Modelling Issues in Denmark

- Energy in Denmark
  From Danish Energy Policy 1976 to Energy Strategy 2025
- Energy modelling
  Top-down, Bottom-up, Market liberalisation, Market power
- Objectives for ETSAP Annex X
  Background and discussion

ETSAP semi-annual Workshop "Models and Studies"
Oxford, UK 15-16 November 2005
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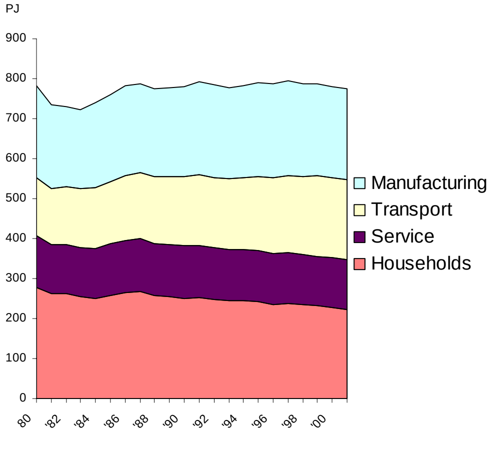
Primary energy in Denmark 1980-2001



- Same total primary energy consumption in 2001 and 1980
- Household consumption decreasing
- Service consumption nearly constant
- Manufacturing consumption depending on economic activity
- Transport energy steadily increasing
- Less direct energy use and more electricity and district heating

Source: Danish Energy Authority. Statistics

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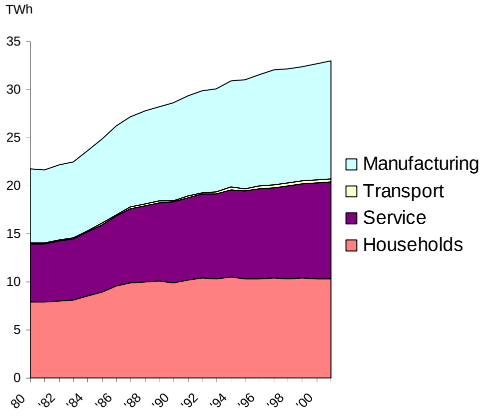
Electricity in Denmark 1980-2001



- 50 % more total electricity
- Large share of combined heat and power
- Moderate increase in household electricity demand
- Larger increase for service and manufacturing
- Significant efficiency gains in all sectors

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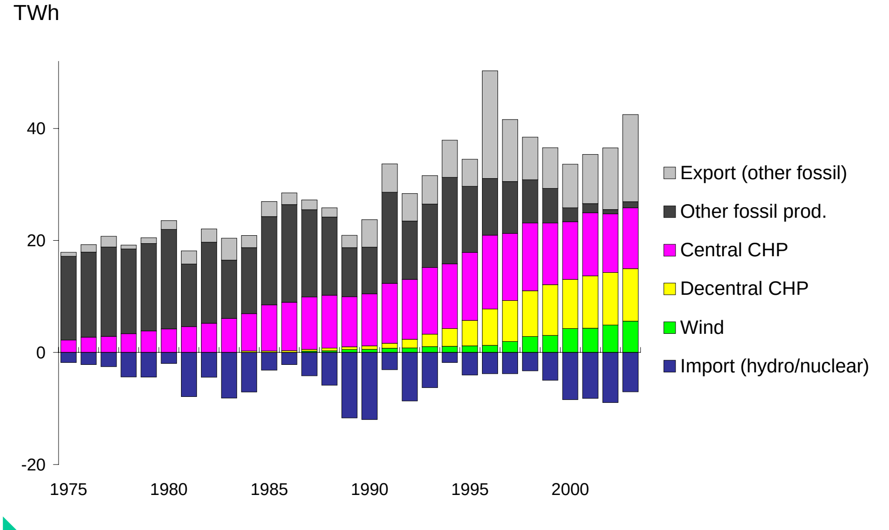
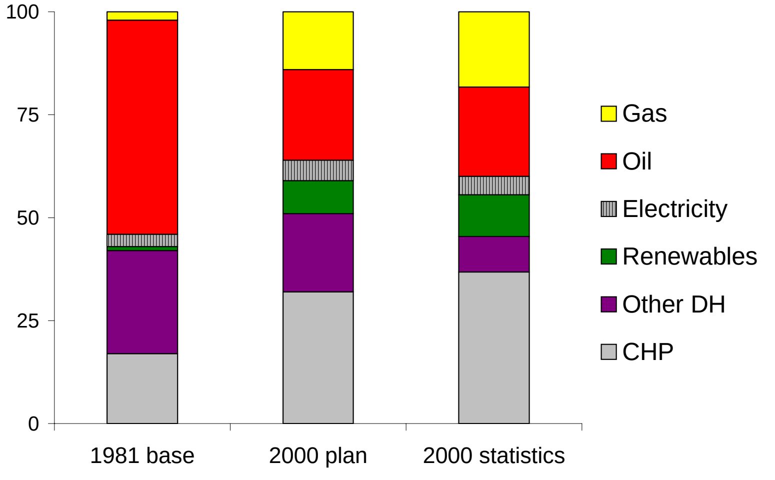
Denmark: Electricity generation and import 1975-2003



Space heating technologies in Denmark Energy Plan 1981 target and status 2000



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CHP regions in Denmark

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- Copenhagen: Interconnected grid. Heat sales 25 PJ per year (7 TWh): 250-350 MW extraction-condensing units and waste incineration.
- Large cities (Århus, Odense, Aalborg, Esbjerg, Little Belt Region): Heat sales 5-10 PJ per year. 250-350 MW extraction-condensing units with abundant capacity.
- Mid-sized towns: Waste incineration and CCGT up to 100 MW.
- Small district heating systems: Gas motors below 20 MW and district heating boilers.

The early development was based on local initiative, i.e. municipalities consumer co-operatives and local business communities.

From 1980 the further expansion was supported by national planning and zoning of urban area for natural gas and district heating.

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Long-term planning with different objectives

The development shows long-term consistency in energy investments since the 1970s, although energy there has been several shifts in energy policy objectives

- Classical energy policy objectives
  - Security of supply
  - Economic efficiency
  - Environmental protection
- New objective from the 1990s
  - Energy market liberalisation and competition

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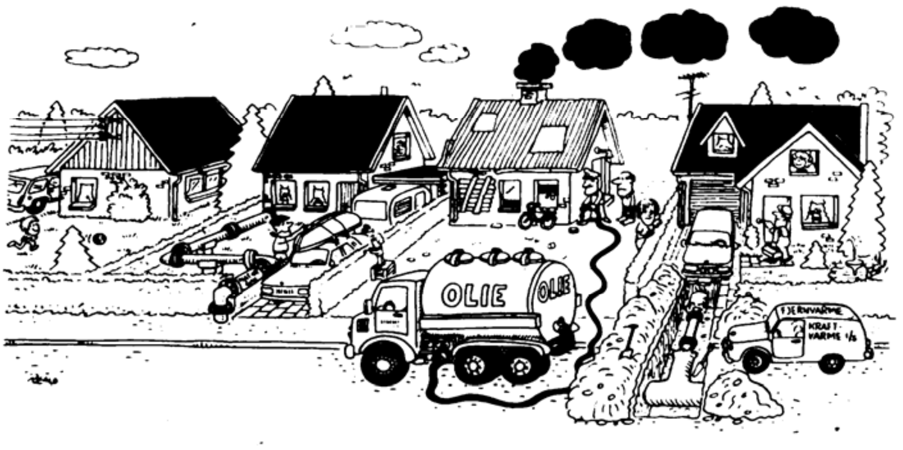
Natural gas to Denmark from 1980



Tegning: Knud Sørensen Schön. Kilde: Naturgas i Danmark, AKF 1980

Sectoral models

Sector	Energy usage	Activity parameters	Models
Residential	Energy services (space heating, light and appliances)	Heated area, number of persons	Activities and unit consumption
Service	Energy services (space heating, light and appliances)	Heated area, number of persons, production values	Activities and unit consumption. Econometric models
Manufacturing industries	Industrial processes	Production values	Econometric models
		Identified technologies and processes	Techno-economic optimisation
Electricity and district heating	Conversion from primary to final energy	Identified technologies and processes	Techno-economic optimisation

Energy and economic models used in Denmark

- ADAM – Annual Danish Aggregated Model. Macroeconomic model hosted by Statistics Denmark and used by Danish ministries and analysts since the mid-1970s.
- EMMA – Energy and eMission Models for ADAM satellite model for ADAM, forecast of energy demand and emissions
- HERMES and E3ME: Macroeconomic models for EU member states etc. focusing on energy demand and environmental impact. various EU research programmes since 1980.
- DES: Accounting systems for energy planning in the 1980s with load-duration/merit-order model for the electricity sector with CHP.
- RAMSES – techno-economic model for electricity and heat in several region with merit-order optimisation on an hourly basis. Most detailed for West and East Denmark, less detailed for Finland, Sweden and Norway. Exogenous investment in new capacity. Output on regional electricity prices, fuel and emissions.
- EFOM-CHP: Small application of EFOM focusing on CHP regions in a competitive electricity market.
- Balmorel (Baltic Model of Regional Electricity Market Liberalisation): an 'open source' model for analysis of regional electricity and heat markets with international trade.
- WILMAR (Wind Power Integration in Liberalised Electricity Markets) based on Balmorel, but stochastic extension to include endogenous treatment of stochastic wind power production forecasts. Optimise simultaneous day-ahead and intraday power markets..
- MARS (MARket Simulation) – imperfect competition, Nash equilibrium – hourly simulation of Nord Pool's market area and Northern Germany.

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ADAM: Annual Danish Aggregated Model

Main characteristics

- Macroeconomic model with Keynesian properties in the short and medium term and neoclassical properties in the long term.
- Developed and hosted by Statistics Denmark
- Regularly used by the Ministry of Finance
- Generally available for licensing

History

- 1972 - First solution of the model
- 1973 - First systematic use of the model for economic forecasts
- 1976 - Energy import calculated in the model
- 1982 - Number of branches increased from 6 to 18
- 1986 - Financial submodel incorporated into the model
- 1986 - First satellite model for industrial energy demand
- 1995 - More simplified relation for income taxes
- 1995 - Environmental satellite models
- 1997 - EU harmonised national accounting system implemented
- 2006 - Major revision with fewer industrial branches

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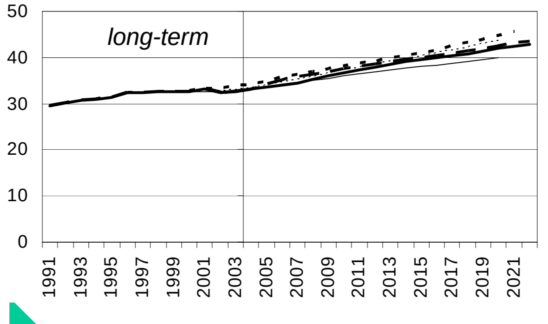
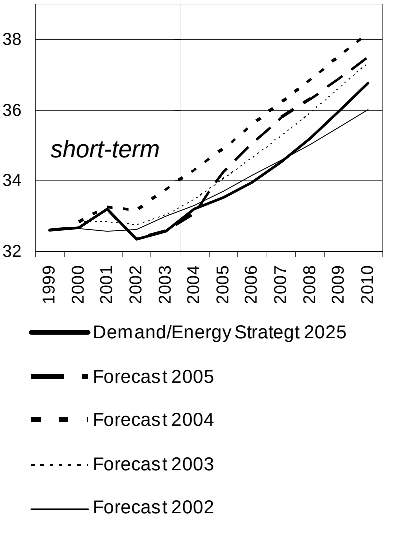
Comparison of EMMA results Forecasts made 2002-2005

Total electricity demand in Denmark, TWh





Geographical structure model for optimisation of electricity and heat markets

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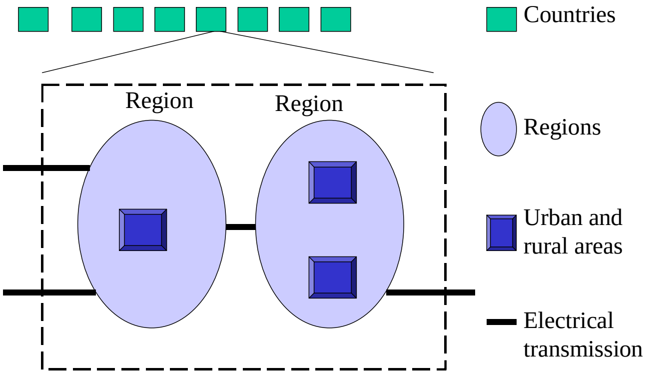
The capacities for combined heat and power (CHP) must be assigned to an area with a district heating network (or an industrial plant with a heat or steam requirement).

Large-scale interconnected district heating networks will allow dispatch among many heat generating units.

Electricity-only technologies and electricity demand is specified for each region or country with dispatch among generating units and import.

Electricity trade place among regions which may represent a utility firm or a country.



Balmorel (Baltic Model of Regional Electricity Market Liberalisation)

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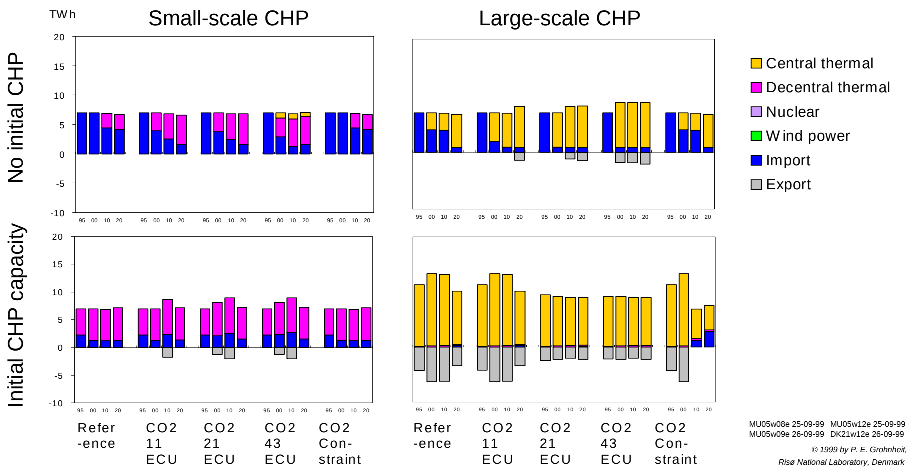
The Balmorel model – including the GAMS code and data describing the power system in the countries in the Baltic Sea Region – is available from www.balmorel.com.

Examples of the experience using BALMOREL – both as an ‘open source’ model and further development of the model, either commercially or internally in energy companies or authorities.

- Analysis of the operation of a pumped storage in Lithuania using models with different time resolution
- Economic analysis of the energy sector in Lithuania in 2001 as a part of a twinning project between system operators and consultants in Denmark and Lithuania, financed by the Danish Energy Agency.
- Analysis of the Nordic hydro-thermal electricity system. Comparison of the results with a more detailed ‘unit-commitment’ model with finer time resolution.
- A detailed analysis of the Danish electricity market with many CHP areas and large foreign trade.
- Analysis of the future generating capacity in the liberalised electricity market for the area of the NordPool spot market – Security of supply.

Electricity generation in CHP regions 1995-2020



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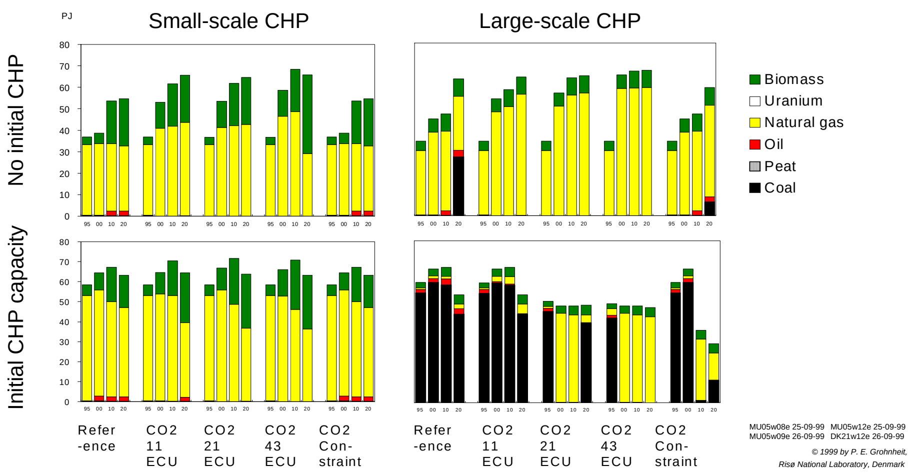
Primary fuels in CHP regions 1995-2020



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The impact of wind (EMELIE hourly version)

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Consumer prices (Winter Day)		Denmark West	Denmark East	Norway	Sweden	Finland	Germany North
No wind	Competitive	126	126	62	63	71	92
	Cournot-Nash	153	151	71	71	83	103
Average	Competitive	117	117	59	60	68	83
	Cournot-Nash	149	148	71	71	82	100
Full wind	Competitive	107	107	59	60	68	73
	Cournot-Nash	147	146	71	71	82	99

EUR/MWh

Marginal generation cost (Winter day)		Denmark West	Denmark East	Norway	Sweden	Finland	Germany North
No wind	Competitive	33	33	33	33	33	33
	Cournot-Nash	39	39	39	41	34	27
Average	Competitive	24	24	30	30	30	24
	Cournot-Nash	25	32	39	41	33	26
Full wind	Competitive	14	14	30	30	30	14
	Cournot-Nash	14	26	39	39	33	24

EUR/MWh

All calculations are based on Year 2000 data.
Consumer prices include taxes (most significant for Denmark)

Electricity generation costs in € per MWh

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- My previous mnemotechnic reference in ECU-1990
  10 €/MWh: short term marginal cost of CHP and nuclear
  20 €/MWh: short-term marginal cost of electricity-only
  30 €/MWh: long-term marginal costs of new gas-fired stations
  40 €/MWh: long-term marginal costs of new wind turbines at good locations.
- Inflation in ECU/€ 1990-2000 ads 25 %, 1990-2005 nearly 40 %
- Higher prices on fossil fuels increase short-term marginal costs
- Examples of market and feed-in prices
  0 *€/MWh*: Nord Pool events in Denmark West with low demand and much wind
  5 €/MWh: Very low spot price at Nord Pool (Norwegian summer night)
  34 €/MWh: Nord Pool forward annual contracts 2008 (3 Nov. 2005)
  50 €/MWh: Typical peak hour spot price on the European Energy Exchange
  70 €/MWh: Feed-in price for the planned Horns Rev 2 off-shore wind farm
  90 €/MWh: German feed in law for wind (2002)
  200 €/MWh: Very high spot price on Nord Pool (Danish winter afternoon 2002)
  480 €/MWh: German feed in law for photovoltaics (2002)
  500 €/MWh: Nord Pool event 24 January 2000, 07-08h
- Market price for CO_2 allowancies: 22 €/ton CO_2 (Nord Pool Nov. 2005), equivalent to 16 €/MWh generated by a coal-fired unit at 47% efficiency (Nordjylland, Denmark)

WILMAR: Wind Power Integration in Liberalised Electricity Markets

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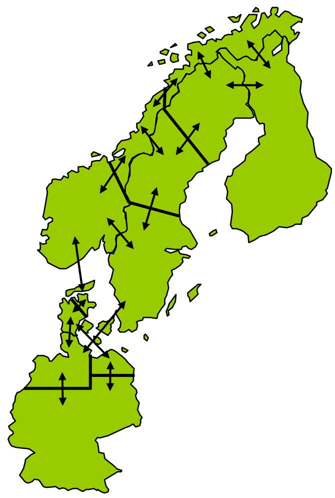
- EU 5th Framework Programme 2002-2005
- Description of the electricity system in 2010 with regional division to reflect spatial concentration of wind power and electricity demand and bottlenecks in the transmission system.
- Collection wind speed, wind power, hydro inflow, creation of stochastic models for wind power production
- Development of a strategic planning tool (hourly model)
- Analysis of system stability (below one-hour time resolution)
- Analysis of emission-trading and green markets
- Distribution of the integration costs
- Dissemination: www.wilmar.risoe.dk
- New EU project: SUPWIND



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WILMAR: Model results on impacts of wind power production

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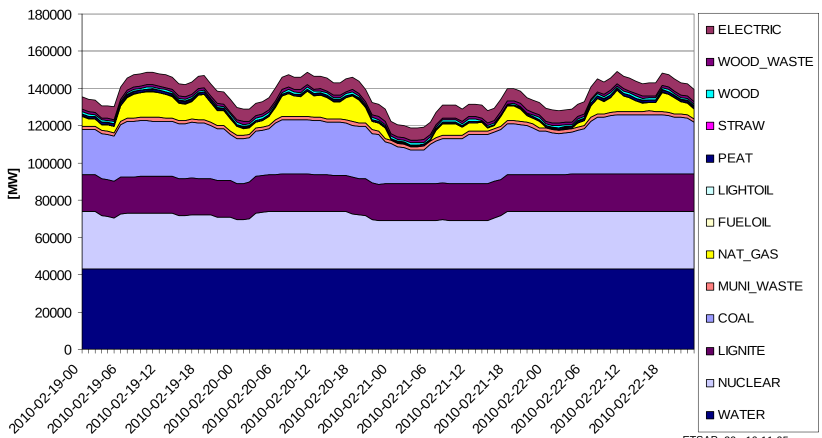
Model scenario “2010_20%”: Forecasted wind power capacities in 2015 equal to cover 20% of the annual electricity demand for Finland, Sweden and Norway, 29% for Denmark and 11% for Germany

Capacity on line for the time period 19.02-25.02.2010 and model scenario “2010_20%”:



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Modelling Issues in Denmark

- Energy planning from 1976
- Heat supply planning with expansion of district heating with CHP and introduction of natural gas from 1981
- SO_2 reduction in the early 1980s
- CO_2 reduction from the late 1980s
- Small-scale CHP in the 1990s
- Nordic and Northern European market in the 1990s
- Large-scale use of wind power from the late 1990s
- Further use of biomass after 2000

Danish economy 1977

1970s:

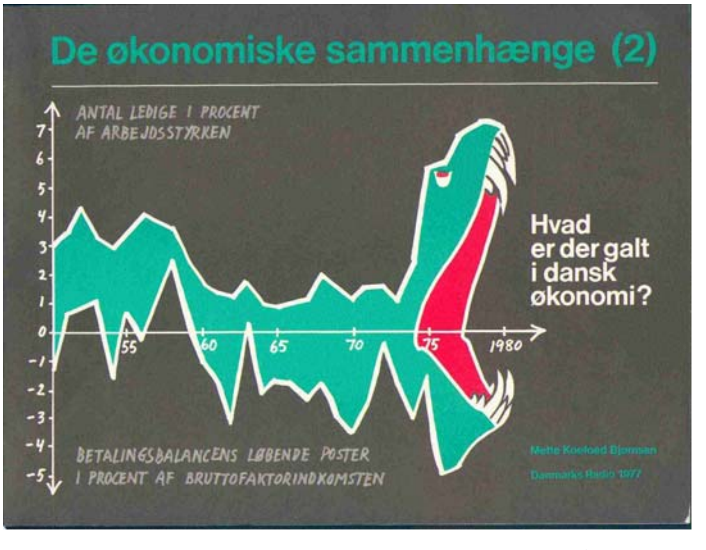
Increasing unemployment

Increasing deficit on foreign trade

1990s:

Low unemployment

Surplus on foreign trade



ETSAP: Modelling and analyses involving Denmark

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- 1981: Danish Energy Agency – MARKAL implementation
- 1995: Benefits from Electricity Trade in Northern Europe under CO_2 Constraints.
- 1998: A MARKAL model for Denmark,, IFE Norway
- 1999: Nordleden 1st Phase. Cross-border grid-distributed energy trade and common action among the Nordic countries to facilitate CO_2 reductions – using MARKAL-NORDIC
- 2003: Nordleden 2nd Phase.
- 2004: NEEDS, New Energy Externalities Developments for Sustainability, Research Stream 2a: “Energy systems modelling and internalisation strategies, including scenarios building”

MARKAL technology recommendations and Denmark

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Typical MARKAL recommendations, e.g. Nordledem

- Widespread use of CHP for industrial and domestic uses
- Fuel substitution when CO_2 is constrained

Status for Denmark by 2005

- Steady improvement in energy efficiency in buildings in 1970s and 1980s
- District heating above 50 %, natural gas about 25 % of space heating
- Large-scale CHP: market saturated in 1980s
- Small-scale CHP: market saturated in 1990s
- Waste incineration as base load for district heating
- Gas-fired boilers for space heating from 1980s and 1990s
- Wind power 10 % of energy consumption by 2000, nearly 20 % by 2005
- Infrastructure for combustion of straw in boilers, small- and large-scale CHP.

New issues

- Potential for micro-scale CHP, when existing small gas boilers are retired
- Alternative and complementary uses of straw: Bioethanol, building materials, more ...
- Energy efficiency improvement in building
- Transport energy increasingly important
- Investnment in new capacity and security of supply in a liberalised market

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Implementation of wind power in TIMES

- A small, but sufficient number of time-slices:
  - Winter/summer, day/night for electricity and heat
  - Full (90% of capacity), average and no wind
  - Full and no wind for winter day
  - Average wind for other time slices
- Considering capacity constraints, i.e minimum capacity requirement
  - ”Soft” constraint for flexible demand
  - Dual values of the capacity requirements equal to some forecast of hourly prices of the power exchange.
  - Further research needed

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Optimisation model details

- Load curve (time slices/load regions): How many?
- Objective function: Overnight investment costs – annuity cut off at the end of the study period plus annual cost. Discounted
- Constraints: Minimum generation and capacity. Maximum investment in each technology
- Number of variable and constraints
- Dual values in linear programming
- Presentation of input and results
- Administration of many scenarios

Questions for ETSAP Annex X

- What can we get from it?
- How can we contribute?

- Further development of tools or ’back to basics’ ?
- Which exogenous assumptions ?