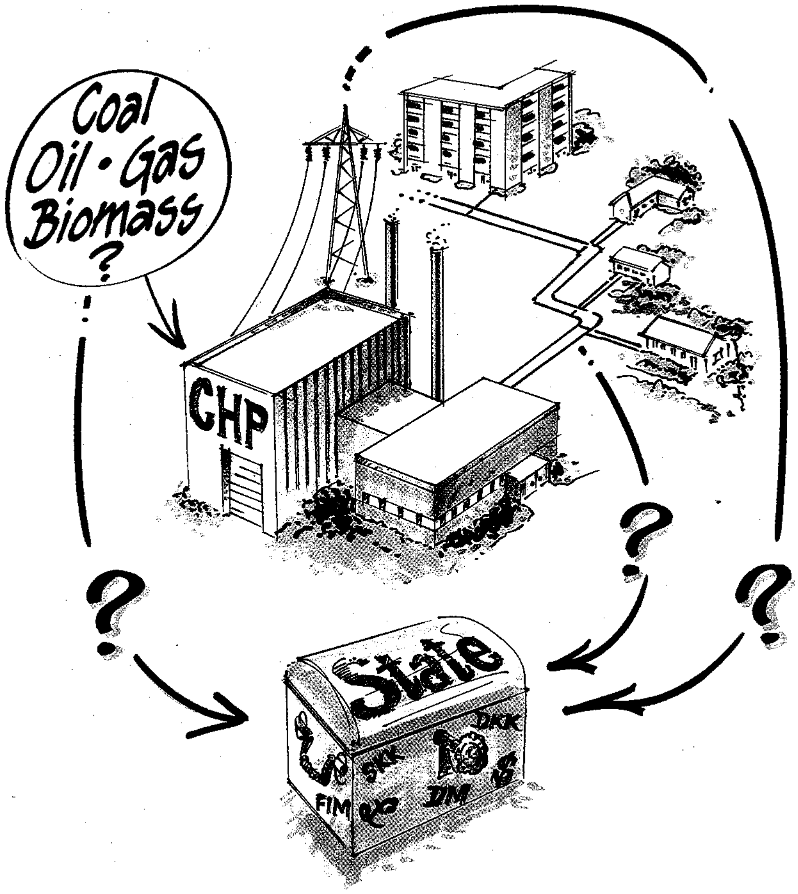
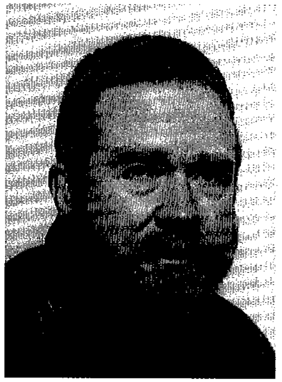
NORDVÄRME

Cogeneration and taxation in a liberalised Nordic power market

By Ole Jess Olsen and Jesper Munksgaard





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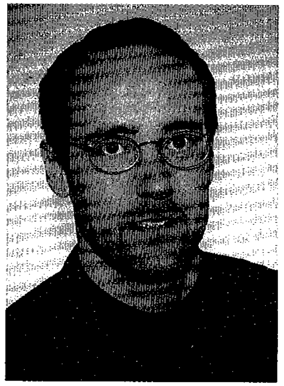

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Summary

This report is about the impact of the liberalisation of the Nordic power market on cogeneration of heat and power. Special attention is given to the effects on competition of the entirely different tax regimes in the Nordic countries. Some of the main questions answered in this study are: Which cogeneration technologies are able to compete on a liberalised power market? What are the consequences of different tax structures in the four countries for cross-border competition? Which principles should be applied if a common Nordic tax structure is to be developed? The following countries are included in the study: Denmark, Finland, Norway and Sweden.

Today, cogeneration provides a larger contribution to the energy supply in the Nordic countries than elsewhere in the world. Power generated by cogeneration plants (including district heating, industrial CHP and large condensing stations with heat extraction possibilities) accounts for about 15 per cent of the electricity supply (77 per cent in Denmark and 32 per cent in Finland). The share of the heat market is of a similar magnitude. Cogeneration's potential share of the Nordic power market is much larger than 15 per cent because of the large potential for substituting existing heat boilers by CHP-plant.

The taxation of energy is important for the competitiveness of cogeneration. The tax regimes differ considerably among the four Nordic countries both concerning the kind of taxation applied (producer or consumer taxes) and the tax incidence. Production (fuel) taxes are used for heat whereas electricity is mostly taxed at the consumer level.

Until 1997 Finland represented the exception to this general picture as a common fuel tax was applied to both heat and power. The tax burden was exclusively determined by the energy and the CO_2-content of the fuel. In 1997 Finland has substituted its fuel tax on generation of power by a consumer tax. Denmark represents the other extreme with very large differences in taxation and tax incidence. The same fossil fuel is heavily taxed when used for heat production and not taxed at all when used for power generation - some fuels are even subsidised. Households pay very high taxes whereas business firms pay very low taxes. The Swedish tax regime is somewhere in between with fuel taxes for heat and a combination of production and consumer taxes for electricity.

For the analysis of the competitiveness of cogeneration we have selected eight different technologies (three of these are gas-fired, one coal-fired, one straw-fired, one peat-fired and one is fired by wood chips) and five

power-only technologies (gas and coal condensing, hydro, nuclear and wind power). Assuming a given market price for heat (power) the production costs of power (heat) for each of the cogeneration technologies are calculated. The assumed market price for heat is given by the production costs of a heat boiler, whereas the assumed market price for power is the average price determined by model simulations of an open Nordic power market.

Our analysis demonstrates that most cogeneration technologies can compete with the power-only technologies. This is the case with respect to both long- and short-term marginal costs. The main exception is the very expensive straw-fired cogeneration technology.

The analysis is extended to include the effects of the existing tax regimes (in 1996) in Denmark, Finland and Sweden as well as of the combined energy/CO_2-tax that was proposed in 1992 by the European Commission. Each of the four tax regimes preserve the competitiveness of cogeneration within its own regime, i.e. if a given cogeneration technology is competitive without taxes it will remain so in a closed market when either Danish, Finnish, Swedish or European taxes are added. However, the four tax regimes result in very different costs for the same technology and sometimes also in different rankings of the technologies included in our analysis. The implication of this is that the same cogeneration technology will be exposed to very different conditions in an open power market with cross-border competition, if the present tax regimes in the Nordic countries are allowed to continue.

There are good economic reasons for applying taxes to achieve environmental objectives. The social costs of such taxes can be lower than the costs of other means of regulation such as administrative regulation. It can be demonstrated that a given reduction of CO_2-emissions from the Nordic countries can be achieved to a much lower cost by a combination of fuel taxes and an open Nordic power market than by a continuation of the present national policies and closed power markets. However, to achieve this purpose the taxes should provide clear, direct and relevant signals about environmental costs. Production (fuel) taxes should be preferred to consumer taxes as producers are better informed and more likely to react on the price signals provided by the tax than consumers are. The same emission should be subject to the same tax burden irrespective of where it comes from. To achieve that and to avoid unfair and inefficient competition producer taxes should be introduced internationally.

The present Nordic tax regime for heat and power is far from this goal. And the recent Finnish decision to abolish its fuel tax for power and substitute it by a consumer tax is a step in the wrong direction. A step in the right direction would be to introduce the Finnish fuel tax (or a close substitute such as that proposed by the European Commission) in the other Nordic countries.

A common Nordic fuel tax will support the competitiveness of cogeneration which is considered beneficial for the environment because of the high energy efficiency of cogeneration. A common fuel tax is compatible with a competitive power market and, therefore, is a much more efficient policy for encouraging cogeneration than the present national policies.

The introduction of a common fuel tax such as the Finnish one in the other Nordic countries will only raise a small percentage of the revenue provided by the present consumer taxes on electricity in Denmark and Sweden. However, it is possible to achieve this fiscal purpose by a continuation of a part of the consumer tax. As a consumer tax will not create any harmful effects on competition in the power market it can be designed individually by each country to achieve its fiscal objectives.

1. Introduction

This report is about the impact of national energy taxes on the competitiveness of cogeneration in a liberalised Nordic power market. The existing taxation of energy varies considerably among the Nordic countries[1]. Heat and power taxation is no exception to that. As long as district heating and power was organised by national and regional monopolies, such variations did not raise major problems for the choice of energy and energy supplier. Taxation was organised to achieve purely national objectives.

Since the deregulation of the Nordic power market this has no longer been the case. The Norwegian market was opened for competition in 1991 by a change of the electricity act. Finland and Sweden followed the same course in 1995-96 by changes of their electricity acts (cf. Larsen and Olsen, 1995). In January 1996, a joint Norwegian-Swedish power pool started its operation and thereby created a common market for the two countries. The liberalisation of the electricity supply industry in the three countries has provided all customers with access to all national suppliers and to suppliers in the neighbour countries as well. Liberalisation in Denmark has not yet gone that far - only very large customers and distribution companies (with an annual consumption above 100 GWh) are allowed to buy electricity direct from producers (third party access). Nevertheless, the limited opening of the Danish market should be enough to expose the power producers to some competition.

Cogeneration of heat and power (CHP) has large actual (16 per cent of total heat supply) or potential impact (more than 30 per cent) on the supply of heat in the Nordic area. It is considered an environmentally beneficial technology because of its high energy efficiency when compared to conventional condensing power plant.[2] Cogeneration is used both in combination with the supply of district heating that amounts for a large share of the heat supply in Denmark, Finland and Sweden (cf. Table 1) and as industrial cogeneration (in particular in Finland and Sweden). In Denmark and Finland, the major part of district heating is produced from cogeneration (CHP). In Sweden, most district heating comes from heat boilers which means that the country has a large potential for expanding cogeneration. The eventual exploitation of this potential will most of all depend on the future political decisions

1. Iceland will not be considered in this report.

2. The total energy efficiency of a natural gas turbine is about 50% when used for electricity production only as compared to 90% if all heat produced is utilized, see table 6.

concerning nuclear power.

The Nordic market for power is dominated by hydro and nuclear power (cf. Table 2). Because of natural conditions and because of political attitudes, there will presumably not be built much new capacity applying these technologies. It means that fossil fuels (coal and gas) and renewables (biofuels and wind power) will be the relevant alternatives for the choice of new power plant in the Nordic area. Power generated in plant with cogeneration possibilities that now accounts for about 15 per cent[3] of total electricity production is an obvious candidate for new generating capacity.

In the following sections we analyse the impact of the existing energy taxes on the competitiveness of cogeneration (in combination with district heating) in an open market for power. The present energy taxes in the four Nordic countries, their division among consumers and producers and the revenues they create are presented in Section 2. In Section 3, the cost of heat and power from different cogeneration technologies and the influence of taxation on their competitiveness is calculated and analysed. In Section 4, some economic principles of energy taxation are presented and compared with the existing taxation of heat and power in the Nordic countries. The consequences of introducing a more efficient tax scheme are discussed.

Table 1. Heat production in the Nordic countries in 1995 (in TWh)

	Denmark	Finland	Norway	Sweden	Total
District heating	28	25	1	39	93
- of which cogeneration	*18*	*19*	*0*	*8*	*44*
Electricity	3	8	35	28	74
Oil	14	17	7	27	65
Natural Gas	10	1	0	2	13
Biofuels (wood, straw etc.)	3	4	7	16	30
Sum	58	55	50	112	275

Source: Nordvarme, 1996

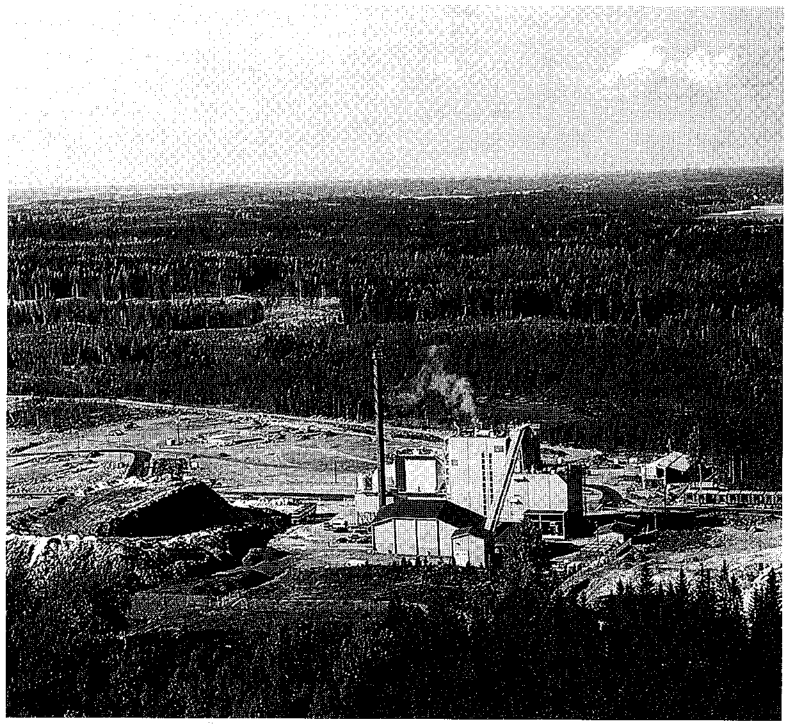
[3] *In this figure is included all power production from the Danish extraction-condensing plant.*

Table 2. Power production in the Nordic countries in 1995 (in TWh)

	Denmark	Finland	Norway	Sweden	Total
Hydro power	0	12	120	67	199
Nuclear power	0	18	0	67	85
Cogeneration[1]	27	20	0	9	56
Condensing power	8	12	0	1	21
Sum	35	62	120	144	361

1) Including industrial cogeneration (Finland and Sweden) and all power generated by extraction-condensing plant (Denmark).

Source: Nordvarme 1996; and Swedish Association of District Heating Utilities.



Finnish biomass CHP plant owned by Forsa Energy Company.

2. Taxation of heat and power in the Nordic countries[4]

Two major differences exist between the Nordic countries with respect to the taxation of heat and power:

- The use of fuel and consumer taxes varies among sources of energy and among countries. Fuel taxes are mainly applied to heat whereas consumer taxes are mainly applied to power.
- The tax incidence per unit of heat or electricity produced or consumed varies enormously.

The implication of such large variations in taxation is of course different incentives for producers and consumers of heat and power in the Nordic countries. We will return to this discussion in Section 4 and limit the presentation in this section to the existing heat and power taxes in the four countries.

2.1. Fuel and consumer taxes

Finland is the only one of the four Nordic countries that has attempted to employ the same principle of taxation for different energy industries and different applications of energy. Until the end of 1996 the system was as follows (it will be applied everywhere in our calculations):

- each fuel is taxed according to its energy content (25 per cent of the tax) and its content of CO_2 (75 per cent of the tax). The share of energy in the tax is 3.5 FIM/MWh fuel, whereas the share of CO_2 is 38.3 FIM/ton CO_2
- biofuels (wood) are not subject to taxation whereas peat is exempted to the CO_2-part of the tax
- hydro and nuclear power are both subject to specific production taxes
- imported electricity is taxed to prevent it from being favoured. This tax is defined as the weighted average of the domestic tax on electricity and is calculated to 22 FIM/MWh electricity (cf. Finnish Association of District Heating Utilities).

The tax regime in Finland is being changed in 1997 to one more like that in Denmark and Sweden with consumer taxes for electricity.

Denmark and *Sweden* use fuel taxes for heat and consumer taxes for electricity. There are, however, exceptions to this rule. In Denmark, wind turbines and cogeneration on biofuels (straw and wood) are subsidised with 270 DKK per MWh electricity, whereas cogeneration on natural gas is subsidised with 100 DKK per MWh electricity[5]. The fuel applied to heat production (except from biofuels) is taxed according to its content of energy, CO_2 and SO_2.

[4] *The exchange rates applied in the paper are the following: 1 DKK = 0.78 FIM = 1.12 SEK = 1.11 NOK = 0.14 ECU.*

[5] *In 1997 the subsidy has been reduced to 70 DKK per MWh for most cogenerators.*

With respect to natural gas, the Danish tax regime is a bit complicated. Natural gas utilised in heat production includes a direct tax (0.22 DKK/m^3 CO_2-tax and 0.01 DKK/m^3 energy tax) and a shadow tax as well. The latter is the result of the Danish pricing of natural gas that was introduced during the Mid-Eighties. Its purpose was to protect and finance the heavy investments in the national gas transmission system, that was completed at that time, against the effects of declining international fuel prices. The gas price is determined to make it possible for gas to compete with the most likely alternative fuel including taxation. For a household consumer the alternative heat technology in most cases is an oil-fired boiler and the gas price includes the duty on light oil. For a CHP-generator, where the alternative typically is a fuel oil boiler, the price of gas used for heat production includes the tax on this fuel, whereas the price of gas used for power production, which is not taxed, is much lower (cf. Danish Association of District Heating Utilities).

In *Sweden*, power taxes are mainly paid by the consumers (manufacturing industry is exempted from the tax), whereas heat taxes are fuel taxes (defined according to the content of energy and CO_2 respectively). Exceptions to this rule are the SO_2-tax (30 SEK/kg sulphur) and the NOx-tax (40 SEK/kg NOx), which are paid by power producers too. Hydro and nuclear power are subject to specific production taxes as in Finland and wind power is subsidised as in Denmark (cf. Swedish Association of District Heating Utilities).

The level of energy taxation in Denmark and Sweden is in general much higher than in Finland (cf. Table 3 and 4).

Today, all power production in *Norway* comes from hydro power plants. Electricity is the main source used for heating (70 per cent). Electricity is subject to a combination of producer and consumer taxes (cf. Norwegian Association of District heating Utilities). The tax on power generation is differentiated according to the age of the hydro power plant (the older the higher the tax). Fossil fuels (coal and oil) used for heat production are taxed in Norway. Concerning the future, an important issue is the taxation of natural gas used in power production as the combined cycle gas turbine (CCGT) is considered as the most promissing alternative to the construction of new hydro power capacity. It has not been decided yet whether natural gas should be taxed or not.

The Nordic producer and consumer taxes for heat and power are summarised in Table 3. Different taxes are added to provide a single figure (in DKK) for each technology and for each group of consumers.

Table 3. Taxation of heat and power in the Nordic countries in 1996 (DKK/MWh)

	Denmark	Finland	Sweden [5]	Norway
1. Power				
Production taxes				
Hydro	-	5	36[4]	14
Nuclear	-	30	11	-
Wind	-270	0	-80	-
Fuel taxes				
Coal	0	21	18	-
Oil (fuel oil)	0	21	18	-
Gas	0	7	0	?
Peat	0	5	28	-
Wood, straw, etc.	-270	0	0	-
Consumer taxes				
Households[1]	469	0	85	48
Business firms	100	0	0	0
2. Heat				
Coal (0.8% sulphur content)	171 (0.8% sulphur)	21	145 (0.5% sulphur)	-
Oil (fueloil)	185	21	125	-
Gas	21 (167[3])	7	74	?
Peat	-	5	25	-
Wood, straw, etc.	0	0	0	-
Electric heating[2]	434	0	85	47

1) In Sweden and Norway, only mining, manufacturing and green houses are exempted from consumer taxes on electricity; in Denmark, all business firms are exempted.
2) The same groups as in note 1 are subject to taxation.
3) Including shadow tax on natural gas that is only relevant for small (decentral) CHP-plant.
4) New generators pay lower taxes (differentiated according to the year of inauguration).
5) The NOx-tax that is recycled to the firms paying the tax is not included for Sweden.
Source: The four Nordic Associations of District Heating Utilities; Nordisk ad hoc gruppe 1995.

2.2. Revenues from taxation of electricity

The revenues from energy taxation are of very different magnitudes in the four Nordic countries. The revenues from electricity taxation in 1995 are shown in Table 4. They are largest in Denmark, smallest in Finland and in between in Sweden and Norway, but closest to the Danish level. The high Danish taxes are exclusively consumer taxes that are mainly paid by households and the public sector. As these groups together consume about 40 per cent of total electricity consumption, they are exposed to an extremely high tax incidence.

Table 4. Taxation of electricity in the Nordic countries in 1995

	Denmark	Finland	Sweden	Norway
1. Average consumer tax (DKK/MWh)	203	0	35	25
- households	302	0	57	46
- industry	35	0	0	0
2. Average fuel- and production duties (DKK/MWh)	0	24	6	12
3. Total revenues (billion DKK)	7	2	5	4
4. Revenue per MWh - (DKK/MWh)	203	25	41	39

Source: Nordisk ad hoc gruppe 1995.

3. The competitiveness of different power technologies

Competition should select the most efficient power technologies, i.e the technologies implying the lowest production costs. The investor will select the power production technologies having the lowest long run production costs. Thereby he expects to maximise his revenue.

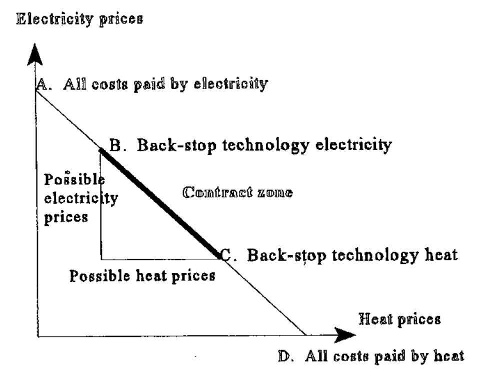
The competitiveness of different cogeneration technologies in an open Nordic market for power is the subject of this section. A simple model for analysing long- and short-term marginal costs is employed in the analysis. The division of common costs between heat and power is of course decisive for the resulting cost estimates of the two goods and, therefore, for the competitiveness of cogeneration. Principles for this division are discussed in the first subsection. The technologies included in the analysis are presented in the following subsection. The production costs of selected cogeneration technologies are then calculated as an indicator of their competitiveness and compared with the production costs of the competing power-only technologies. The production costs are calculated with and without the relevant fuel and production taxes in Denmark, Finland and Sweden.

3.1. Division of costs for cogenerated heat and power

The allocation of total production costs (the overwhelming part of which are common costs)
is decisive for the competitiveness of cogenerated heat and power. If back-stop technologies in the form of heat-only and power-only generation are available (perhaps in the disguise of a market price), it is possible to delimit a contract zone that contains the set of possible cost-allocations between heat and power. Outside this zone, cogeneration can not compete with the back-stop technology of either heat or power which is then the cheapest supply option for consumer (his or her distribution company). The argument is illustrated in Figure 1.

Theoretical principles exist for the choice of allocation in the contract zone in order to maximise the total revenue of cogeneration. The so-called Ramsey pricing (cf. Baumol and Bradford, 1970) will allocate production costs in inverse proportion to the prices elasticities of the two products. If we, for instance, assume that heat demand is relatively inelastic (because it is expensive for district heating customers to change to another type of heat) and electricity relatively elastic (because competition in the power market provides the customers with cheap alternative sources), heating will be forced to pay the lion's share of production costs (the selected point of allocation is closer to C than to B in Figure 1). This could be a description of the Nordic scene after the opening of the power market for competition.

Figure 1. Division of costs between cogenerated heat and power



With respect to our analysis, we define the back-stop technology of electricity (point B in Figure 1) as the expected (average) equilibrium price in the Nordic power market (cf. Section 3.1.1). Similarly, we have selected a gas-fired heat boiler (or biomass-fired boiler) as the back-stop technology of heat (point C in the figure)[6].

For non-competitive technologies there will be no positive contract zone at all. The straw-fired cogenerator which has been selected for our calculations in Section 3.4 is an example of that. For other technologies the contract zone can exceed point A or point D indicating that the selected back-stop price allows all costs (more than) to be covered by either the power or the heat production. This is indicated by a negative price in our calculations. An example is the wood chips cogenerator.

3.1.1. Prices in an open Nordic power market

Which prices will be the result of an open Nordic market for electricity? Such a market has been modelled by various Norwegian researchers. The type of models applied are partial equilibrium models simulating a Northern European power market. Partial equilibrium means that there are no price and quantity effects on other sectors of the economy. The assumptions of the production costs of the power technologies included in the models are relatively simple. Cogeneration technologies are

[6] *The arguments for choosing a heat boiler and not a cogenerator as the back-stop technology are as follows: the district heating costumers demand a cheap and reliable supply of heat; they have no interest in selling power and also feel repelled by this market because of its price volatility.*

generally not included. Details about the models can be found in the quoted literature (cf. the sources to Table 5). Prices are calculated at the power station level.

Table 5 shows different scenarios for power prices in the four Nordic countries. The first scenario represents the initial situation before the power market is liberalised. Two scenarios simulate the consequences of liberalisation in the short term whereas the remaining two simulate the long-term consequences.

Table 5. Prices in an open Nordic market for power*

	The situation before the market was opened (1991)[1]	Free trade - short term[2] (1994)	Free trade - short term[3] (1990)	Free trade - long term[1] (2005)	Free trade - long term[4] (2000)
	DKK/MWh	DKK/MWh	DKK/MWh	DKK/MWh	DKK/MWh
Denmark	320	160	130	230	250
Norway	130	170	110	210	200
Sweden	230	170	110	250	210
Finland	290	180	110	250	230

*) The studies reported in column 2 and 4 include only the four Nordic countries, whereas the studies reported in column 3 and 5 also include some Central European countries, first of all Germany.
Sources: 1) Johnsen og Mysen, 1994; 2) Halseth, 1996; 3) own calculations on the results from Amundsen et.al., 1994; 4) Amundsen et.al., 1993.

The short-term prices indicate a situation with excess capacity and, therefore, are determined by the variable (fuel) cost of condensing technologies (coal and gas). Similarly, the long-term prices indicate a situation with capacity constraints in which it has become profitable to invest in new capacity.

The figures could also be interpreted as representing respectively peak and off-peak prices within the same year which corresponds to an annual average price of 200 DKK/MWh in the Nordic power market. This is also the average (unweighted) annual "world market" price after the year 2000 calculated in a recent study by Statistics Norway (cf. Hansen, Johnsen and Oftedal, 1996). The "world market" consists of the four Nordic countries, Germany and the Netherlands.

3.2. The selected heat and power technologies
Seven cogeneration technologies have been selected for our analysis
- 1. CHP gas turbine (5-15 MW)
- 2. CHP gas motor (0.2-5 MW)
- 3. Combined cycle gas turbine (75-400 MW), extraction condensing
- 4. Coal steam turbine (400 MW), extraction condensing
- 5. Straw-fired steam turbine (5-50 MW), backpressure
- 6. Peat-fired steam turbine (60-120 MW), backpressure
- 7. Wood chip steam turbine (17-48 MW), backpressure.

All technologies exist at the present Nordic market and will presumably dominate the market in years to come. The economic and technical parameters of the selected cogeneration technologies are presented in Table 6.

Some definitions might be helpful:
- "Fuel costs" are specified in DKK/GJ according to the data sources used in our study, i.e no explicit heating values have been used. In Energistyrelsen (1995) the following heating values are used for the energy price forecasts: Natural gas (39 MJ per m^3), coal (25.2 GJ/ton) and straw (14.5 GJ per tonne).
- "The CO_2 emission" for biofuels (including peat) has been defined as zero according to the fuel cycle principle. Of course that is a matter for discussion and involves some political opportunism.
- "Investment period" is the time (in years) it takes to built the plant.
- " Investment costs" are defined as unit costs, i.e as mio. DKK per MW power capacity.
- "O&R costs" are operation and maintenance cost per year as a percentage of total investment costs.

Table 6. Economic and technical parameters for CHP-technologies[a]

Type of technology	Gas turbine	Gas motor	Gas c.c	Coal	Straw	Peat [d]	Wood chips [d]
Total efficiency	0.90	0.89	0.88	0.91	0.84	0.88	0.88
Efficiency of power production	0.35	0.39	0.55	0.45	0.23	0.29	0.23
Fuel costs[b] (DKK/GJ)	22	22	22	12.7	16.6	16	14.2 (26.0)
CO_2-emission (kg/GJ)	57	57	57	95	0	0	0
SO_2-emission (kg/GJ)	0	0	0	0.05	0.1	0.1	0.02
NOx-emission (kg/GJ)	0.05	0.14	0.05	0.05	0.23	0.1	0.05
Investment period[c]	1.5	1	3.5	4.5	2.5	2.5	2
Investment costs (mio.DKK/MW)	5.25	5.64	5.17	8.54	22.3	8.53	7.90
O&R costs (%)	3	5.6	2.5	3	5	1.2	1.2
Lifetime (years)	25	22.5	30	30	30	25	25

Sources: Energistyrelsen, 1995 (for gas, coal and straw technologies); the data for the peat and wood chips technologies are provided by the Finnish Association of District Heating Utilities.

a) The following general parameters are used for all cogeneration technologies:
•Real rate of interest: 5 per cent[7].
•Annual hours of generation: 4,500 for heat and 5,300 for electricity for the two condensing-extraction technologies; 4,500 for all other technologies.

b) It is reasonable to assume a common price for fossil fuels that are sold on a world (European) market. For biomass (straw, peat and wood chips) it's much less reasonable as the prices of these fuels will very much depend on local conditions (availability). The prices of wood chips that we were told can be used to illustrate that: in Finland it was 14 DKK/GJ, in Sweden it was 26 DKK/GJ and in Denmark 30-34 DKK/GJ. The Finnish and the Swedish price are applied as alternatives in our calculations.

c) Inclusive interest during the construction period.

d) The assumption has been made that the emissions of peat and wood chips are identical to those of straw. The same kind of assumption has been made for the efficiency of power production.

[7] A real rate of interest on 5% has often been used in the power production sector. However, one can argue that this interest rate should be higher (ex. 10%) in a competitive market in order to take into consideration risk.

It appears from Table 6 that the technologies are very different with respect to efficiency of power production and costs. Power efficiency varies between 23% (straw-CHP) and 55% (gas combined cycle). The gas technologies have the highest fuel costs. However, their investment costs are low (about 5 mio. DKK/MWh). Straw-CHP has far the highest investment costs of 22 mio. DKK/MW.

Five power-only technologies have been included in the analysis as competitors to cogeneration:
• 8. Combined cycle gas turbine, condensing mode
• 9. Coal dust steam turbine, condensing mode
• 10. Hydro power station
• 11. Nuclear power station
• 12. Wind turbine (600 kW)

Sources: Energistyrelsen 1995; Grohnheit, 1996; and Larsen and Munksgaard 1996.

Taxation: In the following calculations we will apply the heat and power taxes presented in Table 3 to the selected technologies. Only production and fuel taxes that are relevant for the competitiveness of different technologies are included.

3.3. Production cost and competitiveness of cogeneration

In this section the results from the analysis are presented for the selected technologies. The objectives of the analysis are the following:
• To calculate the levelised costs of heat and power production for each of the selected cogeneration technologies asssuming that the price of either heat or power is exogenously given by the back-stop technology.
• To calculate short-term as well as long-term marginal costs for each technology. Short term marginal costs represent fuel costs only whereas long-term marginal costs also include investment costs and operation and maintenance costs.
• To analyse the influence on the heat and power prices of alternative tax regimes.

The cost of heat and power for each of the selected cogeneration technologies are calculated under the following assumptions (for the non-CHP technologies only the production costs of power are listed):
• The back-stop price for heat in Denmark and Finland is 41.3 DKK/GJ (without taxes). This price represents the long-term production costs of a gas-fired boiler. In Sweden the back-stop price is 47.0 DKK/GJ assuming that a biomass-fired boiler is the back-stop technology.
• The back-stop price for power, 200 DKK/MWh, is the simulated

average price (on an annual basis) in the Nordic power market (cf. Section 3.1.1).[8]

• When the price of power (heat) is calculated from our model, the price of heat (power) is given by the back-stop price.

• All heat (power) produced by each technology is sold to the back-stop price

• The residual costs are levelised on the power (heat) produced by each technology and thus represents the price to be compared with that of the other technologies

• A negative price indicates that all costs are covered and a surplus obtained from selling the produced heat (power) to the back-stop price. The model utilises this surplus as a subsidy to electricity (heat). The negative figure shows the subsidy per Mwh electricity (GJ heat).

• The production costs are calculated at the CHP-station, i.e. the costs of constructing, operating and maintaining district heating and power grids are not included, nor are administrative costs.

For each technology the following cost-figures are calculated:
1. Long-term marginal costs of electricity assuming a back-stop heat price (Table 7.1).
2. Short-term marginal costs of electricity assuming a back-stop heat price (Table 7.2).
3. Long-term marginal costs of heat assuming a Nordic market power price (Table 7.3).
4. Short-term marginal costs of heat assuming a Nordic market power price (Table 7.4).

Each cost-figure is calculated without taxes as well as including the production and fuel taxes of Denmark, Finland and Sweden as presented in Table 3.

The cost figures in Table 7.1 show that *without energy taxes* all cogeneration technologies, except for straw, are able to compete with the condensing technologies, and even with hydro power. Most efficient is cogeneration based on wood chips. It is one of two technologies having negative long term marginal costs. That means that the technology is more efficient for purely heat production than the assumed

[8] *The price will of course fluctuate during the year thereby providing flexible generators with some options for production planning and a higher average price. Cogeneration is not a very flexible technology as it must always meet the demand for heat. However, heat demand will mainly take place during the winter term of the year, where electricity prices are higher than the annual average. Therefore, cogenerators can expect to get an electricity price above the average. Such deviations from the average are not considered in the following.*

back stop technology (a gas fired boiler). Due to the very high investment costs straw-CHP is by far the most inefficient technology for electricity production.

Table 7.1 Long-term marginal costs of electricity (DKK/MWh)

	Without energy-taxes	With Danish taxes	With Swedish taxes	With Finnish taxes
Nordic power price (assumed)	200	200	200	200
Gas turbine	109	24	206	118
Gas motor	177	92	257	185
Gas Combined cycle	154	79	194	163
Coal	121	160	286	161
Straw	421	-314	367	401
Peat	55	-296	103	55
Wood chips when fuel cost is: - 14.2 DKK/MWh - 26.0 DKK/MWh	 -53 132	 -819 -634	 -111 74	 -74 111
Gas condensing	230	230	230	243
Coal condensing	250	250	290	296
Hydro power	180	180	216	185
Nuclear power	220	220	231	251
Wind power	280	10	200	280
Back-stop heat price (DKK/GJ)	41.3	90.0	47.0	43.3

It is obvious that the *Danish tax regime* which subsidises small cogeneration plants on natural gas and biomass has a significant influence on the cost figures. The costs vary between -819 DKK/MWh (wood chips-CHP) and 250 DKK/MWh (coal condensing). Each of the biomass technologies have negative long term production costs and are the most efficient technologies given the Danish tax regime.

The *Swedish tax regime* does not influence the cost figures as radically as the Danish tax regime which is mainly explained by the lack of direct subsidising of gas and biomass. However, the ranking of the technologies is nearly the same. The main difference is represented by straw cogeneration that has the highest production costs. Lowest production costs have wood chips and peat cogeneration.

The *Finnish tax regime* has the least influence on the market signals compared to the tax regimes of Denmark and Sweden. The ranking of the technologies according to cost figures is about the same as in the scenario without taxes, i.e wood chips and peat cogeneration have the lowest long-term marginal costs, whereas straw CHP is the most expensive technology.

Looking at the long-term cost figures in Table 7.1 across the columns provides an indication of the variations in the competitiveness of each technology when the tax regime is changed. The biofuel technologies are most competitive under the Danish tax regime. There are two reasons for that: electricity produced on biofuels is subsidised; the back-stop heat price in Denmark is twice as high as in the two other countries. The high price of heat makes all Danish cogeneration technologies competitive on the Nordic power market when the long-term price level is higher than 160 DKK per MWh. Contrary to that the Swedish tax regime makes it difficult for cogeneration to compete on the power market with the exception of peat and - in particular - wood chips cogeneration. The Finnish tax regime supports peat and wood chips cogeneration and - with a price level of 200 DKK per MWh - also gas and coal cogeneration.

Table 7.2 below shows the short-term marginal costs of electricity production. The short-term marginal costs reflect the fuel price and the energy efficiency of the plant.

The cost figures in Table 7.2 show that *without energy taxes* all cogeneration technologies can compete with gas and coal condensing production and even with nuclear power. The short-term marginal costs are negative for most af the cogeneration technologies. The main reason is that the fuel costs are low compared to the value of the heat produced which is equal to the *long-term* production costs of the back stop technology for heat production. The table shows that the biomass technologies are the most efficient in the short-term perspective due to low fuel prices (when the high fuel price for wood chips is assumed, its marginal cost becomes close to that of gas and coal).

The influence of the three tax regimes on the short-term costs figures in Table 7.2 are similar to the influence on the long-term marginal costs as described above. *The Danish and the Swedish tax regimes* encourage the competitiveness of the biomass technologies. All tax regimes make it possible for cogeneration to compete with the fossil fuel condensing technologies and for the biomass technologies it is even possible to compete with hydro and nuclear power in a short-term perspective.

Table 7.2. Short-term marginal cost for electricity (DKK/MWh)

	Without energy-taxes	With Danish taxes	With Swedish taxes	With Finnish taxes
Nordic power price (assumed)	200	200	200	200
Gas turbine	-7	-92	90	2
Gas motor	13	-72	93	21
Gas Combined cycle	68	-7	108	78
Coal	-27	-12	137	13
Straw	-135	-870	-189	-155
Peat	-101	-452	-53	-100
Wood chips when fuel cost is: - 14.2 DKK/MWh - 26.0 DKK/MWh	 -197 -13	 -963 -779	 -256 -71	 -219 -34
Gas condensing	144	144	144	157
Coal condensing	102	102	142	148
Hydro power	0-10	5-15	36-46	25
Nuclear power	60	91	71	91
Wind power	0	-270	-80	0
Back-stop heat price (DKK/GJ)	41.3	90.0	47.0	43.3

In Table 7.3 and 7.4 the production costs of heat are calculated for the relevant cogeneration technologies assuming 200 DKK/MWh as the market price of power on the liberalized Nordic power market. All electricity produced is sold at this price (determined by the technical parameters and the assumed annual hours of production, cf. Section 3.3). As in the tables above the costs are calculated without energy taxes and including the present tax regimes for Denmark, Sweden and Finland (the 1996 regime).

Table 7.3 below shows the long-term marginal costs of heat production.

The cost figures in Table 7.3 demonstrates that in a *scenario without energy taxes* cogeneration based on coal, wood chips (assuming low fuel costs) and natural gas combined cycle will have the lowest production costs. At the other extreme cogeneration based on straw is by far the most expensive technology. The long-term marginal costs of heat produced on straw is about four times higher than on coal. Due to the higher power efficiency of the gas combined cycle technology compared to the gas turbine and the gasmotor its costs of heat production are much lower.

Table 7.3 Long-term marginal cost of heat (DKK/GJ, electricity price 200 DKK/MWh)

	Without energy-taxes	With Danish taxes	With Swedish taxes	With Finnish taxes
Back stop technology a)	41.3	90.0	47.0	43.3
Gas turbine	25.2	59.0	48.0	28.8
Gas motor	36.2	66.6	59.3	40.2
Gas combined cycle	16.3	24.1	43.8	23.4
Coal	15.9	77.3	74.4	30.8
Straw	64.4	36.2	64.4	64.4
Peat	21.2	21.2	33.5	23.3
Wood chips when fuel cost is: - 14.2 DKK/MWh - 26.0 DKK/MWh	 16.4 34.6	 -10.1 8.0	 16.4 34.6	 16.4 34.6

a) Natural gas boiler except for Sweden (wood chips-boiler).

The *Danish tax regime* has a significant influence on the cost figures and on the ranking of the technologies. Coal cogeneration now causes the highest heat costs of all the technologies. Including the Danish taxes in the coal prices increases costs by five hundred percent. The subsidy to biomass cogeneration gives rise to negative long-term marginal costs for wood chips cogeneration (assuming low fuel costs).

The *Swedish tax regime* does not have the same radical influence on the costs as the Danish regime. However the ranking is influenced. Straw cogeneration nearly has the same long-term marginal costs as coal cogeneration, which is the most expensive technology. It is worth noticing that the Swedish tax regime gives rise to cost figures that are generally higher than the tax regimes of the two other countries.

The *Finnish tax regime* has the smallest impact on the production costs

and the ranking of the cogeneration technologies. The largest difference compared to the scenario without taxes takes place for cogeneration on coal. In this case the long-term marginal costs are increased by one hundred percent.

Table 7.4 below shows the short-term marginal costs of heat production.

Table 7.4. Short-term marginal cost of heat (DKK/GJ, electricity price 200 DKK/MWh)

	Without energy-taxes	With Danish taxes	With Swedish taxes	With Finnish taxes
Back stop technology a)	23.2	71.9	28.9	25.3
Gas turbine	4.6	38.4	27.5	8.3
Gas motor	0.7	31.0	23.8	4.7
Gas Combined cycle	-30.5	-22.8	-3.0	-23.4
Coal dust	-31.5	29.9	27.0	-16.6
Straw	6.2	-22.1	6.2	6.2
Peat	-0.5	-0.5	11.8	1.6
Wood chips when fuel cost is: - 14.2 DKK/MWh - 26.0 DKK/MWh	 2.2 20.3	 -24.3 -6.2	 2.2 20.3	 2.2 20.3

a) Natural gas boiler except from Sweden (wood chip boiler).

Table 7.4 reflects the production costs for existing plants for which capital costs are considered as sunk costs. It demonstrates that without energy taxes the two condensing extraction technologies (gas combined cycle and coal dust plant) are by far the most efficient. Straw and peat cogeneration are the most expensive technologies in the short term perspective. However, the short-term costs of all cogeneration technologies are significantly lower than the short-term costs of the back-stop technology which means that cogeneration in general is very competitive on the "heat-market" compared to traditional heat boilers.

The influence af the three alternative tax regimes is much the same as described above: The *Danish taxes* have a significant influence on the cost figures both with respect to magnitude and ranking, whereas the *Finnish taxes* only have a little influence. The *Swedish taxes* tend to equalise the heat costs of the different technologies. However, the Swedish tax regime also causes the highest average production costs (both in the short and in the long run).

4. Some principles of energy taxation and their application to the supply of heat and power.

Taxes are usually designed to achieve different objectives. Energy taxes are no exception to that. They can be motivated by fiscal goals, environmental goals as well as by considerations of income distribution and industrial policy. The present Nordic energy taxes were primarily introduced to realise objectives that were specific for each nation. As long as the Nordic energy markets remained closed for competing suppliers, the problems were small. However, after the opening of the Nordic power market for competition the present structure of energy taxes has demonstrated certain weaknesses with respect to economic efficiency and fairness. Power generation is not carrying the same tax burden in different parts of the market. Neither is the tax burden of different generating technologies consistent with obvious environmental objectives.

For political reasons, it is no easy task to revise the existing energy taxes that are often connected to strong vested interests. In a research report published in 1995, Atle Midttun and Oskar Hagen discussed the Nordic electricity taxes and the apparent contradiction between a proclaimed high environmental profile and a practice with low taxes paid by the national producers of electricity. They consider this a good example of the adjustment of what the political scientists call "numerical democracy" and "corporate pluralism". To please the electorate that is increasingly "green" oriented, a high environmental profile that also includes environmental taxes is announced. To please strong economic interests, i.e. the electricity supply industry and the large, energy intensive manufacturing firms, the tax structure is designed in a way that is relatively painless to these interests.

In this section, the correspondance of the present Nordic energy taxes with economic principles of taxation are discussed. An alternative tax structure that is in better harmony with economic and environmental principles is suggested and we apply our model to calculate its consequences for the competitiveness of different power technologies.

4.1.Principles of energy taxation

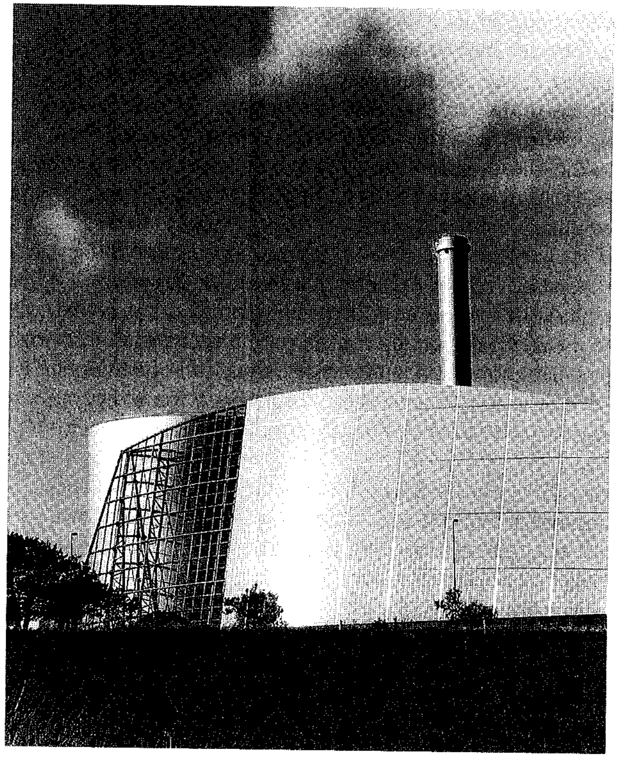
Three general objectives are mainly considered when designing taxes:
1. To provide revenue to finance public sector activities (services, investments and transfers of income).
2. To correct an otherwise inefficient use of economic resources (e.g. to correct for externalities that are not included in the market prices of goods and services).

3. To redistribute income.
With respect to energy taxation, it is mainly the first two objectives that are relevant. There are, however, energy taxes where income redistribution is the main objective. A case is the new Swedish taxation of hydro power plant. From January 1997 hydro power is no longer taxed according to the amount of energy produced but according to the real estate value of the power plant. The main objective is to capture part of the economic rent earned by old plant.

It is important to keep the various objectives separate as they have different implications for the design of taxation. A tax that has as its main objective the creation of revenue for the public sector should have as little impact as possible on the economic decisions of consumers and producers to avoid increased inefficiencies in the allocation of economic resources.

The situation is very different for taxes that have as their main purpose the correction of an inefficient use of economic resources. For such taxes the indication of success is whether the inefficiencies are corrected and not the revenues that are raised by the tax. Environmental taxes could be good examples of that. Their purpose is to compel producers and consumers to internalise the non-paid costs of pollution. If the most economic alternative after the tax has been introduced is to avoid the use of the pollutant, the tax has achieved its objective but will raise little money for the public purse.

These considerations lead to the following list of priorities when designing taxes:
1. Taxes that contribute to correct inefficient uses of economic resources should be introduced first as they have a positive effect on the economy.
2. Taxes that are neutral with respect to the economic decisions by consumers and producers should be introduced next as they are not distorting the economy.
3. As this is not enough to cover the public sector's need of finance, non-neutral taxes with distorting effects on the economy are unavoidable. The effect of such taxes on the allocation of economic resources should be as small as possible. This is an argument for selecting a broad tax base as is the case with a general income tax or a value added tax. They will not discriminate between different sources of income or between the purchases of different goods and services. The tax incidence that is required to raise a certain amount of money will also be smaller than for taxes on specific types of income or on selected goods and services which will also result in less distortion of the economy (cf. Christiansen 1996).



CHP-plant in Viborg. (Photo: Jesper Vig)

The purpose of an environmental tax is to signal the external costs of pollution, that are not included in market prices, and thus to improve the market mechanism by creating better coincidence between social and private costs. The magnitude of the tax can either be determined by the cleaning costs or by an evaluation of the harmful effects of the pollution. A tax is often considered a less costly alternative to achieve an environmental goal than direct regulation (cf. DØR, 1993). As already emphasised, its main purpose is not to create revenue for the public sector. However, if the environmental tax creates revenue, it can be used to substitute other, socially more costly taxes (cf. above). An environmental tax should be as precise as possible to provide correct signals to those who cause the problem and are in a position to act. In the case of emissions this means that the tax should preferably be put directly on the harmful emission.

With respect to energy the emission of CO_2 is now the most discussed environmental problem. For practical reasons it is difficult to tax the CO_2-emission directly and, therefore, a substitute must be found. As the

fuel burned to produce energy causes a fixed proportion of CO_2-emissions, it is obvious to tax the fuel input that is easy to measure and control. The energy producer will immediately feel the impact of the tax and, therefore, be prompted to do something about it. She is often also the actor with the most relevant knowledge of alternative production technologies.

A CO_2-tax on energy consumption will not have the same effect. The consumer has much less motivation and opportunity to react which means that the tax must be higher to achieve the same reduction of CO_2[9]. When CO_2-taxes are applied to electricity consumption an additional incentive problem occurs. The tax is usually determined by the average CO_2-content of all power supplied to the consumers. It means that the consumer can choose to purchase less electricity as a response to taxation but not to substitute more polluting by less polluting power technologies.

4.2. Do the Nordic energy taxes fit with these principles?

Energy taxes are nowadays marketed as environmental taxes. The Nordic energy taxes are no exceptions to that. Nevertheless, it only requires a quick look at the presentation in Section 2 to see that the existing Nordic heat and electricity taxes are far away from the principles discussed in the previous section. Often the tax has only a very indirect connection to the relevant source of emission. Further, the external cost of a given pollution (e.g. the emission of a tonne CO_2) signalled by the tax varies considerably among different production technologies and for the same technology when it is employed in different countries. The cost signal is also of extremely varying magnitude for different groups of customers (e.g. households and large business firms).

The most obvious example is the electricity tax that is mainly collected from a minor part of consumption: households, public institutions and small business enterprises. As these consumers are much less price elastic than large manufacturing enterprises, which are exempted from the electricity tax, it has more the identity of a consumer (or fiscal) tax than an environmental tax. The explanation of the deviation from the ideal is mainly political. The electricity supply industry and the large manufacturing enterprises are strongly opposed to efficient environmental taxes as they claim that such taxes will harm their ability to compete if not introduced on an international level.

[9] *When a country's energy policy has as a separate objective the encouraging of energy savings (to improve the security of energy supply and/or to avoid depletion of non-renewable resources) a consumer tax is of course an appropriate tool.*

Among the four Nordic countries, the Finnish energy tax that existed until the end of 1996 comes closest to the principles discussed in the previous section. Also the Swedish sulphur- and NOx-taxes are good examples of environmental taxes. They are all fuel taxes that reflects the harmful impact (emissions) of each fuel. There is no discrimination with respect to different applications of the fuel (e.g. for heat and power) nor is there any discrimination between different customers.

The Danish and Swedish electricity taxes are mainly consumer taxes with fiscal purposes. The recent change of name to environmental taxes is more a change of label than of practice. The present discussion in Norway of a fuel tax on natural gas that will be burned in combined cycle gas turbines to generate electricity seems more likely to be concluded with a Danish/Swedish solution than with a Finnish solution.

The introduction of competition in power in the Nordic countries exposed the existing tax structures to pressure. The Finnish generators (including the cogenerators) using fossil fuels had their costs increased by the fuel tax and could not compete with the non-taxed generators in the other countries. As a consequence the Finnish power industry has been pushing its government to have the fuel tax changed to a consumer tax as in the other Nordic countries. The recent decision to change the Finnish energy tax is the result of this pressure.

It can be demonstrated that a given reduction of the emissions of CO_2 can be achieved to a much lower social cost by a combination of an open market for power and fuel taxes than by a continuation of the present national policies (cf. Gjelsvik 1996). Unfortunately, the expected outcome of the present tax discussions will leave these opportunities unexploited and even be worse than the initial situation. Such an outcome will also make it more difficult for the Nordic countries to join forces and put pressure on the European authorities to have the internal market for gas and electricity accompanied by environmental taxes.

4.3. Suggestions for a common Nordic tax structure

In 1992 the European Commission proposed a common energy tax for the Union. The tax should be composed as a 50/50-energy and CO_2-tax (cf. Nordisk ad hoc gruppe 1995). The suggested initial level of taxation was 3 USD per barrel crude oil. Nuclear power and large hydro power plant were only supposed to pay the energy-part of the tax whereas small hydro power plant and renewables should be exempted from the tax. The level of taxation in the EU-proposal is similar to that of the (former) Finnish energy tax. Only the proportion between the energy- and the CO_2-part is different (50/50 instead of 25/75).

We have calculated the levelised costs (long- and short-term) of heat and power including the suggested European taxation for the selected cogeneration and power technologies. The taxes are:

- 9.6 DKK/MWh fuel for gas
- 12.1 DKK/MWh fuel for coal and peat (this is different from the Finnish energy tax, where peat was not paying the CO_2-part of the tax)
- 5.43 DKK/MWh for large hydro power plants
- 15.02 DKK/MWh for nuclear plants.

The results are presented in Table 8.

Table 8. Heat and power prices under the assumption of the European tax regime (in DKK)

	Power long-term (MWh)	Power short-term (MWh)	Heat long-term (GJ)	Heat short-term (GJ)
Gas turbine	115	-1	30	11
Gas motor	188	24	42	6
Gas Combined cycle	157	71	26	-9
Coal dust	112	-36	23	-13
Straw	380	-176	62	7
Peat	76	-80	27	5
Wood chips when fuel cost is: - 14.2 DKK/MWh - 26.0 DKK/MWh	 -84 103	 -229 -41	 16 35	 2 20
Gas condensing	247	161		
Coal condensing	276	128		
Hydro power	185	5-15		
Nuclear power	235	75		
Wind power	280	0		
Back-stop heat price[1] (DKK/GJ)	44	44	44	26

1) The production costs of the gas-fired boiler introduced in Section 3.1. Long-term marginal costs are listed in the three first columns and short-term marginal costs in the fourth column.

The European tax regime provides similar results as the Finnish tax regime reported in Section 3.4 which was to be expected. All cogeneration except straw is competitive with most other power technologies. Some of them can even compete when new plant (long-term marginal costs) is compared with existing condensing plant (short-term marginal costs).

The introduction of such a tax system will leave the Nordic countries, in particular Denmark, with a significant drop in revenues from energy taxation. The residual revenue can be obtained by a continuation of consumer taxes.

5. Concluding remarks

Cogeneration accounts for about 15 per cent of the supply of heat and power in the Nordic countries. Its potential is at least the double of this figure.

The taxation of energy is important for the competitiveness of cogeneration. The tax regime is very different in the Nordic countries both with respect to the use of production (fuel) and consumer taxes and with respect to the tax incidence. After the opening of the Nordic power market for cross-border competition such differences have become an increasing problem. Similar power technologies are exposed to taxes of very different magnitudes and the taxation of different power technologies does not appear consistent with obvious environmental principles.

There are good economic reasons for applying taxes to achieve environmental objectives. The social costs of taxes can be lower than the costs of other means such as direct regulation. However, to achieve this purpose the tax should provide clear, direct and equal signals about the relevant environmental cost. To avoid inefficient and unfair competition among the power industries in different countries environmental taxes should be introduced internationally. The recent Finnish decision to abolish its fuel tax and substitute it by a consumer tax demonstrates how important this is.

An environmental tax will not necessarily create much revenue. As energy taxes in the Nordic countries nowadays are supposed to contribute significantly to public finance a revenue gap can occur. This gap can be closed by a continuation of consumer taxes with mainly fiscal purposes.

Our analysis of the production costs of different power technologies demonstrates that cogeneration can compete with respect to both long- and short-term marginal costs. The only exception is straw-fired cogeneration. Consistent environmental taxes like the Finnish energy tax and the tax suggested by the European Commission will increase the competitiveness of cogeneration.

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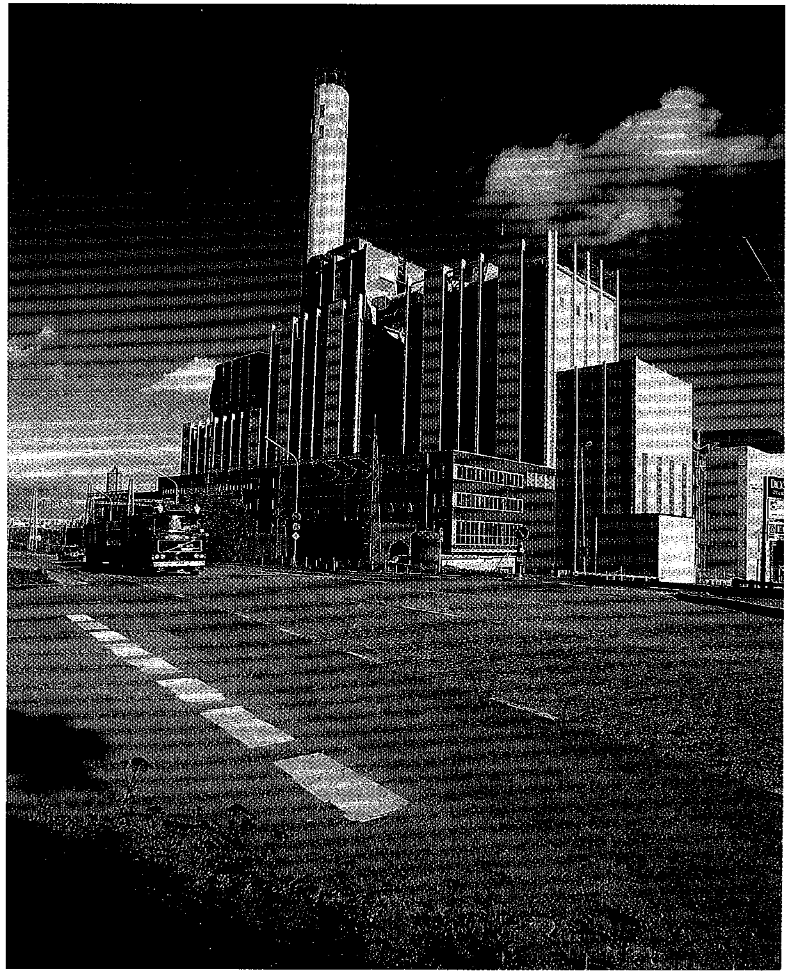

CHP plant in Västerås.

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