

**Presentation at
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***Modelling of regional energy collaboration
in the Nordic countries***

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Outline

- Nordic energy systems
- History of regional energy collaboration
- Policy tools
- Modelling of regional energy collaboration in the Nordic system – MARKAL_Nordic
- Deregulation and expanding system boundaries
- Future issues



Nordic power supply

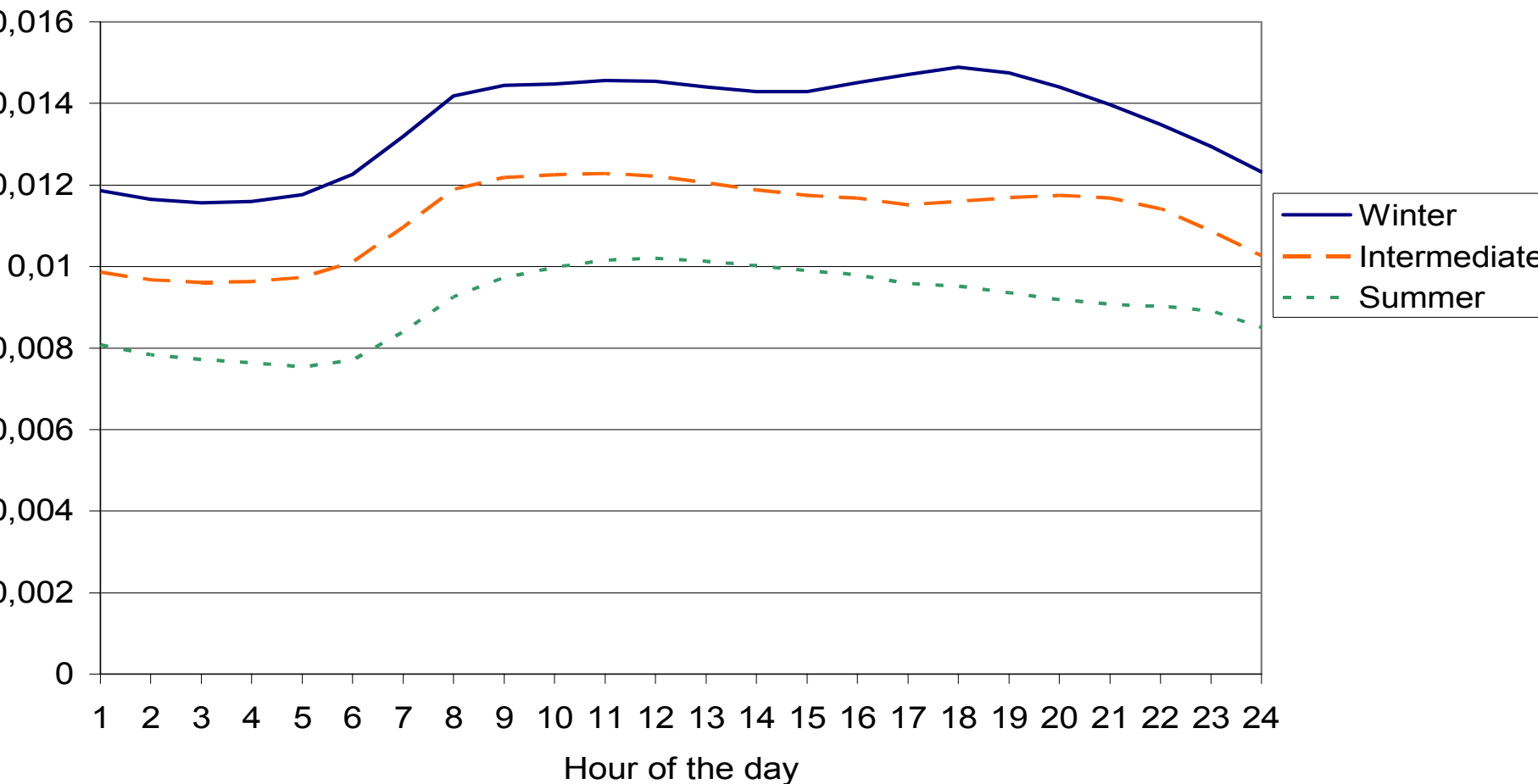
(approx values)

- Norway – 100 % hydro
- Sweden – 50% hydro + 50% nuclear
- Finland - 70% fossil & bio thermal + 30% nuclear
- Denmark – 85% fossil & bio thermal + 15% wind

Heat supply systems

- Norway – very large share of electric heating
- Sweden – large shares of both district (boiler only plants) and electric heating + oil/bio burner
- Finland - district heating (combined heat and power based) + electric heating + oil/bio burner + natural gas
- Denmark – district heating (combined heat and power based) + natural gas

Power generation variations over hours of the day and seasons shown as hourly shares of total generation in Sweden



Resource variations

- Norway – oil & gas (but no domestic gas grid) + hydro & wind resources
- Sweden – hydro & bio + limited wind resource
- Finland – bio
- Denmark – oil & gas + wind resources

Electricity cooperation

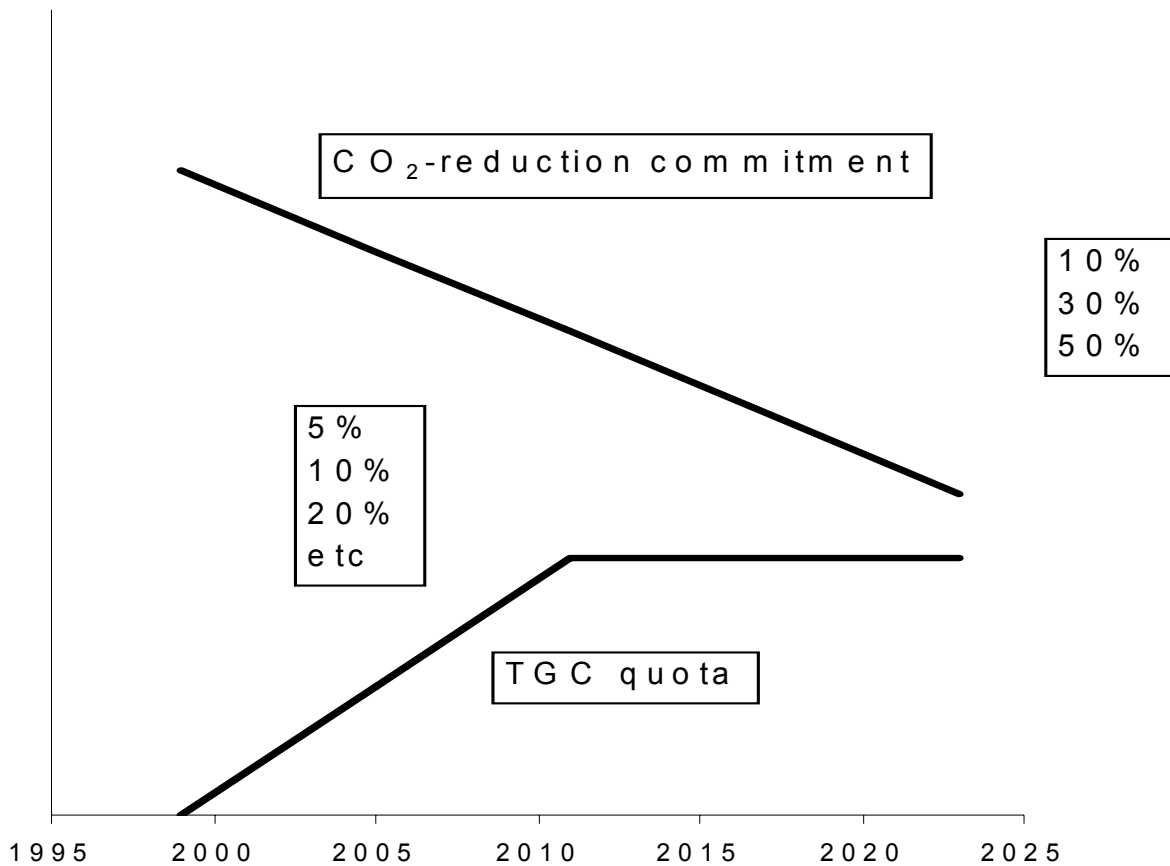
- Long history of electricity cooperation (almost a century)
- Complete market deregulation (started in Norway in early 90ties, completed in Denmark a decade later)
- Common power trade market - NordPool

Energy policies

- CO₂-taxes ~ 3 NT/kg CO₂
- Tradable green electricity certificates (TGC)
 - wind, bio, peat, small-scale hydro power
 - large-scale hydro not included
- Tradable CO₂-emission permits (TEP)
- Nuclear power phase-out in Sweden but not in Finland

$$PP_{\text{consumer}} = PP_{\text{market}} + P_{\text{certificate}} \times \text{certificate obligation} + \text{taxes etc}$$

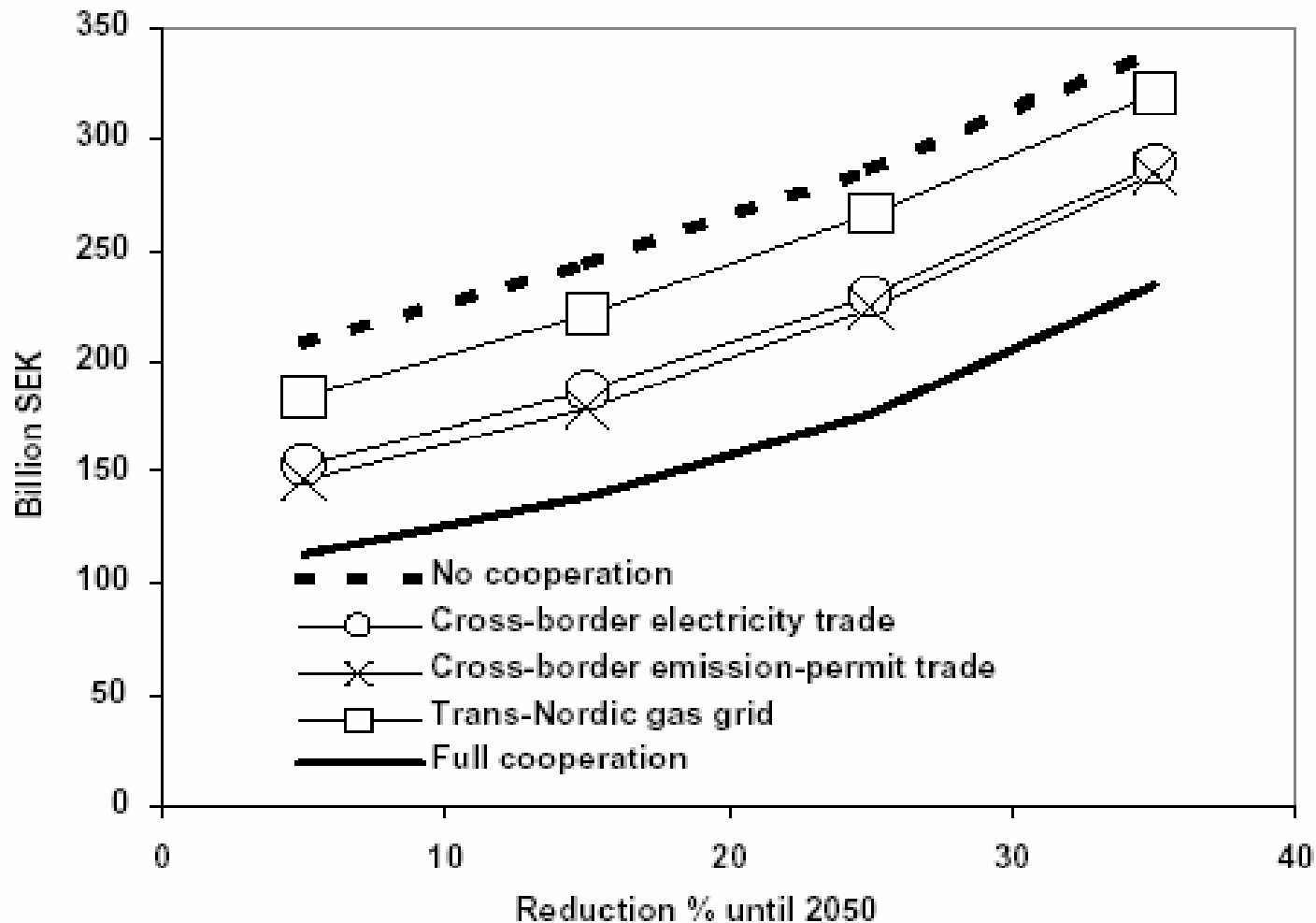
$$P_{\text{certificate}} \approx \text{Cost for generating 1 MW "green electricity"} - PP_{\text{market}}$$



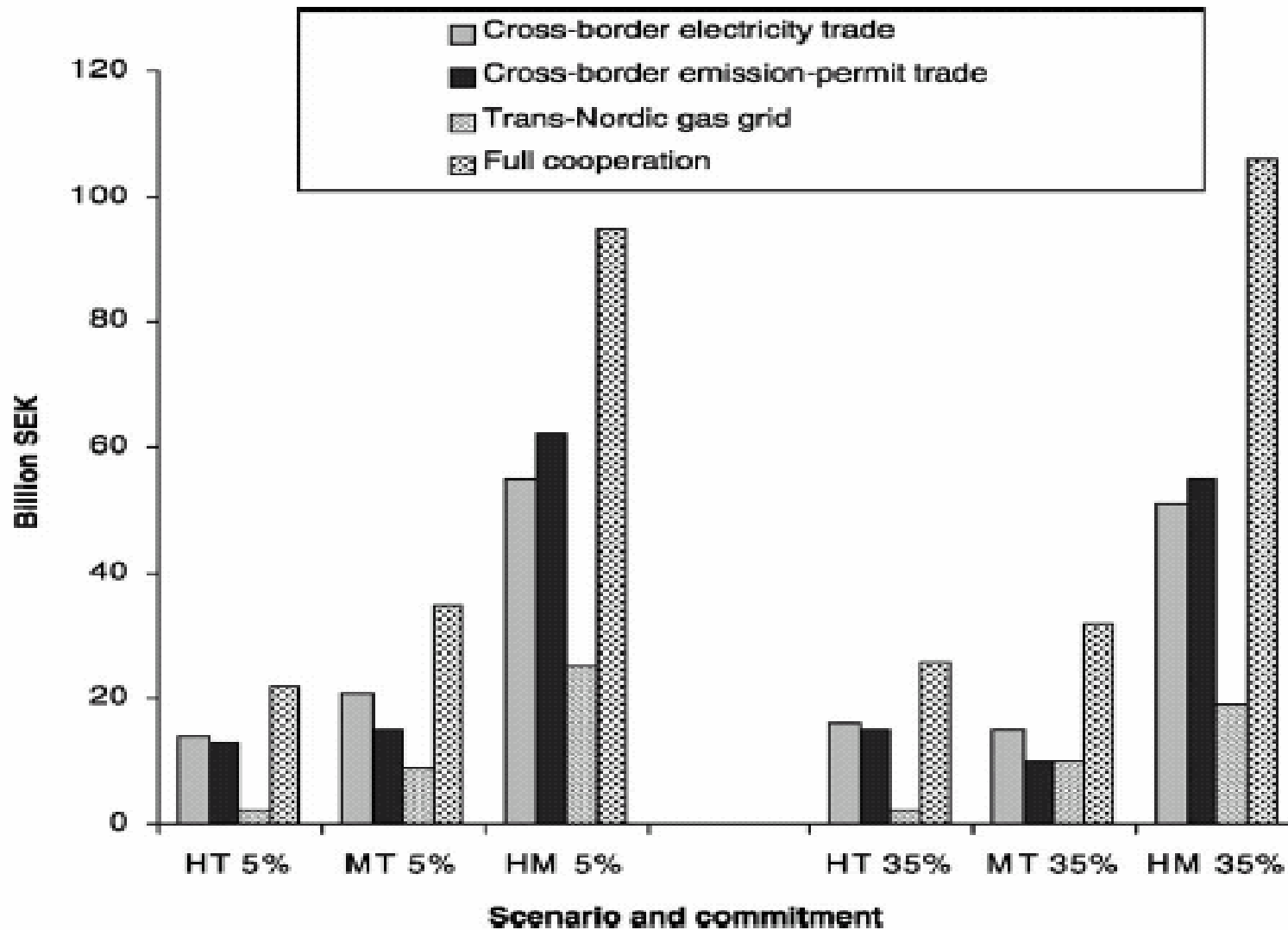
MARKAL_Nordic

- Four country data bases merged
- Possibility for trade (power, certificates, permits) between countries
- Most often used for analysis up to year 2050
- CO₂ abatement policies
- CO₂ taxes and most other policy measures (subsidies etc removed)
- Scenarios including different demand growth
- Transport sector included but not modelled

CO₂ abatement costs at national commitments and at different degrees of Nordic energy collaboration (HyperMarket scenario)

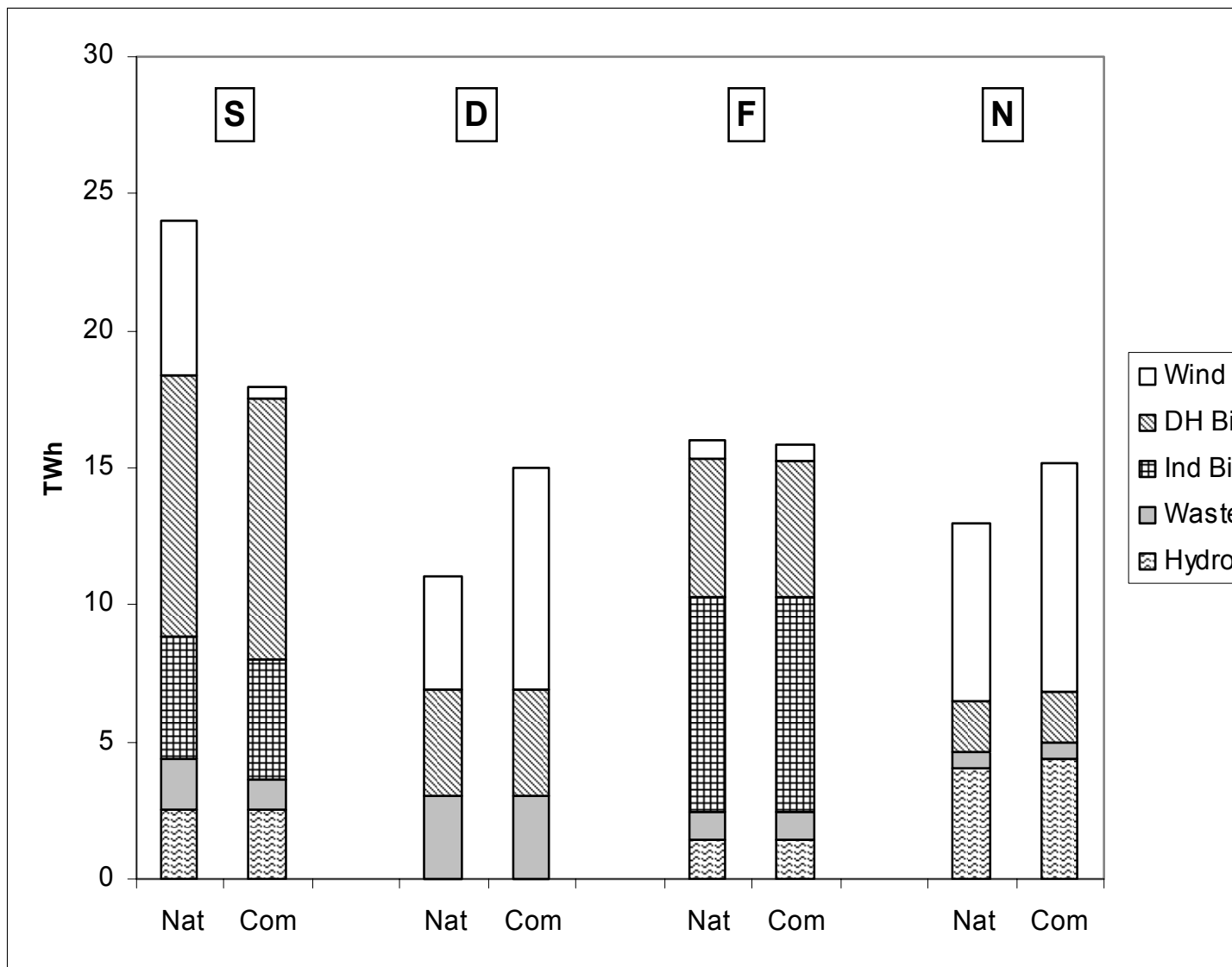


Benefits from cooperation in different scenarios and at different CO₂ commitments

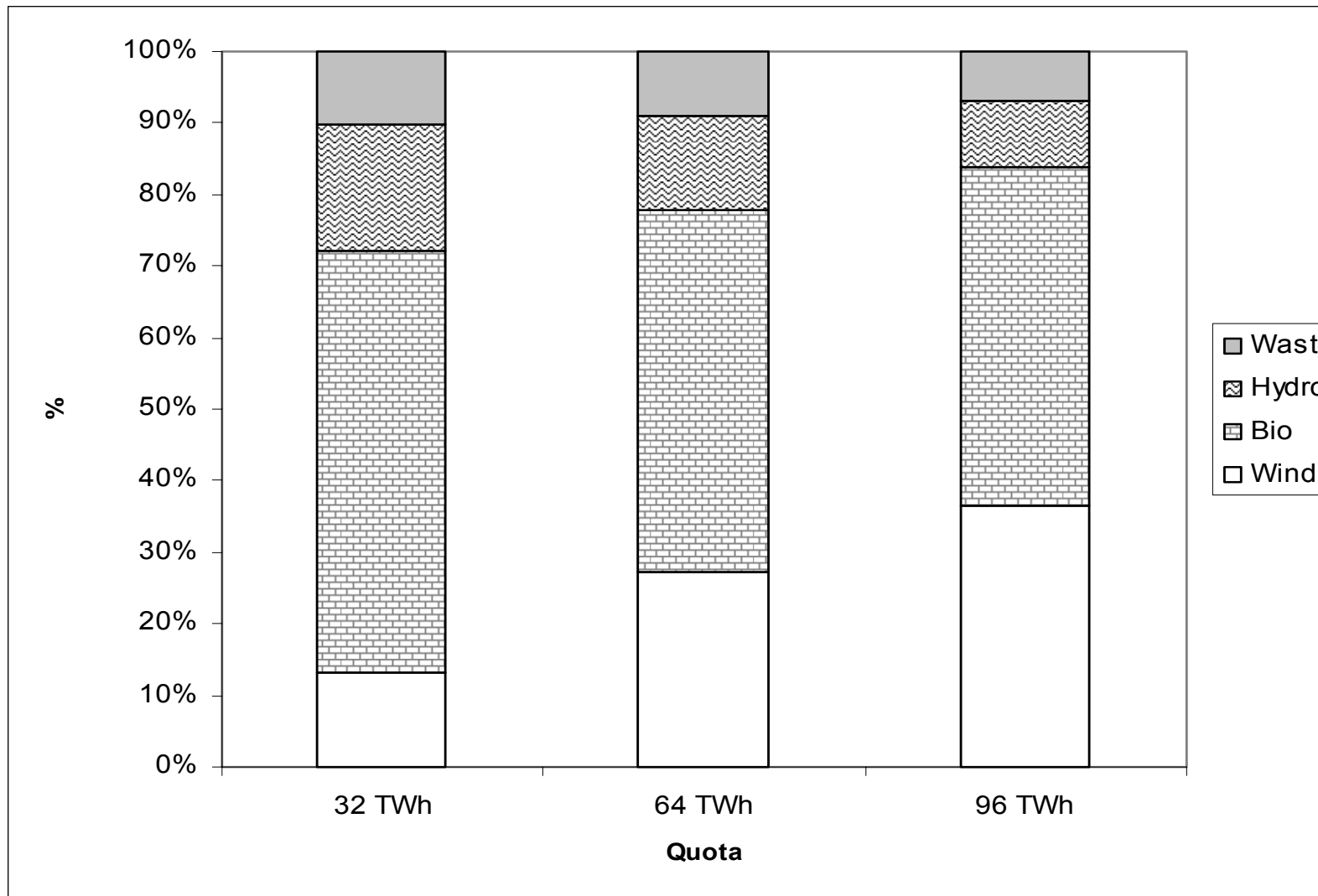


Tradable green electricity certificates (TGCs)

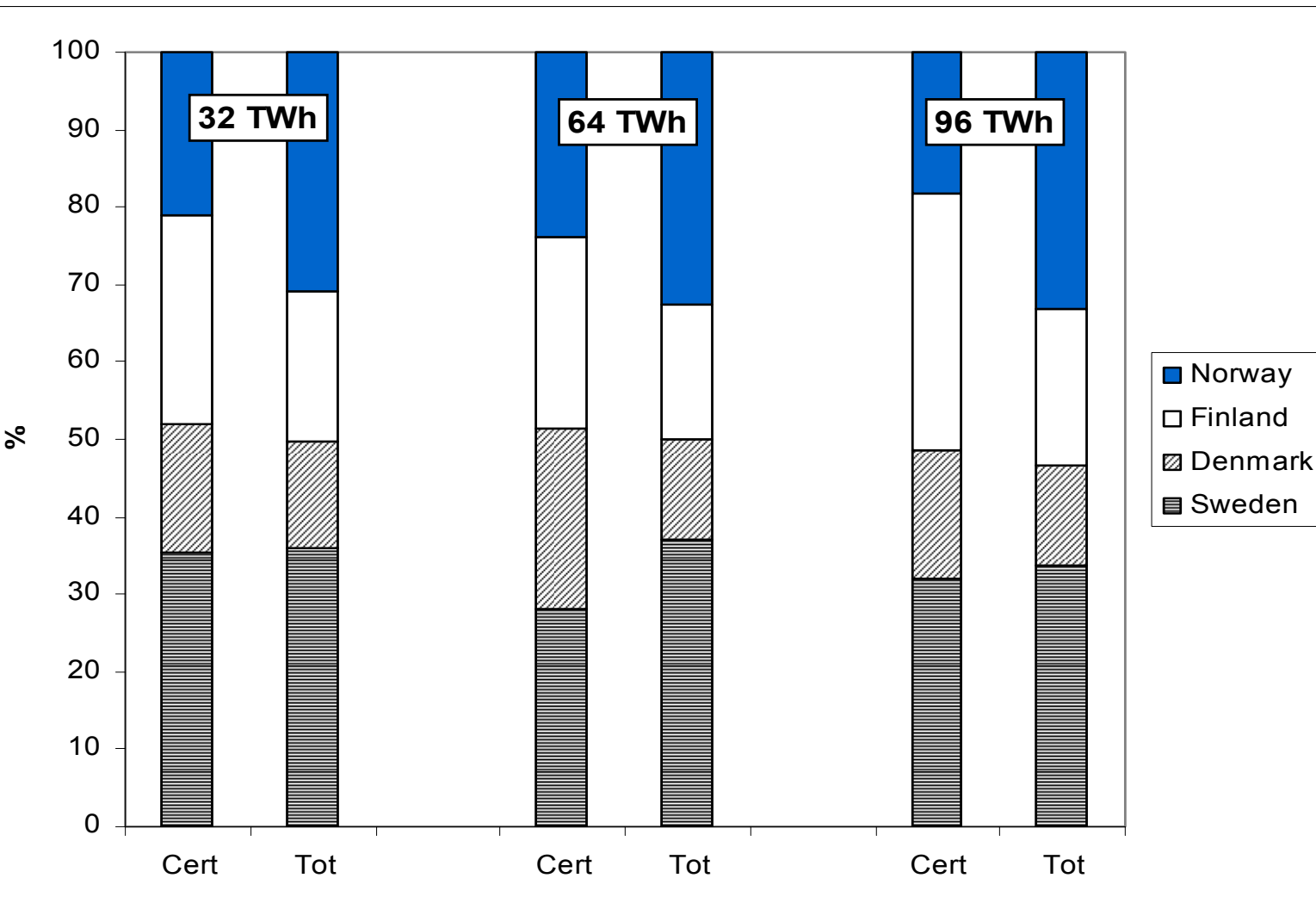
Difference in renewable power generation between scenarios where certificate trade is not allowed and allowed, respectively



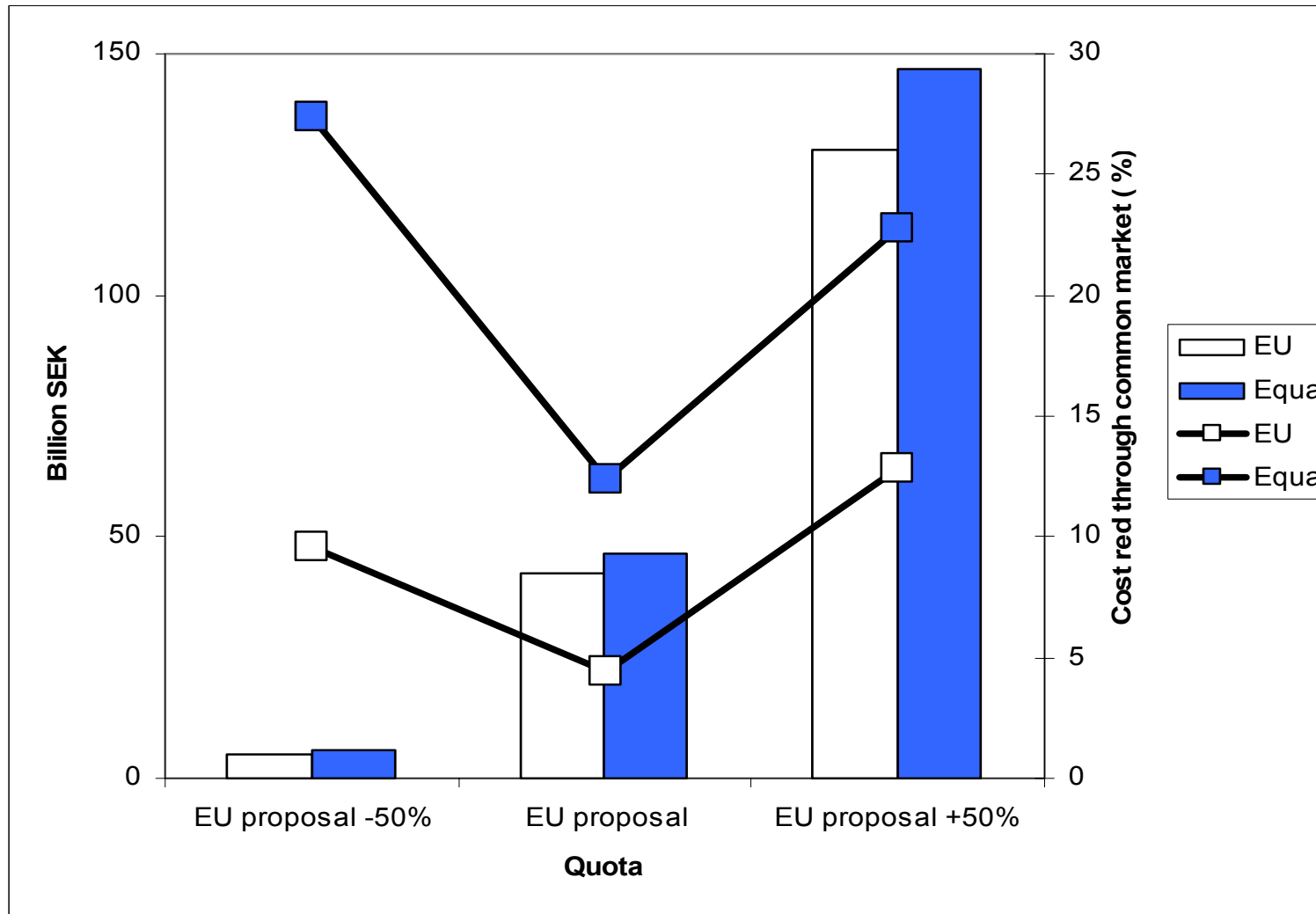
relative distribution among renewable power generation at different certificate levels in a scenario where certificate trade between the Nordic countries is allowed



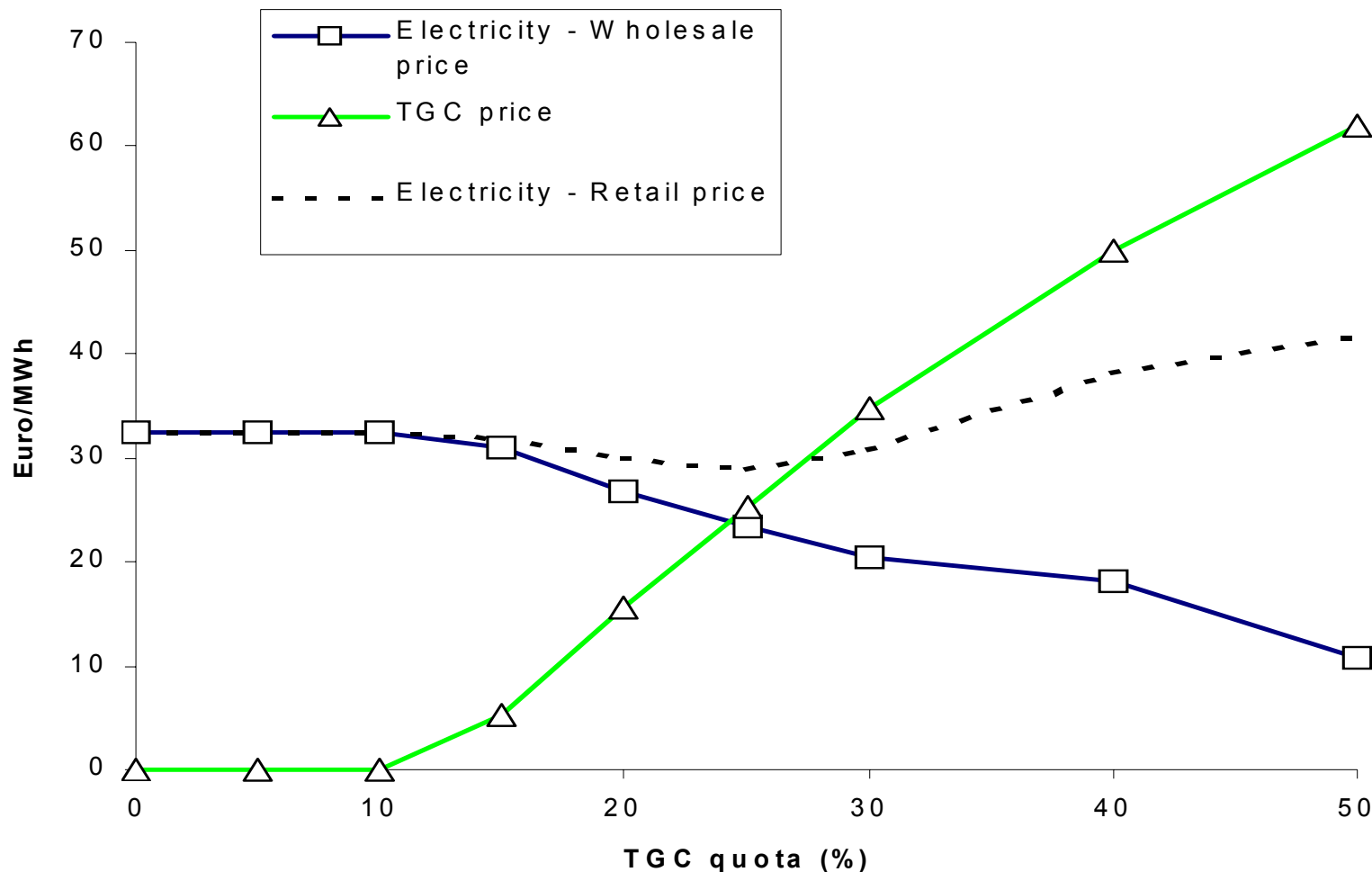
Distribution among the Nordic countries of tradable green certificates and total electricity generation when certificate trade between the countries is allowed



Total system cost shown for two slightly different distribution of the TGC between the countries (bars) and the cost reduction at joint implementation (black line)

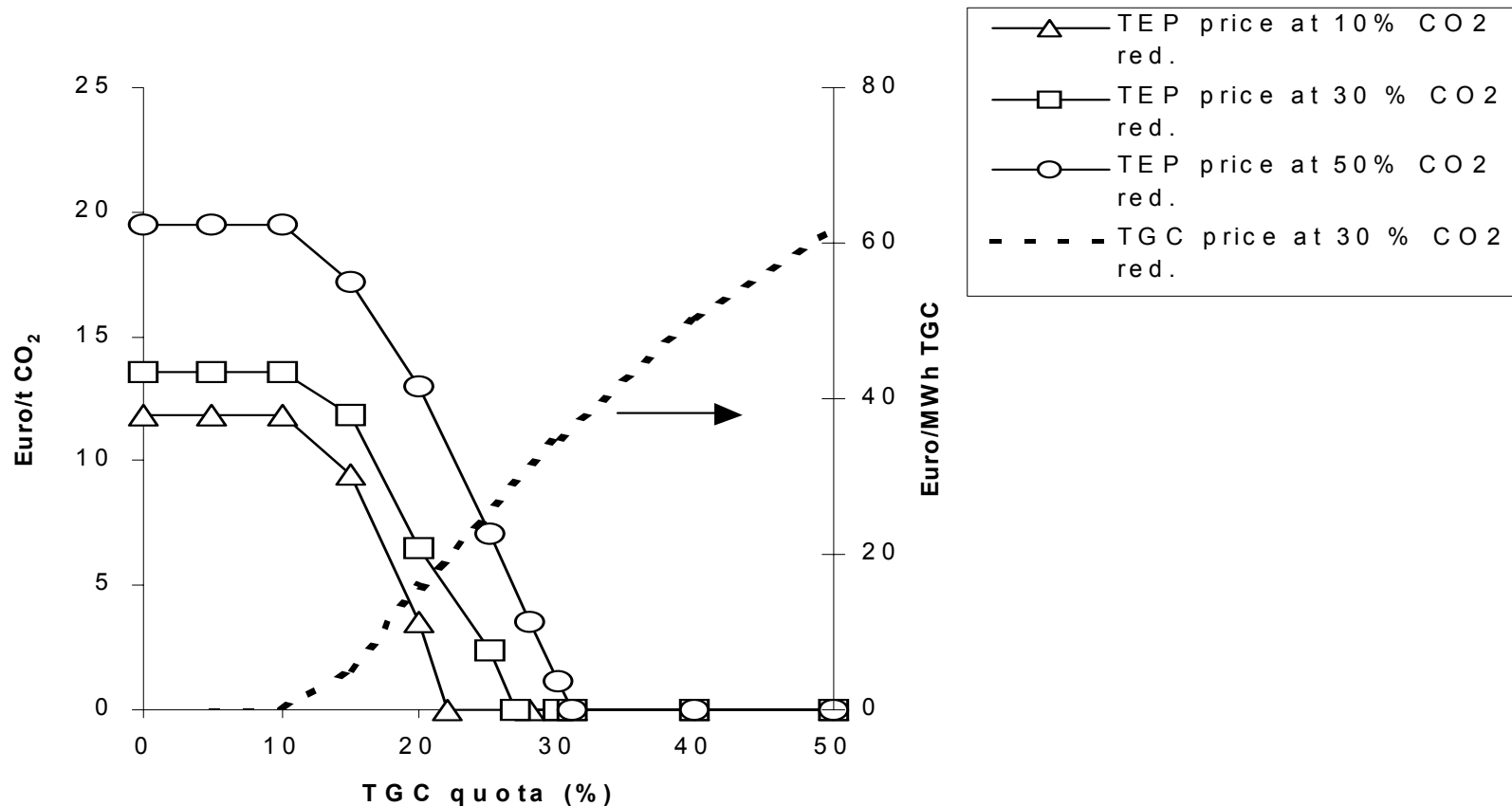


Calculated annual average wholesale and retail electricity prices, and TGC prices in 2015, as a function of TGC quota

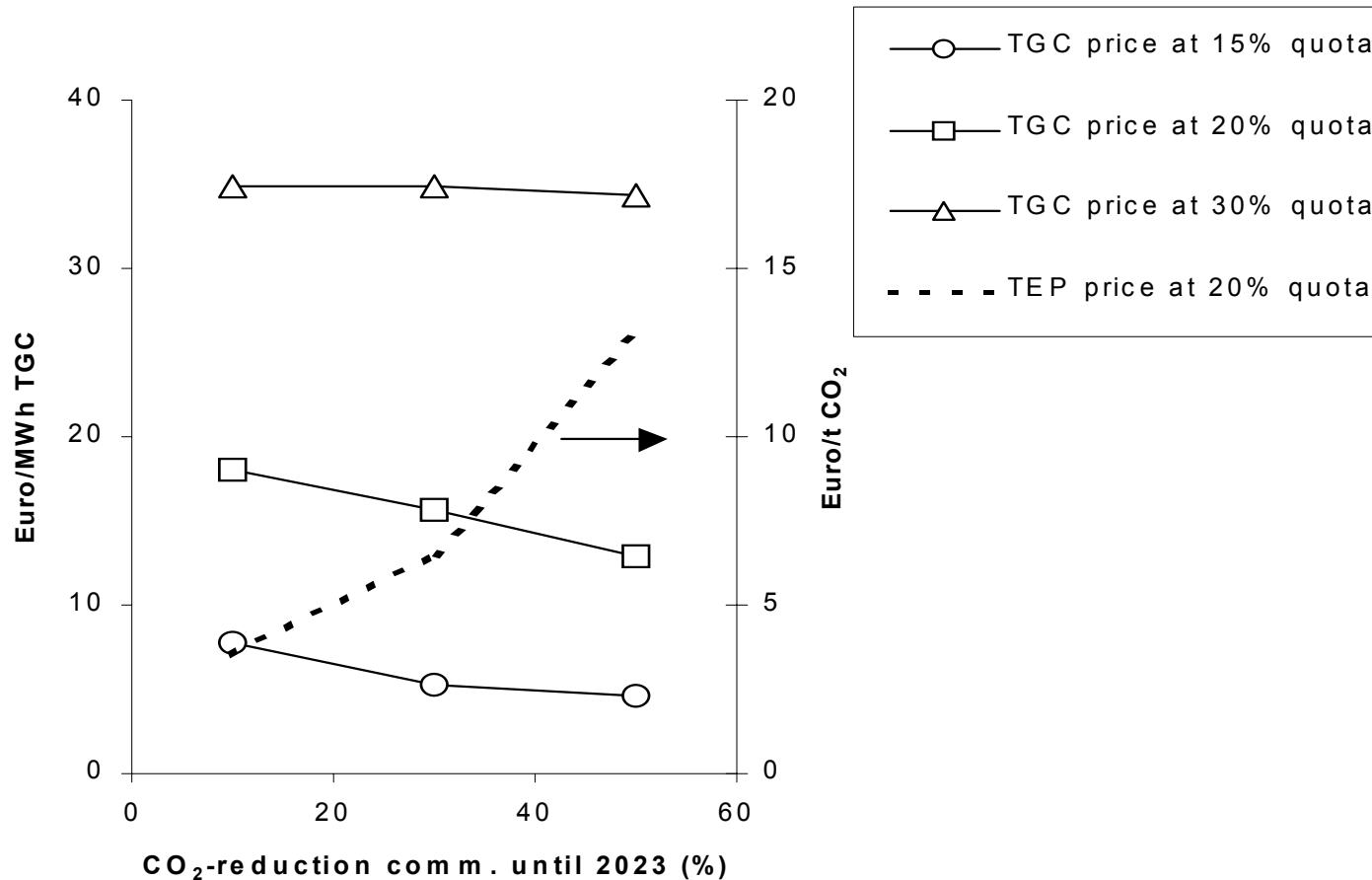


TEP and TGC at the same market

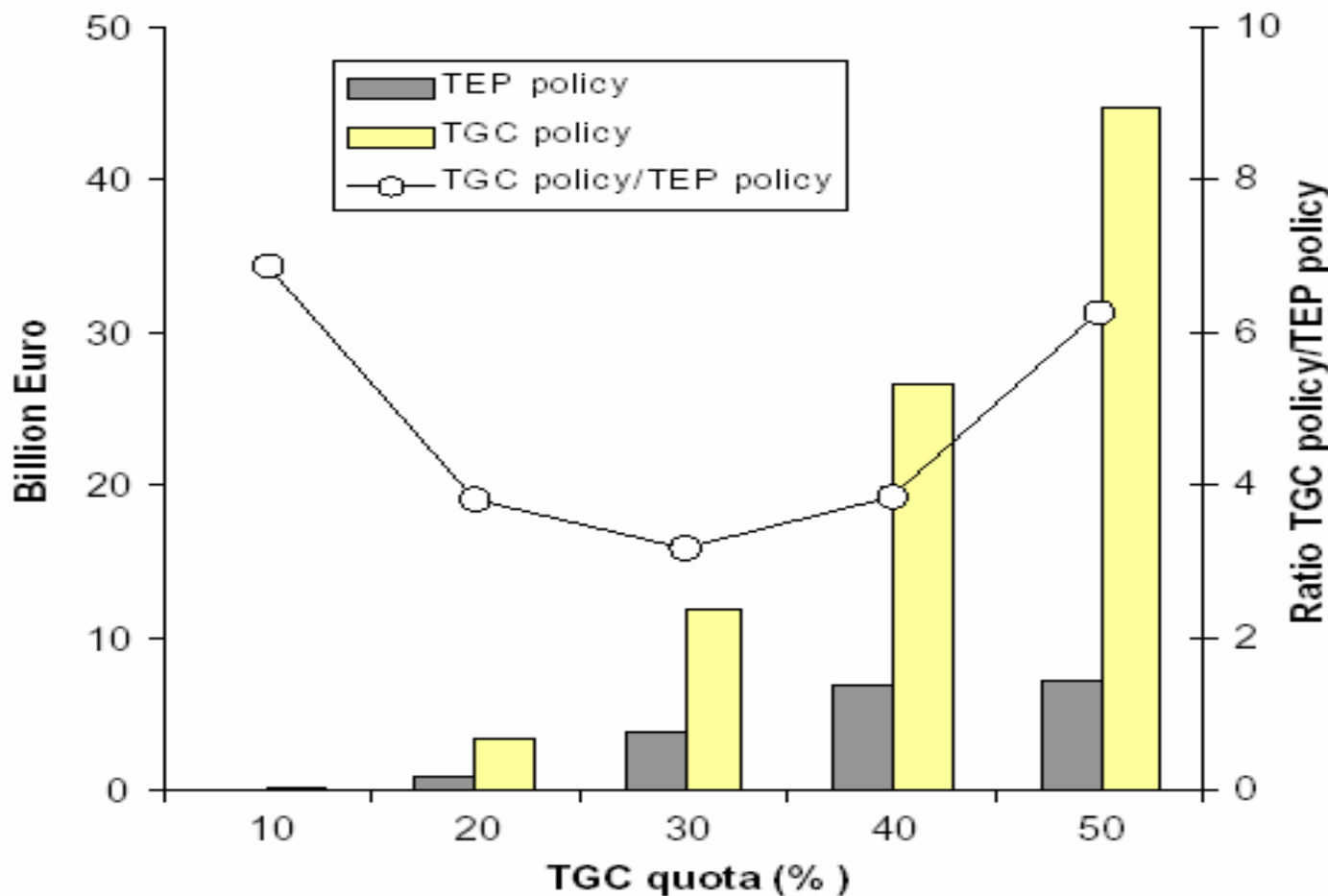
TEP prices for three different CO₂-reduction commitments as a function of TGC quotas. The broken line shows the TGC price for a given CO₂-reduction commitment of 30 percent until 2023



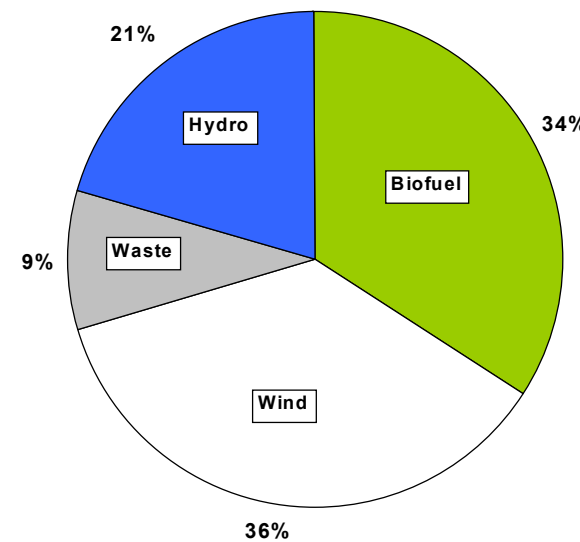
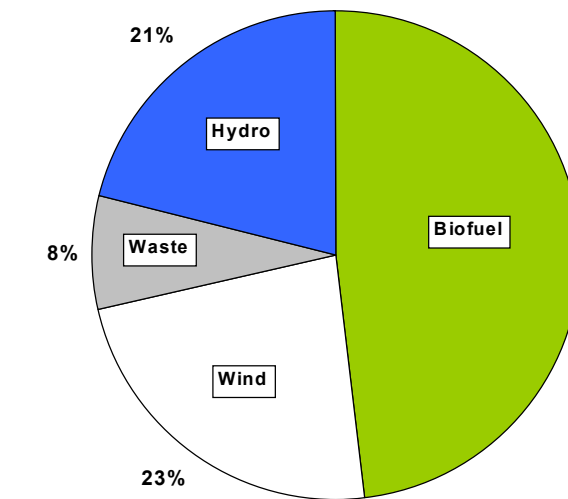
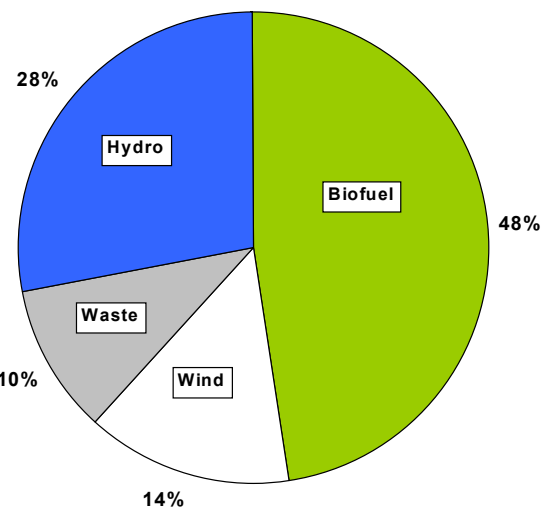
TGC prices for three different TGC quotas, shown as a function of CO₂-reduction commitments. The broken line shows the TEP price for a TGC quota of 20 percent



Total system costs for reduction of a given amount of CO₂ for tradable electricity certificates (TGC) and tradable emissions permits (TEP), respectively, and the ratio of the cost of the two policies



Market shares within the TGC scheme measured in percent of total TGC-generating electricity production in the Nordic countries for three cases: a) in 2011 fulfilling a TGC quota of 15 percent; b) in 2011 fulfilling a TGC quota of 20 percent; c) in 2017 fulfilling a TGC quota of 20 percent

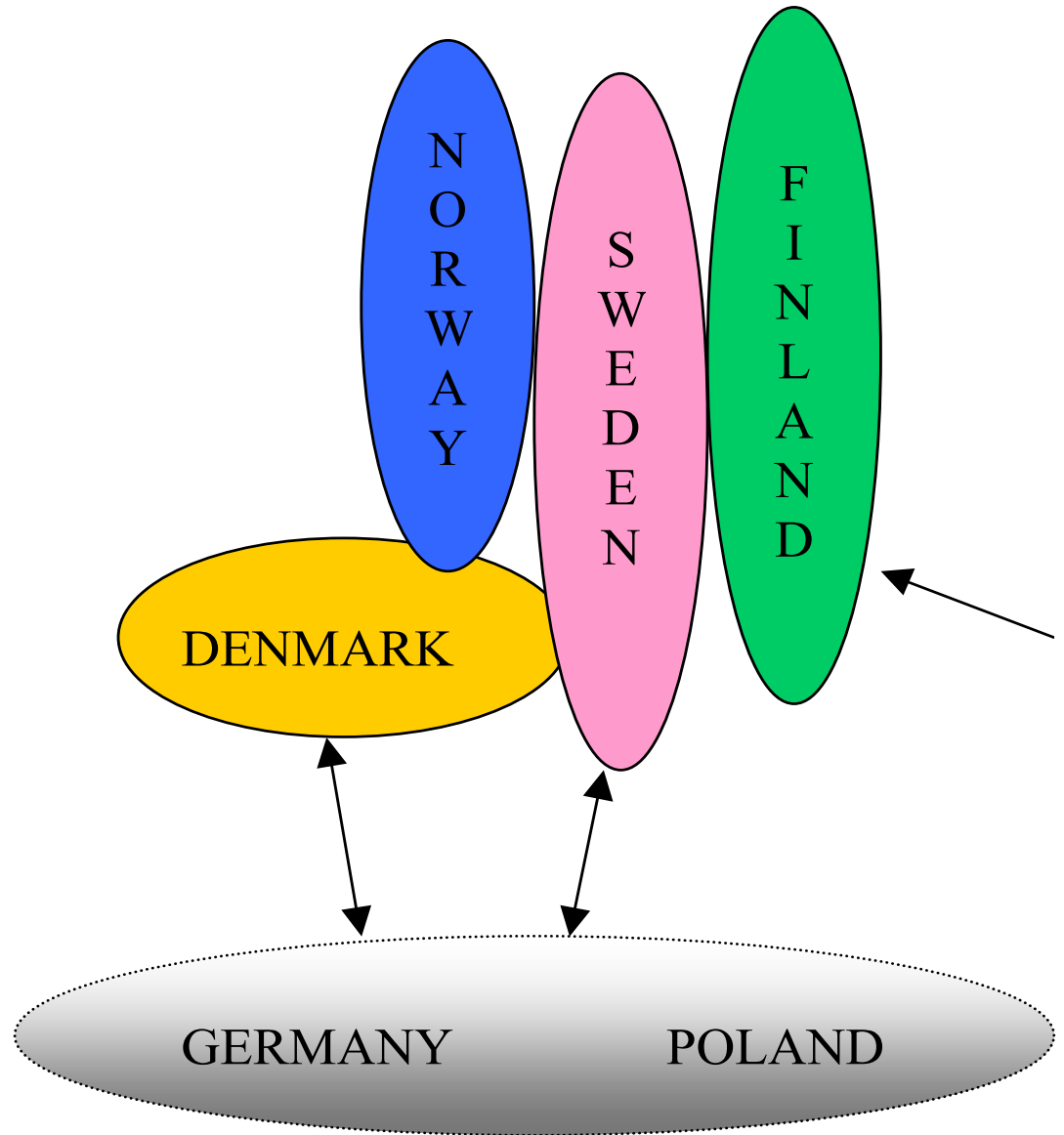


a

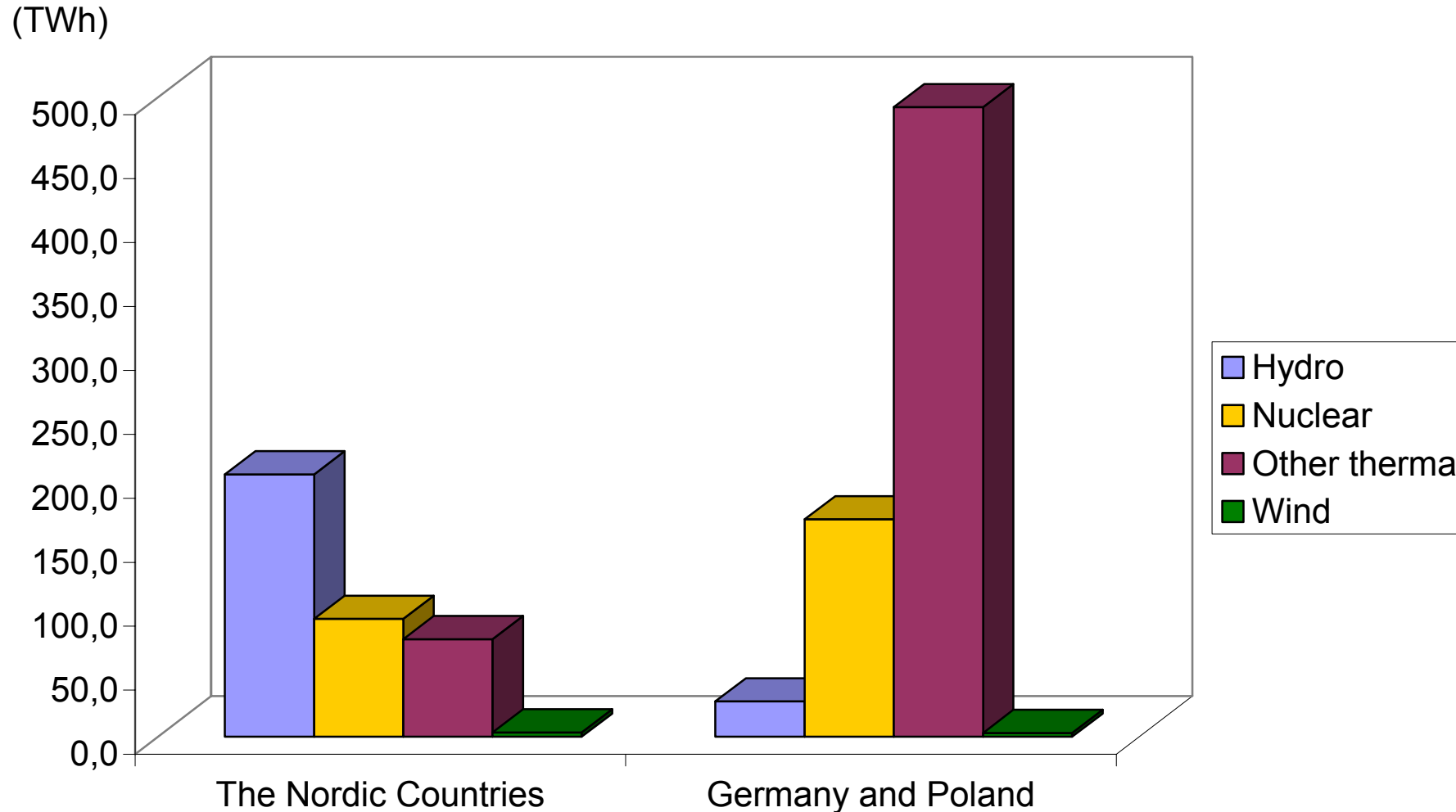
b

c

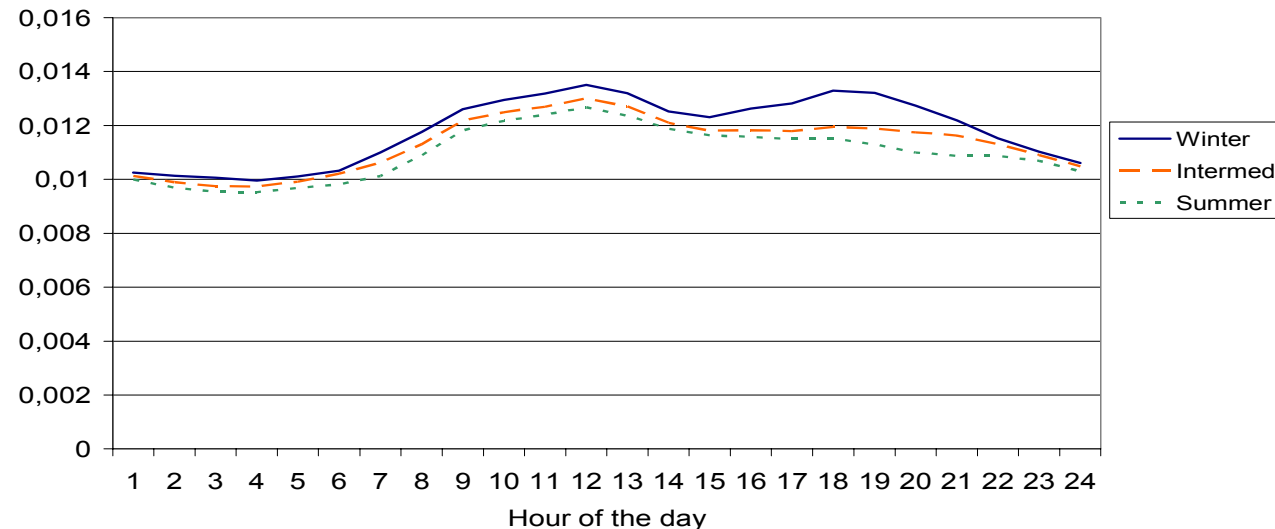
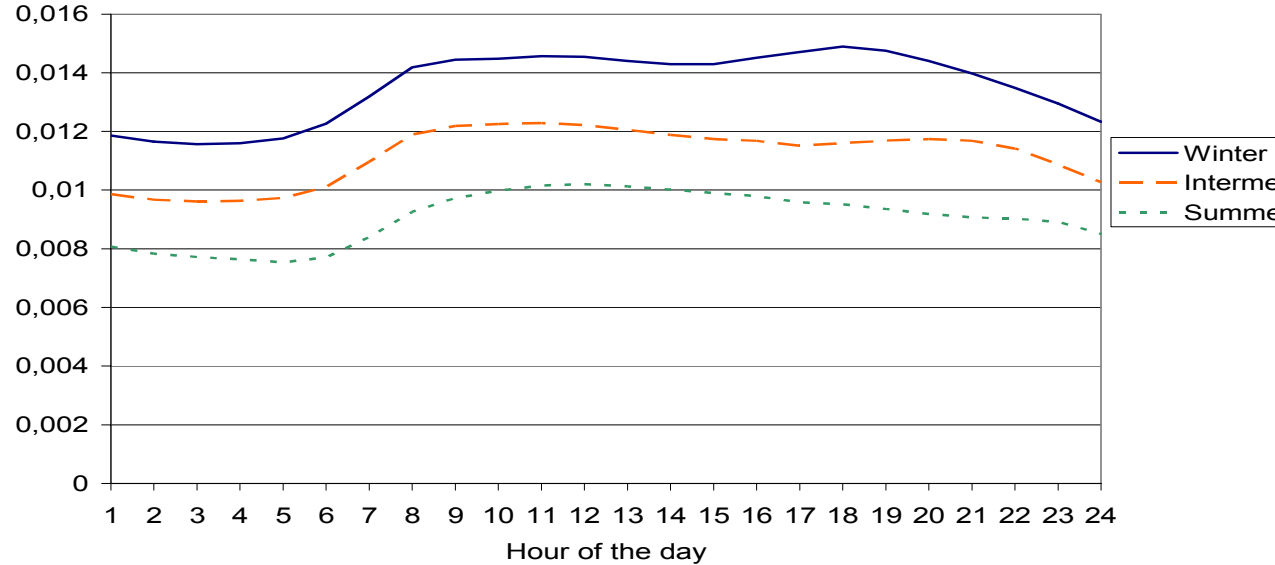
Schematic picture of the Nordic and neighbouring countries and the main power transmission lines between them



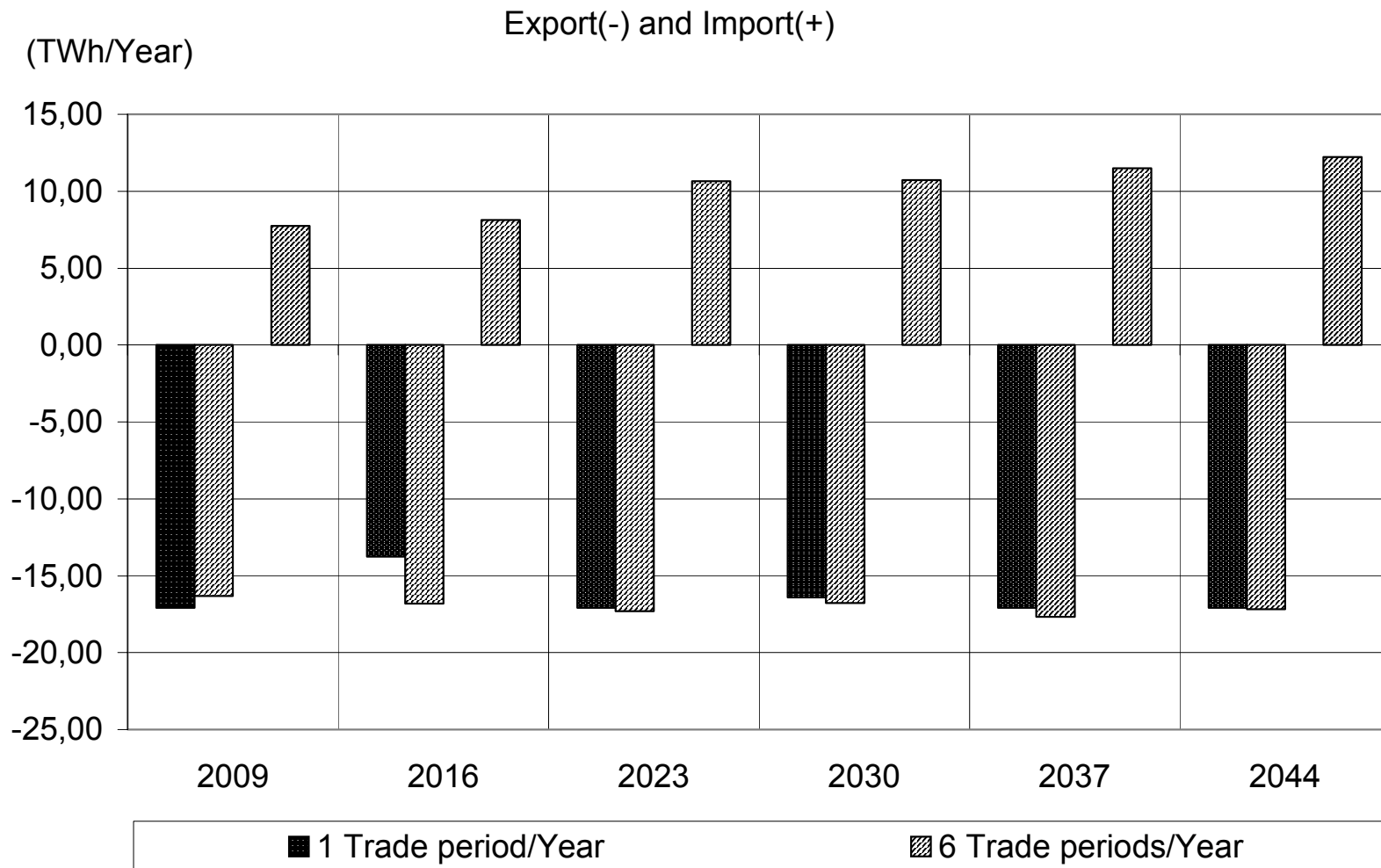
Power generation 1999



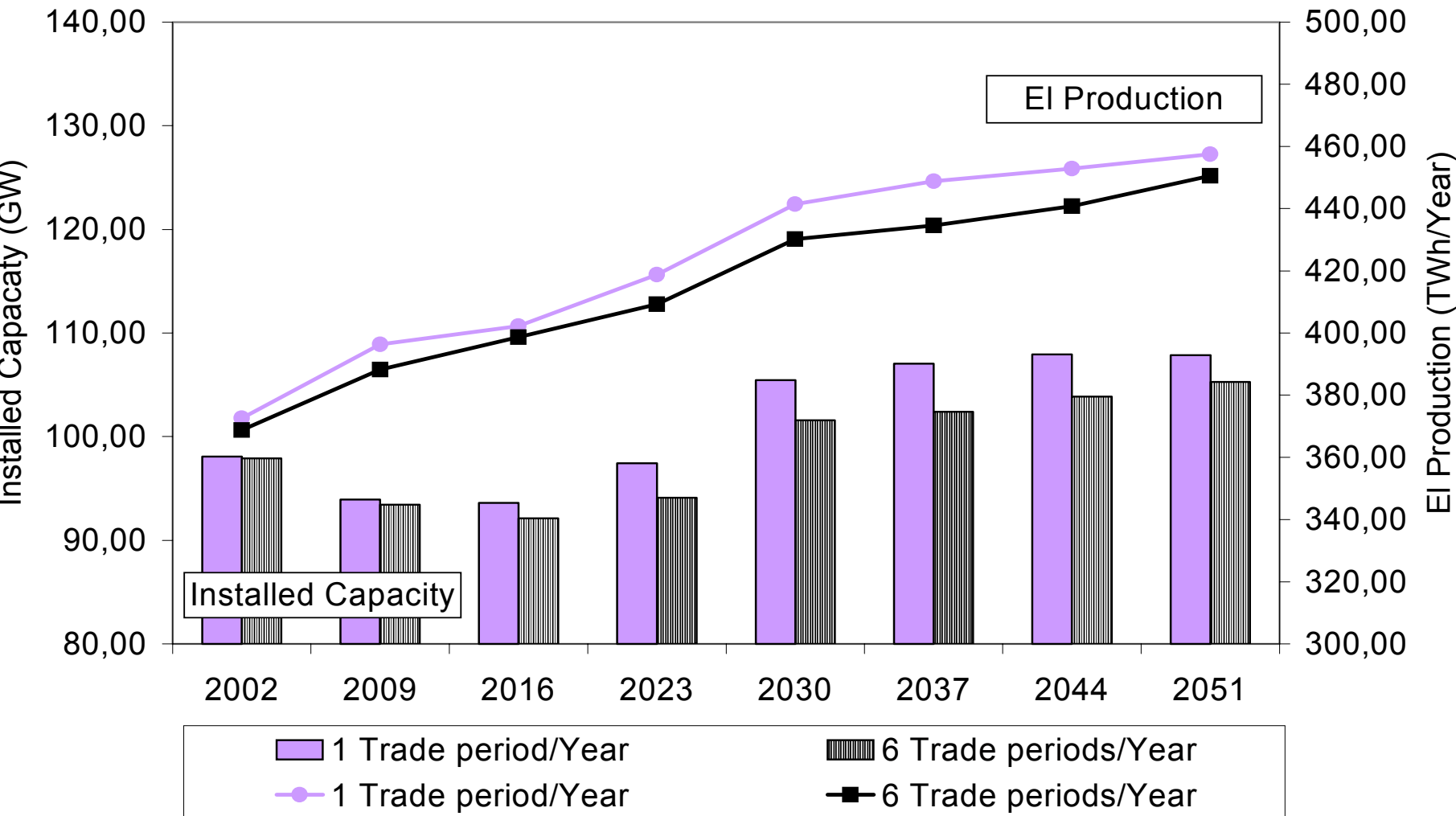
Power generation variations over hours of the day and seasons shown as share of total generation in Sweden and Germany, respectively



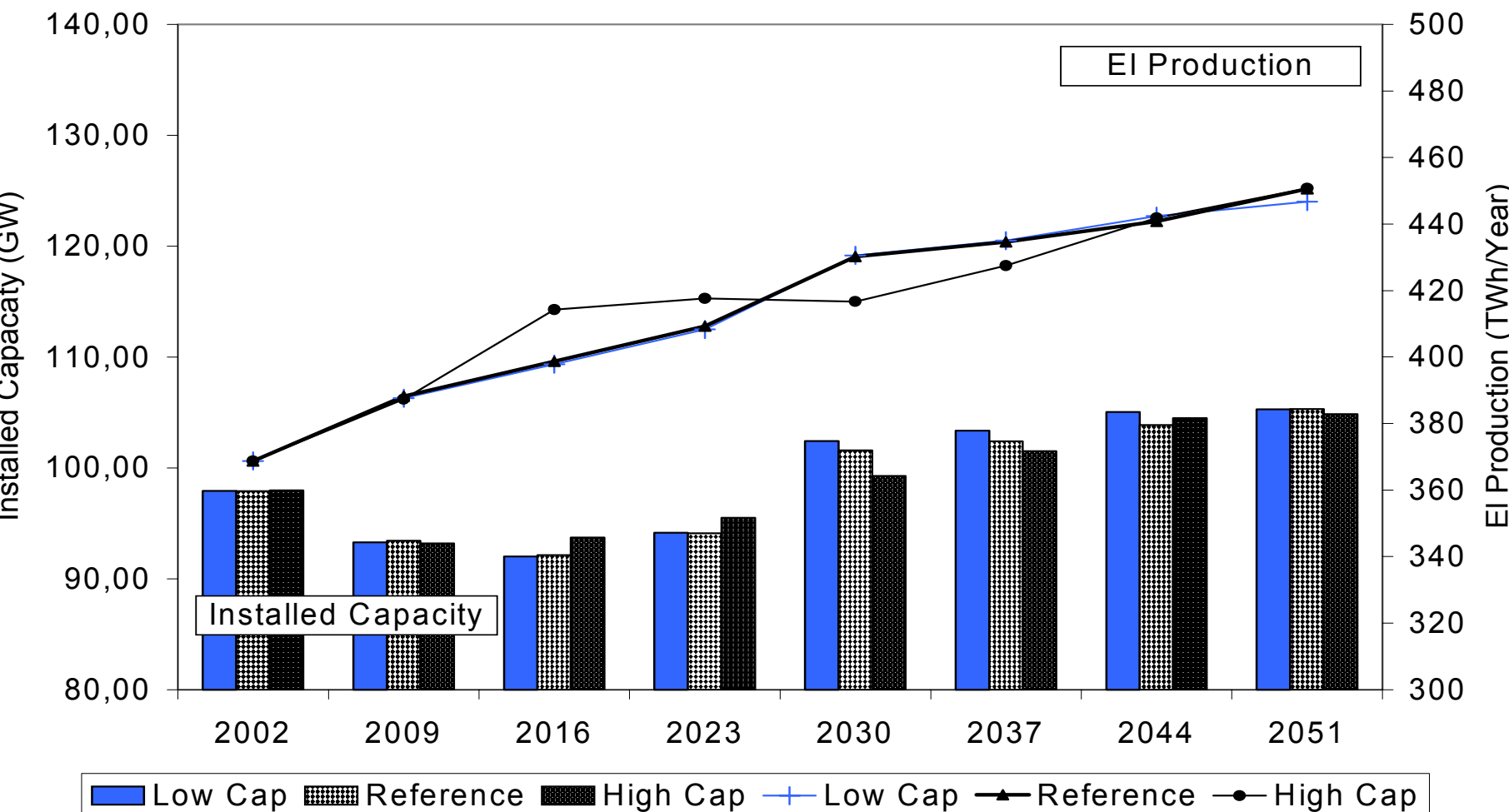
Improvement of the trade representation gave a large impact on the model results



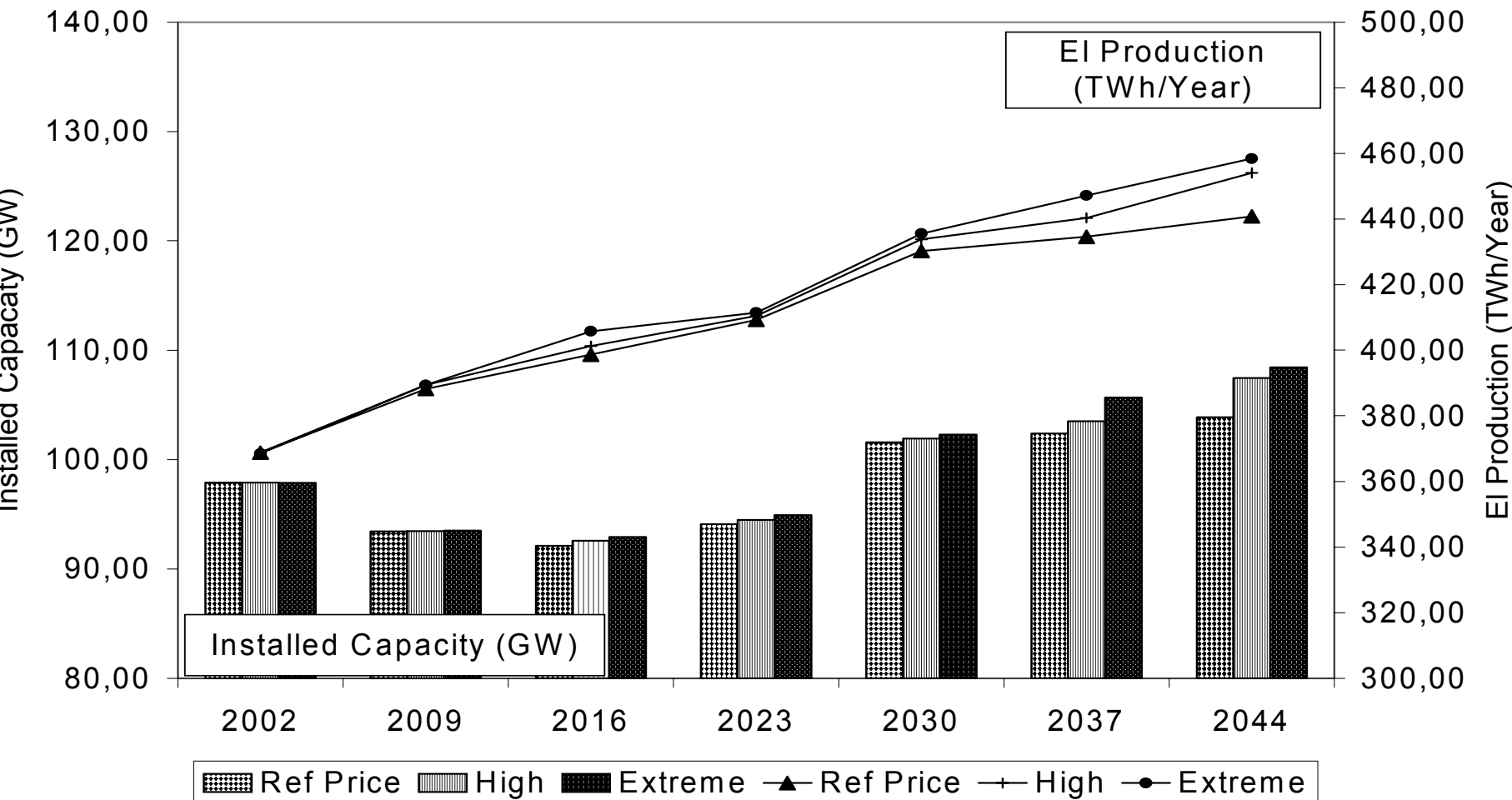
Value of power trade with the northern continental European



Model results of total installed capacity and total power generation in the Nordic countries as a function of the transmission capacity between the Nordic and German/Polish power systems



Model results of total installed capacity and total power generation in the Nordic countries as a function of the German power price



Other issues

- Nordleden was a project with large stakeholder involvement
 - stakeholders from four countries representing government agencies, industry & private organisations →
- Communication of the results important & difficult →
- Model results turned out to be an effective way of communication

Further reading

- Unger & Ahlgren; Energy Policy 33 (2005) 2152-2163
- Unger & Ekvall; Climate Policy 3 (2003) 279-294

Future issues

- Only using MARKAL_Nordic instead of MARKAL_Sweden
- System boundaries will be Europe or Northern Europe
- Supply security and system efficiency (including CHP and polygeneration plants) issues → modelling of interconnected local power and heat systems (distributed energy)

Acknowledgements

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...and finally I would like to thank the
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