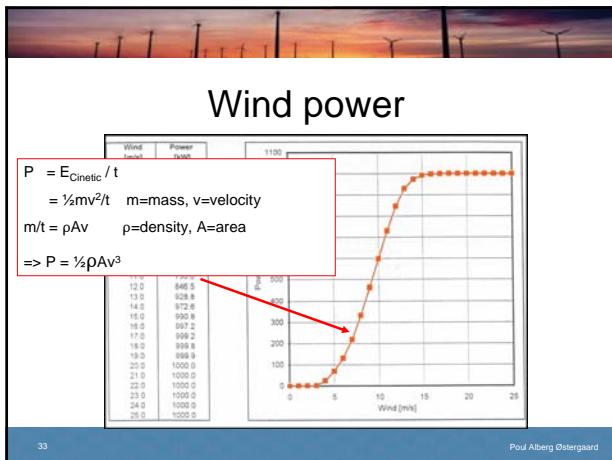
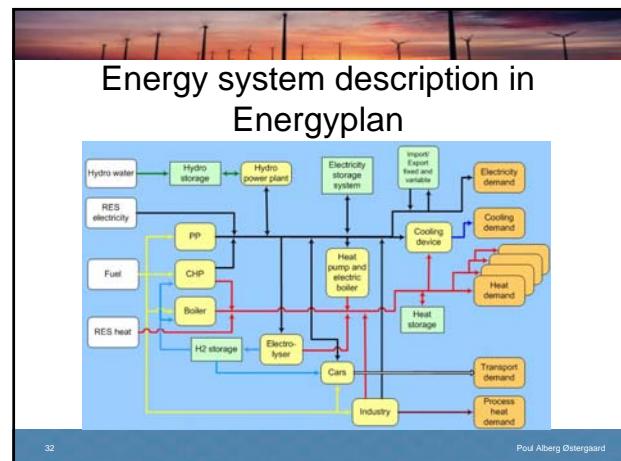
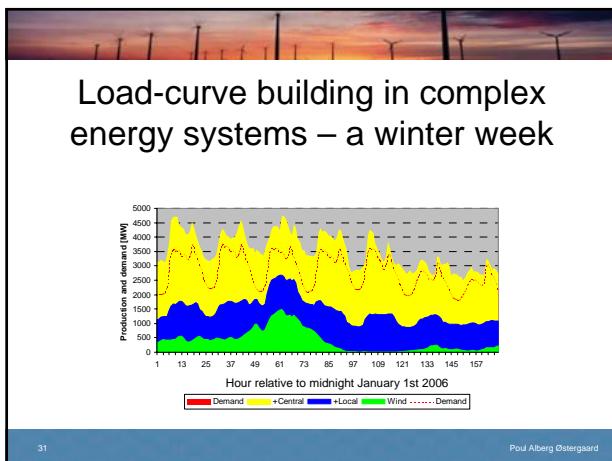
Title	Fuel	RES	Planning approach	Focus
Danish energy policy 1976	Nuclear	No	One alternative Prognostic	Security of supply
Energy plan 81 (1981)	Coal	A little	More alternatives Prognostic	Societal costs
Energy 2000 (1990)	Natural gas	Some	Programmatic	Environmental compliance
Energy 2000 – the follow-up (1993)	Natural gas	Some	Ditto; IRP	Ditto
Energy 21 (1996)	Natural gas	More	Ditto	Environmental compliance; re-regulation
Energy strategy 2025 (2005)	Natural gas	Maybe	Market improvement	Cost effectiveness

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The screenshot shows the EnergyPLAN 7.00 software interface with the following details:

- Header:** EnergyPLAN 7.00 - F901 Reference
- Toolbar:** File, Edit, Help, Import, Export, Calculate, Register, Options, Settings.
- Search Bar:** Loading Time = 00:00:00 Must be between 1 and 0
- Navigation:** Foreground, Help, Cost, Regulation, Dispatching, Remodeling, Storage, Coding, Individual, Industry, Transport, Waste.
- Section:** Electricity Demand and Fixed Import/Export
- Electricity Demand:**
  - Electricity demand: 103 GWh/year
  - Electric heating (dhw): 0 GWh/year
  - Electric cooling (cooling): 0 GWh/year
  - Electric coding (if included): 0 GWh/year
  - Gas demand (gas), heating: 103.00 GJ/year
- Import/Export:**
  - Import/Export fixed and variable: 0 GWh/year
  - Electricity demand: 0 GWh/year
- Bottom:** Total electricity demand: 103.00 GWh/year

**a. EnergyPLAN 7.00: Final Reference**

Ok, Exit, Help, Forecast, Heat, Cool, Regulation, Output, Settings, Disincentivization, District Heating, Residential Heating, Storage, Codes, Individual, Industry, Transport, Waste.

Loading Time = 00:00:00 Must be between 0 and 0

CHP, Heat Pumps and Boilers at District Heating Systems:

**Group I: Direct heating g. I is meant to represent systems without CHP plants**

Demand	[0]	GWh/year	Scale demand	[0]	GWh	Percent	[0]	GWh/year
Efficiency	[0.3]		Site demand	[0]	GWh	Percent	[0]	GWh/year

**Group II: Direct heating g. II is meant to represent CHP systems based on small CHP plants**

Demand	[0.4]	GWh/year	Scale demand	[0]	GWh	Percent	[0]	GWh/year
Efficiency	[0.3]		Site demand	[0]	GWh	Percent	[0]	GWh/year
CHP	[1700]	0.30%	COP	[30]	MWh	Heat storage g. 2	[31]	MWh
Heat Pump	[0]	0.00%	Fuel boiler	[0]	MWh			
Boiler	[0]	0.00%	Gas boiler	[0]	MWh			

**Group III: Direct heating g. III is meant to represent DH systems based on large CHP extraction plants**

Demand	[0]	GWh/year	Scale demand	[0]	GWh	Percent	[0]	GWh/year
Capacity	[0]	MW	Efficiencies	[0]	MWh	Heat storage g. 3	[0]	MWh
CHP	[0]	0.00%	Gas boiler	[0]	MWh			
Heat Polder boiler	[0]	0.00%	Fuel boiler	[0]	MWh			

In common for all three districts

- Change
- Distribution of demand
- Distribution of site thermal
- Sum of direct heating demand
- Change
- Sum of site thermal
- 0.00 GWh/year

Diagram illustrating the flow of energy in a district heating system. Energy enters via Fuel, Solar, and Wind sources. It can be processed by CHP, Boiler, or Heat Pump units. The system includes a central Heat storage tank. The output is distributed to Residential, Commercial, and Industrial loads.

Distribution of fuel	Coal	Oil	Natural gas	Biomass
(GWh/year)	Variable	Variable	Variable	Variable
CHP1	[0]	[0]	[0]	[0]
CHP2	[0]	[0]	[0]	[0]
CHP3	[0]	[0]	[0]	[0]

The screenshot shows the EnergyPLAN 7.00 FRH Reference interface. The main title is "Electricity production from Renewable Energy and Nuclear". Below the title, there is a table with data for different energy sources:

	Source	Capacity [MW]	Distribution [km]	Production [GWh/year]	Efficiency [%]	Post Condition
Change	Wind	100	0	100	90	Wind, Head, Wind
Change	Res. Power	0	0	0	0	Wind, Head, 1_M
Change	Hydro	20	0	20	90	Hydro, Head, 1_M
Change	Rise Rate	0	0	0	0	Hydro, Head, 1_M, Change

A red oval highlights the first two rows (Wind and Res. Power). Below this table, there is another section for Hydro Power:

	Capacity [MW]	Distribution [km]	Annual water usage [GWh/year]	Efficiency [%]	Storage [MWh]	Pump Capacity [MW]	Pump Efficiency [%]
Capacity	0	0	0	0	0	0	0
Efficiency	0.33	0	0	0	0	0	0
Storage	0	0	0	0	0	0	0
Pump Capacity	0	0	0	0	0	0	0
Pump Efficiency	0.33	0	0	0	0	0	0

At the bottom left, there is a "Geothermal Power" section:

	Capacity [MW]	Distribution [km]	Annual production [GWh/year]
Capacity	0	0	0
Efficiency	0	0	0

On the right side of the screen, there is a flow diagram illustrating the energy system:

```

graph TD
    H[Hydro water] --> HSS[Hydro Storage]
    HSS --> HPP[Hydro PP]
    RES[RES electricity] --> GP[Geothermal power]
    GP --> HPP
    HPP --> Grid[Grid]
    HSS <--> Grid
  
```

The screenshot shows the 'Energy芋田7.00 - FISH Reference' window. At the top, there are menu options (File, Edit, Help), a toolbar with icons for Print, Save, Copy, Paste, Cut, Undo, Redo, and a magnifying glass, and a status bar indicating 'Loading Time = 00:00:00' and 'Must be between 0 and 6'. Below the toolbar are tabs: Forepage, Print, Cost, Regulation, Output, Settings, Electricity/Fossil, Districtheating, Removable/Cogp, Storage, Coding, Individual, Indirect, Transport, Waste. The Waste tab is selected. A large section titled 'Waste: Heat, electricity and biofuel from energy conversion of waste' contains descriptive text about waste-derived products and their distribution across three district heating zones. Below this is a table:

Distribution of Waste	Change distribution		constant				
	Waste input	DH production TWh/a		Electricity production Efficiency %	Budget transportation Efficiency TWh/a	Budget DH-plus Efficiency TWh/a	Varius fixed etc. Efficiency TWh/a
SH4-1	100	72.15	0.00	16.54	0	0.00	0.00
SH4-2	0	0.00	0.00	0.00	0	0.00	0.00
Total	100.00	72.15	0.00	16.54	0.00	0.00	0.00

A red oval highlights the first two columns of the table.

The EnergyPLAN model first calculates in accordance with the Technical Regulation strategy, and then if activated in accordance with the Market Economic strategy.

**Technical Regulation:**

Minimum grid stabilisation production share:  0.3  0.5  0.7

Stabilisation share of CHP2:  1  2  3

Minimum CHP up g.r. 3:  0  0.5  1

Heat Pump Maximum load:  0.5  1.5  2.5

Maximum import/export:  0  1000000000  10000000000

No Market Economic Regulation   Change Overall Demand

Define prices on external electricity market: Average price: DKW (MWh)

Addition factor:  0  0.5 MWh Multiplication factor:  0  1  2

In case of Overall Market Strategy 3: the following price is added to the system price in case of a price increase

The calculation is based on marginal production prices as defined in Input section

New Market Heat Regulation:  Active  Inactive

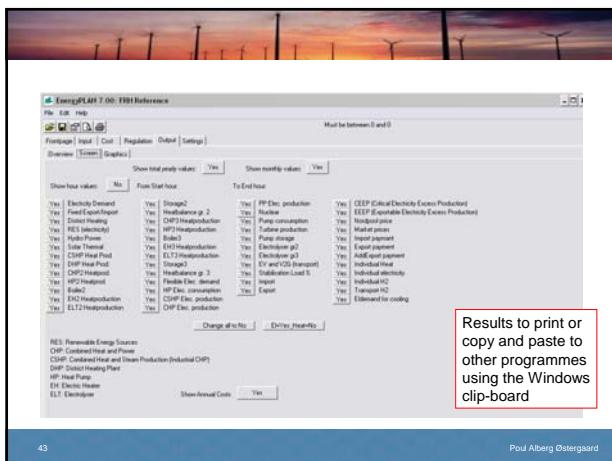
**Regulation strategies**

- 1: Heat demand
- 2: Heat demand and electricity
- 3: Heat demand and electricity
- 4: Triple tariff

**CEEP:** See next slide

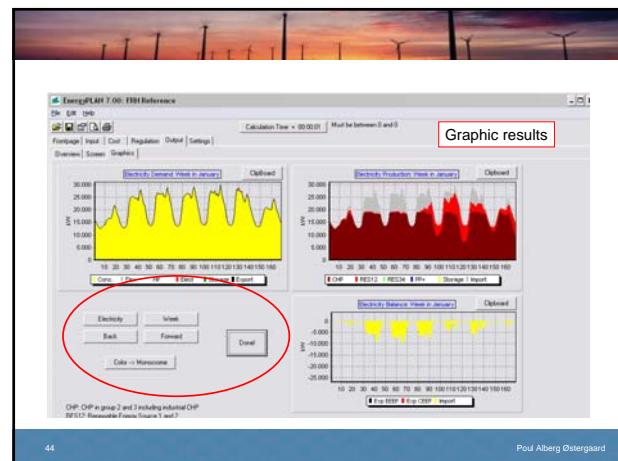
**Minimum stabilisation share:**  
**Minimum production on plants that can control frequency and voltage**

**Maximum import and export**



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