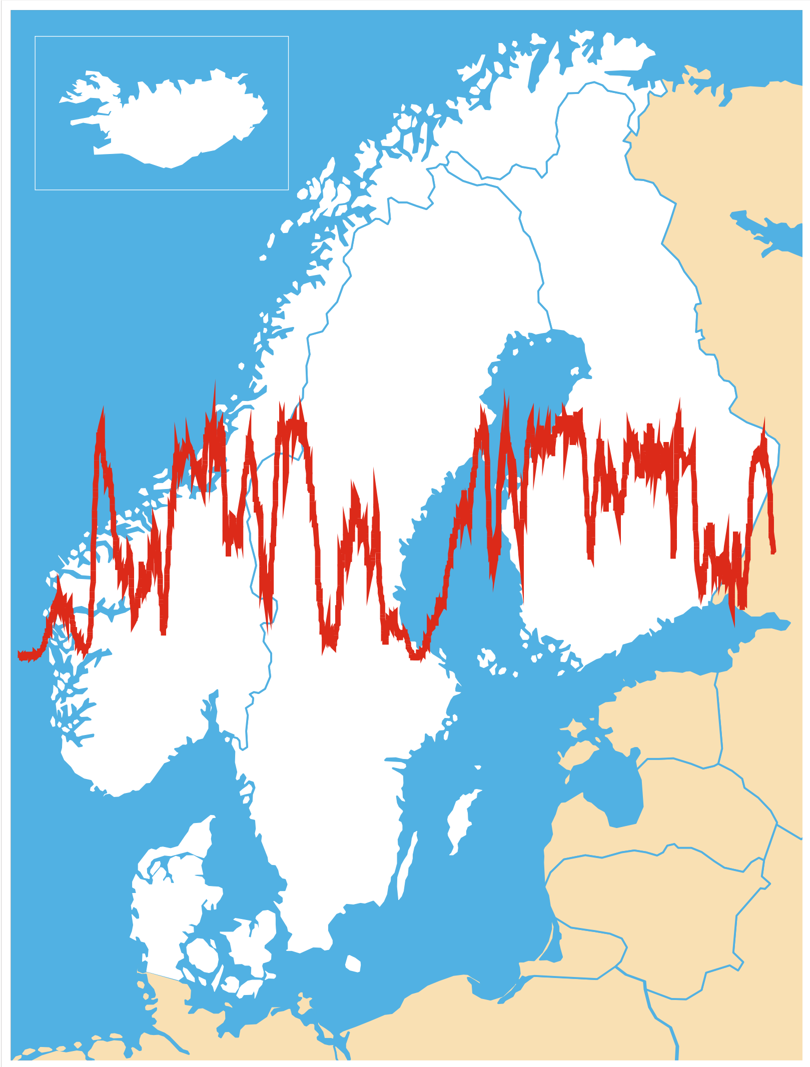
Nordel's Annual Meeting 2000

Non-dispatchable Production in the Nordel System



Nordel's Grid Group, May 2000

Table of Contents

Executive Summary

Key Problems as to Non-dispatchable Production in the Nordel System

Nordel has conducted an initial study of the impact of large amounts of non-dispatchable power production on the system. Non-dispatchable production is to be understood as wind power, local combined heat and power (CHP) units and industrial plant characterised by the fact that electricity production can only partly be regulated on the basis of electricity consumption. As wind power is highly non-dispatchable and is boosting in the Nordic countries, the analysis focuses on technical problems associated with the expansion by wind turbines in relation to the rest of the Nordic electricity system.

Nuclear power stations are also difficult to regulate and are unfit for fast regulation. They either run full production or no production at all. However, as distinct from wind turbines, nuclear production is under full control, giving nuclear power stations a completely different degree of production value in the electricity system.

The Nordel System Must Be Prepared

Non-dispatchable production is characterised by the fact that the technical challenges start in the local electricity network. Increased expansion causes the problems to move on to the regional and national network levels. When the extent becomes dimensioning to the national transmission network, influencing trade with neighbouring systems, the problem becomes international.

Denmark is quite far in this process. A major expansion of the distribution network has rendered it possible to collect energy from 6,000 wind turbines and 800 local CHP units dispersed all over the country. The expansion by wind turbines has now reached a level where the need for a stronger internal transmission network as well as stronger connections to the neighbouring systems is urgent. The same process has started in Sweden, Norway and Finland. If the framework conditions for expansion by wind turbines change in these countries, expansion may boost as the turbine technology today is more advanced than in 1990 when the expansion by wind turbines in Denmark started.

Today there are more than 7,000 wind turbines in Nordel with a total capacity of some 2,000 MW. However, the majority of turbines are smaller than 250 kW. Today turbines of 2,000 kW (2 MW) are built. In year 2005 turbines of 5 MW are expected to be a reality and these turbine types are likely to gain ground in case of offshore expansion or expansion in the mountains.

The EU's white paper on renewable energy (RE), new international targets for expansion by RE, development of an international market for RE certificates as well as the continuous technological development within wind turbines are factors that may change the framework conditions for expansion by wind turbines in Sweden, Norway and Finland radically and seriously change the composition of the Nordic electricity system. This is a development for which Nordel must be prepared.

The estimated potential for exploitation of wind power in the Nordic countries is more than 250 TWh when results from national studies are added up. The realisable potential will depend on the financial assumptions and on incorporation of wind power into the environment. If "mountain turbines" and "offshore turbines" are accepted, the realisable potential is expected to be in the order of 75-150 TWh/year (25,000-50,000 MW). This corresponds to 20-40 per cent of the present annual electricity consumption in the Nordel area.

Non-dispatchable Production Creates Imbalances

Large-scale wind power creates major imbalances in daily operation as production from wind turbines and other non-dispatchable production often exceeds electricity consumption both regionally and nationally. Already today, Denmark experiences major national imbalances, influencing trade with Norway and Sweden on the Nordic power exchange. As a result, imbalances and non-dispatchable production also represent challenges to the Nordic market system.

In general, wind power creates larger imbalances than other non-dispatchable production despite continuous improvement of forecasting tools. However, production variations from one quarter of an hour to the next (called power gradients) will remain unpredictable, and the ability of the remaining electricity system to ensure the balancing of these gradients is decisive to the balance of the total electricity system.

The trend in the Nordel system is towards reduced peak load production possibilities and impaired regulating properties. There is a growing demand for these services, both from the Continent via the North Sea cables and as a result of the increase in non-dispatchable production.

Regulation at Hydropower Stations

An important means to handle large amounts of non-dispatchable power is the regulating capacity at the Nordic hydropower stations. You may say that when non-dispatchable production exceeds consumption wind power can be stored in the Nordic hydropower reservoirs to be consumed when the situation is reversed. In practise, it is limited how much hydropower stations can regulate without waste of water as there are mutual bonds between stations along the same river. Utilisation of the hydropower regulation requires expansion of the transmission network as the need for transmission in Nordels network will generally increase.

One important reason is that much of the wind power expansion must be expected to take place in the southern part of the Nordel area. In the same area conventional power stations are scrapped these years. This means that the regulating properties of the electricity system are reduced in areas where the need for regulating power is actually increased. This puts requirements on the transmission network, which has to transmit power to and from areas with wind power depending on the imbalance and also to ensure that regulating power can be transmitted in case of operating disturbances within the electricity system.

Requirements on Wind Power

Another important means is requirements on control and regulation of wind power. Large numbers of wind turbines will replace conventional power stations to some extent. However, for this to take place the wind turbines must be developed from being passive components connected to the local electricity network to being active power stations connected to the transmission network and capable of supporting the electricity system in critical operational situations.

Control and regulation of wind power stations in an overall perspective are still virgin soil, but technological development opens up new prospects. This forces Nordel to set up recommendations acting as an incentive for wind turbine manufacturers to improve the regulating properties of wind turbines.

Further Activities under the Auspices of Electricity Utilities

Expansion by non-dispatchable power requires further studies of the interaction between transmission network and production facilities. The task of Nordel is to estimate to which extent non-dispatchable production requires expansion of the transmission network and to which extent Nordel should put requirements on production facilities.

As a result, Nordel considers the expansion by non-dispatchable power, including wind power in particular, to be a great challenge to the existing electricity system and the new market system. In-depth studies in this field are thus recommended.

Proposal for Harmonisation under the Auspices of Authorities

Expansion by RE takes place primarily on the basis of energy considerations. In at least three areas the authorities in the Nordic countries could support the development further.

The sale of RE excess power at times when the market price is low and when there is no need for power in the market implies uniform framework conditions in the countries (for instance in areas such as expansion, use and handling of RE certificates, etc.). There is a need for the framework conditions for the system operators to ensure profitability for power stations supplying peak load and regulation services.

Furthermore, a common understanding is needed as to whether expansion of the 400 kV overhead line transmission network in one country may be motivated by power requirements caused by the RE expansion plans of another country.

Technical Summary of Activities 1998-2000

Nordel's Planning Committee (former System Committee) has initiated an analysis of the impact of large amounts of non-dispatchable production on the system, i.e. wind power and local CHP. The technical consequences of large amounts of non-dispatchable production may result in a changed sharing of costs between the Nordel parties according to current rules and agreements. This makes the common analysis of the question within Nordel relevant.

At Nordel's annual meetings in 1998 and 1999 the System Committee/Planning Committee presented a problem formulation and situation report for the task. This summary sums up the results of the activities for presentation at Nordel's Annual Meeting 2000.

Objective of Activities

The objective of the analysis is to make a correct description of the technical problems from a Nordel point of view. The Grid Group has identified a number of problems, but has made no sharp distinction between network problems and production problems.

The report will be able to form a common technical basis for determining the need for expansion of the transmission network and for the subsequent commercial negotiations between the market players.

A common feature of local CHP and wind power is that the energy production is controlled by other factors than the current electricity production. As far as local CHP is concerned, these factors are heating requirements, tariffs and heat storage. As regards wind power, it is the special dependence of wind power on meteorological conditions that is not related to the variations in electricity consumption. As it is not economical to store electric energy in large amounts, it is necessary to procure the power, and so the security of supply, from other sources. The final combination of means will depend on technical possibilities as well as on the market development and negotiations on price and conditions.

The analysis focuses on overall system conditions. The basis for RE expansion is primarily energy considerations, but the technical challenge is the handling of power surplus and deficit. Random fluctuations may create immediate imbalances between consumption and production which have to be eliminated. The regulating power must be transmitted from the regulating unit to the place where the imbalance arose.

The Nordic Potential for Wind Power and Local CHP

Two scenarios have been studied until year 2020 for the total Nordic system. The table below compares key figures for the Nordic system for these two scenarios.

With the present national goals, everything seems to indicate that in 2020 Nordel will comprise at least 10,000 MW of wind turbines. So, in the light of this, scenario 1 is absolutely not an extreme scenario. Scenario 2, however, assumes that the wind power expansion is speeded up compared to present goals.

Year 2020	**Consumption**				**Wind power**		**Local/ industrial CHP**
	Winter		**Summer**		**MW**		
	Max. MW	**Min. MW**	**Max. MW**	**Min. MW**	**Scenario 1**	**Scenario 2**	**MW**
Norway	26,000	22,700	17,100	13,800	1,000	4,000	250
Finland	16,500	10,600	10,900	7,400	500	2,000	3,200
Sweden	32,000	23,000	15,000	9,800	4,000	8,000	3,000 [1]
Denmark	7,500	3,000	6,000	2,500	5,400	7,000	2,550
Total	82,000	59,300	49,000	33,500	10,900	21,000	9,000

Variations in consumption in summer and winter compared to installed non-dispatchable production. As far as electricity consumption is concerned, the figures are approximate figures the purpose of which is just to illustrate the order of magnitude.

Scenario 1 comprises a total non-dispatchable production of 19,900 MW, including 9,000 MW of local CHP. Scenario 2 comprises a total non-dispatchable production of 30,000 MW, including 9,000 MW of local CHP. By way of comparison it may be mentioned that the non-dispatchable production in the Nordel system today accounts for approx. 10,000 MW, including approx. 8,000 MW of local CHP.

It is a characteristic feature of non-dispatchable production that the technical difficulties start on a local scale, moving to regional and national levels when expansion increases. When the extent becomes dimensioning to the national transmission network, influencing trade, the problem becomes international.

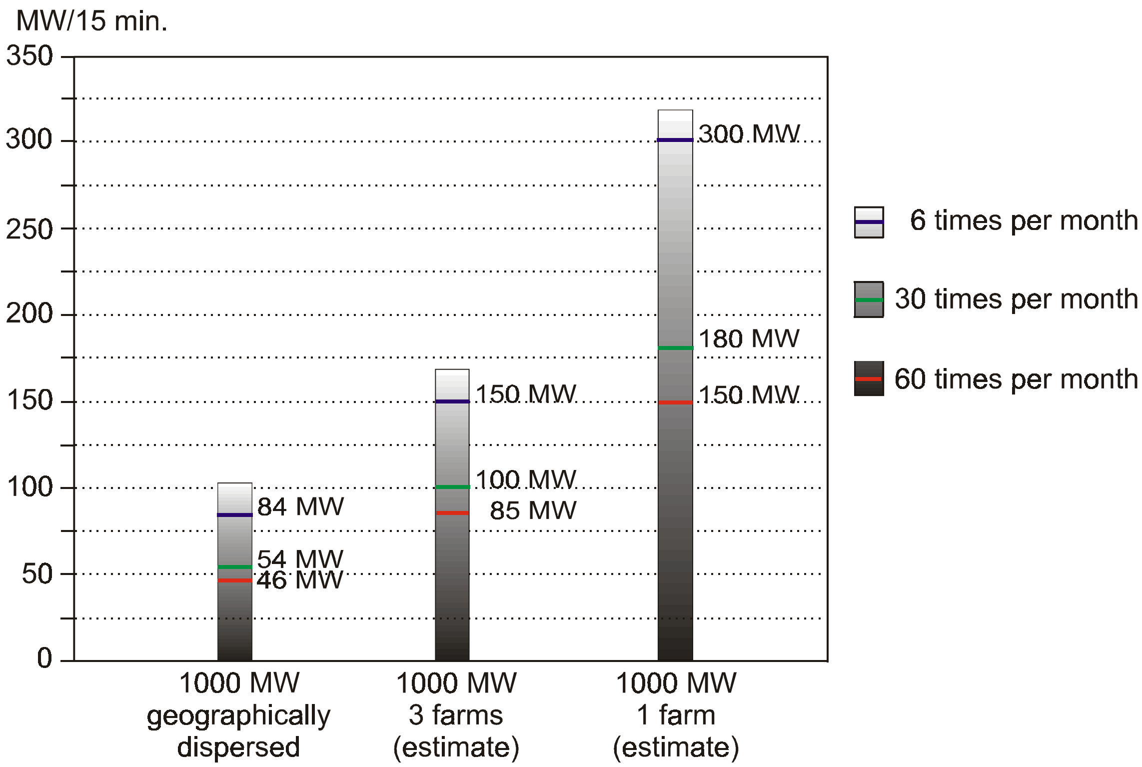
Regulating Requirements and Transmission of Regulating Power

The geographical location and size in terms of power of non-dispatchable production capacity as well as the electricity consumption variations in 2020 are shown in Enclosure 1. The Enclosure illustrates that the imbalances between wind power and regional consumption are unevenly distributed in the total Nordic system, resulting in potential transmission requirements. It appears that the non-dispatchable production is

[1] Only part of this power is non-dispatchable, as some local CHP units in Sweden can produce heat independently of the electricity production.

concentrated in the southern part of the Nordel area. The regulating capacity, however, is mainly placed in the northern part.

The forecasting systems are expected to be improved, allowing imbalances to be traded on the exchange close to the operational hour. However, short-term power variations (0-15 minutes) cannot be predicted. These power variations are handled by the primary regulation, affecting the a.c. links. The size of the power gradients depends partly on the wind turbine capacity in the system and partly on the geographical dispersion of the turbines. Figure 1 shows a situation where the amount of wind capacity is constant (1,000 MW), but where the turbines are integrated into the system in three different ways.



The power gradients' numerical size for three different implementations of 1,000 MW of wind power. The gradients are equally divided on upward and downward regulation.

A large number of turbines within the system will result in large power gradients to be balanced between the areas. Whereas large consumption gradients always occur at the same time in the morning, the power gradients from wind turbines will occur irregularly. This puts completely different requirements on the system. The electricity system must also be able to do the regulation on the mornings when consumption increases at the same time as wind production decreases.

Geographical dispersal reduces the size of the power gradients. The gradients for 1,000 MW of onshore wind turbines only represent 30 per cent of the gradients from an offshore wind farm of 1,000 MW. If the 1,000 MW of offshore turbines is distributed on three sites instead of one, the power gradients are reduced by 50 per cent. A requirement that each regional area in the Nordic countries be balanced separately would result in substantial investments. If the more even production supplied by the geographically dispersed production is taken into account, the need for regulating power of the total system is reduced considerably, but this assumes that regulating power can be transmitted to the regional area where the need arose. In all circumstances it is also assumed that regulating power is available and not disposed of to somebody else, e.g. via the North Sea cables to the Continent. Hydropower stations are usually regarded as extremely suitable for regulation. However, in practice it is also limited how much the hydropower stations can regulate without waste of water. Pumped storage power on a daily basis, as it is known from the Alps, is not installed in the Nordic countries where pumped storage power typically occurs on a seasonal basis.

The present trend in the Nordel system is towards a weakening of the regulating properties of the system as condensing units are being scrapped. However, the need for regulating power increases as non-dispatchable production increases.

Nuclear power stations are not suitable for fast regulation, but decommissioning of such stations removes part of the basic production, which then has to be produced at dispatchable units to some extent. The result may be that scrapping of nuclear power stations indirectly reduces the regulating properties of the system.

Special Conditions for Wind Turbines

The individual wind turbines are small compared to the system on the whole, and disturbances and outages will be quite scattered. A large number of offshore wind farms will be connected to the transmission network by means of branch connections as the power value cannot finance a reserve connection. This means that outage of the branch connection will activate reserves. When the number of wind turbines behind a branch connection exceeds the dimensioning production outage of the area establishment of ring structures in the electricity transmission network is necessary. Until then, outage of the branch connection will result in draws on the reserves via the co-operation connections. In this connection it is doubtful whether the commercial offshore wind farms must and can contribute to the reserves to be used in case of outages of other large production units. This will only be possible if the production from wind turbines has not in advance been regulated according to the wind.

Another special problem is the so-called “cut-out effect” caused by very strong wind. The cut-out effect may cause a large number of wind turbines, irrespective of ownership and location, to trip, influencing the system by a power gradient that is larger than the system dimensioning outage.

Power Shortage

The risk of power shortage may be influenced by large amounts of non-dispatchable production, but only in so far as non-dispatchable production displaces primary power stations. When the expansion by wind power takes place in other areas than where power stations are scrapped, there is a special need to revise the assumptions behind power shortage studies. In so far as power shortage situations have to be avoided by increased network capacity, it will often be insufficient just to reinforce the network to neighbouring areas, as also this area may experience power shortage and internal network constraints.

Consequences for Transmission Network Operation

The outlined transport of regulation services will influence the possible application of the transmission network for other purposes. The operational margin reflects the transmission capacity in a geographical cross-section that is reserved to meet unpredictable changes in power flow. Expansion as outlined in the two scenarios is likely to call for an operational margin increase several places in the network, due to the unpredictable power gradients. As the technical transmission capacity remains unchanged, this can either take place at the expense of the trade capacity or it can speed up the need for increased network capacity. It is doubtful whether an overhead line project in one country can be justified by needs for power and regulation in another country.

Furthermore, planning of transmission capacity for RE regulation must be expected to reduce the possibilities of increased power transmission in wet and dry years when potential profits in the market are particularly large.

Besides, it is a fact that the framework conditions for RE expansion and operation show noticeable differences between the Nordic countries. The sale of RE excess power at times when the market price is low and there is no need for power in the market implies uniform framework conditions.

The Grid Group suggests that the following subjects be studied further:

- Study of the correlation between wind power and hydropower in the Nordel area.
- Nordic analysis of how the market is affected by large amounts of non-dispatchable production.
- Analysis of the regulating capacity of the system and its geographical location. Which units in the existing system will best meet the regulating need?
- New wind turbines located in large farms at sea or in the mountains will have regulating properties, depending on the formulation of the connection specifications. It is necessary to identify the realistic regulating potential of these farms, as it may strongly affect the necessary network expansion.

- General analysis of means to improve the integration of non-dispatchable production in the Nordel system.
- In-depth analysis of the impact of non-dispatchable production on the risk of power shortage.

The proposals for future activities may be considered as part of an overall structural analysis of the Nordic network and may result in a set of supplementary operational and planning criteria.

The Grid Group will apply the results of the activities as a basis for its work on transmission capacities in year 2010.

In future, co-operation between the Operations Committee and the Planning Committee will be imperative.

1. Introduction

Nordel's Planning Committee (former System Committee) has initiated an analysis of the impact of large amounts of non-dispatchable production on the system, i.e. wind power and local CHP. The technical consequences of large amounts of non-dispatchable production may result in a changed sharing of costs between the Nordel parties according to current rules and agreements.

This makes it relevant to analyse the technical problems jointly within Nordel. The technical challenges are associated with imbalances between production and regional consumption, that is, power overflow and power shortage.

Non-dispatchable power is to be understood as production capacity that is not controlled from a central control centre. This production is unpredictable to different degrees, depending on the type. Wind turbines represent the largest degree of unpredictability today, and as the "wind power station" is increasingly the subject of ambitious plans in several EU countries, the focus of the report is on consequences of this.

Nuclear power stations are also difficult to regulate. Due to bonds in relation to the reactor, regulation is relatively slow and often limited. However, unlike wind turbines nuclear production is under full control, which gives nuclear power stations a completely different value in e.g. power shortage situations.

A characteristic of non-dispatchable production is that the technical problems first occur at the local level, moving to regional and national level when expansion increases. When non-dispatchable production has reached a size at which it becomes dimensioning to the national transmission network, as has happened in Denmark, it has a spillover effect on trade and co-operation agreements with neighbouring systems. The problem has thus become international.

The task was initiated in 1998, and since then visions and plans for Renewable Energy (RE) have become increasingly ambitious, particularly in EU countries bordering on the Nordel area. The political aims have been formulated as energy matters between RE and traditional energy production. However, as RE is often identical to non-dispatchable production, the power imbalance problem is more relevant than ever.

At Nordel's annual meeting in 1999 the Planning Committee presented a situation report for the task, identifying a number of technical requirements as to regulating power and transmission capacity within the Nordel system. It is particularly relevant to shed light on the demands for expansion of the transmission network, since the planning horizon for these projects is very long. However, as a fundamental change of the production facilities will be necessary, non-dispatchable production is a challenge that Nordel's committees must co-operate on in the years to come.

2. New Framework Conditions

A large part of the present European production facilities is planned and established on the basis of technical/financial considerations in each country. Development and expansion have largely been left to national power sectors with the acceptance of politicians.

However, the environmental aspect associated with electricity generation and liberalisation of the electricity supply industy means that the future framework for the European production facilities will be created by overall political targets and international trade prospects.

This chapter of the report deals with these framework conditions, under which the Nordel and Nord Pool area will develop.

In November 1998, the European Commission took its first step towards a strategy for RE by publishing a White Paper [2]. The aim is to double the RE share to 12 per cent of energy consumption in year 2010. This implies an increase in the share of RE electricity from the current approx. 14 per cent to approx. 24 per cent of the EU's electricity consumption in year 2010[2]. Since RE is practically tantamount to non-dispatchable production, the EU's target will have a major impact on power imbalances, both regionally and nationally.

Technological development is a key parameter when it comes to expansion by RE. Technological improvements within electricity storage and electricity generation technologies may substantially change the conditions for integration of non-dispatchable production. This report considers the issue on the basis of present technology, where wind turbines, second to hydropower, is the most competitive RE production type.

2.1 National Environmental Targets for Electricity Production

Table 1 shows the RE share of electricity consumption in the Nordic countries in 1996 [3] as well as Nordel's annual report from 1996. The share was calculated both with and without production from hydropower stations larger than 10 MW.

It appears from the table that Denmark's electricity consumption has the absolutely lowest share of RE in the Nordic countries when the technical distinction between production from large and small hydropower stations is disregarded. Based on this, it is

[2] Including production from large hydropower stations.

only natural that Denmark has the largest ambition level when it comes to expansion by RE based on wind power.

	RE share of electricity consumption in 1996	
	Incl. large hydropower	**Excl. large hydropower**
Denmark	6.3 %	6.3 %
Finland	24.1 %	9.2 %
Norway	92.0 %	6.5 %
Sweden	38.2 %	5.3 %

Table 1 *RE share of electricity consumption in 1996 with and without large hydropower stations. In a normal climatic year RE production accounts for about 98 per cent of Norway's electricity consumption.*

Denmark: In 1996 the Danish Government presented its energy action plan "Energy 21" [4]. The plan covers the period until year 2030 with the overall aim to reduce CO_2 emissions in year 2030 to half the 1988 level, assuming that international efforts in technological development and in planning of market terms and measures support this aim.

The Government's target is 20 per cent RE contribution to electricity consumption in 2003, then increasing by 1 per cent annually. Everything seems to indicate that the aim for year 2003 will be met. The aim for 2030 is an RE share of 50 per cent.

Sweden: The Government has no specific target for expansion by wind power, but subsidises energy production, research and demonstration projects within the area [5].

Norway: The Government's aim for wind power is to supply 3 TWh (≈ 1,000 MW) in 2010 [6].

Finland: The Government's energypolitical target is formulated in a number of strategies, inter alia to:

- Promote an energy balance with a lower share of coal.
- Promote application of bioenergy and other domestic energy.
- Maintain a high technological level.

The Government's aim for wind power is for it to supply 1.1 TWh (≈ 500 MW) in 2010 [7].

The aim of the EU's White Paper is an average increase of the RE contribution of ten per cent until 2010. Among the Nordic countries only Denmark has official aims for the percentage increase until 2010.

2.2 Connection and Buying Obligations

In Denmark, the TSOs and network companies are legally obliged to connect new RE and to buy the production from these units. RE receives a subsidy of DKK 0.37 per kWh. In practice, new RE producers pay about ten per cent of the costs associated with connection to the network.

In Finland, distribution undertakings are not obliged to buy RE electricity. The Government subsidises investments into wind power by 30-40 per cent. In addition, the wind power producer receives the electricity tax (FIM 0.041 per kWh) that the consumer pays. In Norway and Sweden, RE producers pay the actual costs associated with connection to the network.

2.3 RE Certificate Market

A liberal electricity market and environmentally political targets can be combined at a special RE certificate market. Europe is quite far in the process of constructing a market of this type [8]. The purpose of an RE certificate market is to promote the development and installation of RE production in the electricity system in a way that enhances mutual competition between RE producers.

The RE certificate is a financial security that can be sold at an exchange for trade in RE certificates independently of the sales of electricity. In this way the producer earns a supplementary profit on RE electricity. Demand for RE certificates is ensured by quotas for buying RE electricity. All electricity consumers must observe these quotas, which are fixed by the national government.

The RE certificate market can be designed to prevent that non-mature RE technologies are outcompeted by wind due to the higher costs in the short run. For example, the EU does not find that the RE certificate market should cover established competitive hydropower stations. According to the EU's White Paper on RE, large hydropower stations are not entitled to subsidies. As a result, a coming single RE market is not expected to cover this type of RE.

TSOs from the Netherlands, Denmark, Germany, England, Belgium and Italy try to carry out a pilot project on a voluntary basis with a view to clarifying how international trade in certificates can work in practice. It must be expected that if the EU does not adopt a directive on a single RE market within the next year, a large number of countries will establish it on a voluntary basis. This will create a voluntary single RE market which more EU countries can join gradually.

The fact that the framework conditions for electricity generation and consumption in Europe seem to approach each other supports the visions for expansion by RE. If trade in RE certificates can take place across borders, this will constitute the first step towards commercial utilisation of the large wind resources in Northern Europe. This puts heavy requirements on the network's transmission capacity.

3. Future Production Facilities

The future production facilities in the Nordic countries will be influenced by the overall framework conditions taking shape on a European level. If the amount of RE is to be increased, the wind resources in Northern Europe will come into even more focus, and so will the problem concerning non-dispatchable production in the Nordel system.

This section gives an impression of the distribution of wind resources in Europe and presents an estimate of the potential for wind power in the Nordic countries. In conclusion, two scenarios for the development of the electricity system are described which represent two degrees of expansion by non-dispatchable production.

3.1 Wind Resources in the Nordic Countries

Based on meteorological data, the Risø National Laboratory in Denmark has estimated the wind resources above different types of landscape, **Figure 1**, and above open sea, **Figure 2**. It is a very overall estimate of resources, but the result is interesting from a Nordic point of view.

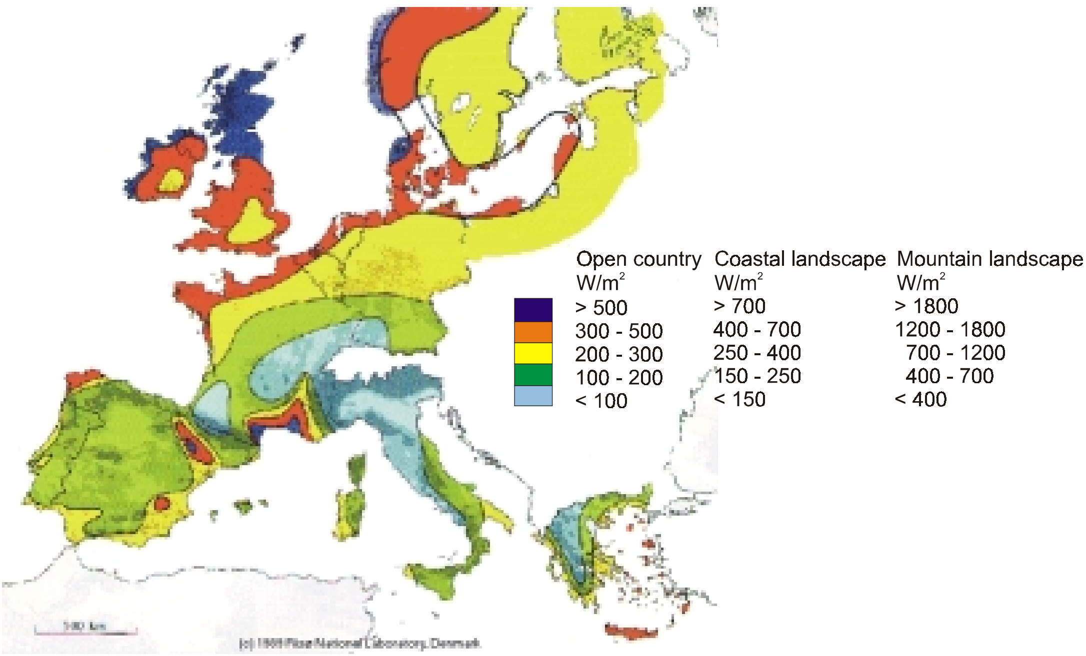


Figure 1 *Wind resources at an altitude of 50 metres above different types of landscape indicated as average values on an annual basis.*

From **Figure 1** it appears that the wind resources above land are very dependent on the type of landscape and the geographical location as seen in relation to the North Atlantic winds. The map also explains why the expansion by onshore wind turbines in Denmark started in the north-western part of Jutland. However, on the west coast of Norway there are places where the energy contents of the wind are substantially larger than on the west coast of Jutland.

In general, the conditions for production of wind power are substantially better in Northern Europe than in the rest of Europe. This is underlined by **Figure 2**, which illustrates the wind resources above the sea. The wind resources along the Norwegian coast are not indicated, but it must be assumed that the resources are typically > 800 W/m^2. In the Baltic Sea and the Gulf of Bothnia wind resources will also be about 800 W/m^2, which is why the wind resources here equal the resources in Danish waters.

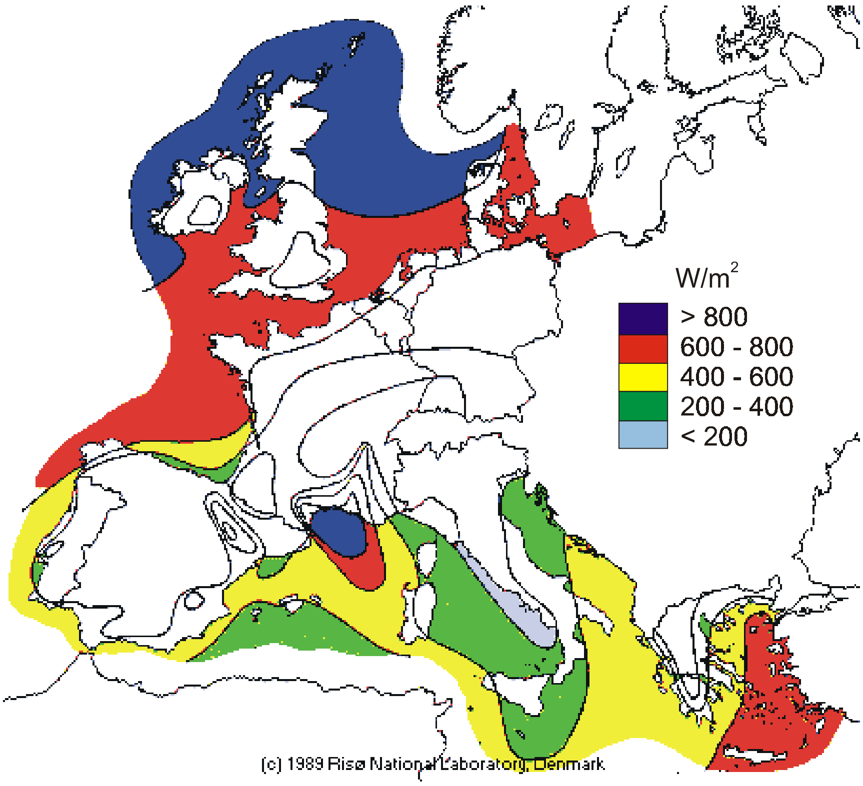


Figure 2 *Wind resources at an altitude of 50 metres at open sea (more than 10 km from the coast) indicated as average values on an annual basis.*

Present technology makes it possible to erect offshore turbines at a water depth of up to 15-20 m. This narrows the potential offshore expansion area considerably, but the potential is still very great.

Satisfaction of the EU's aims concerning RE in connection with an international market for certificates may result in commissioning of relatively many wind turbines in Northern Europe, whereas Southern and Central Europe focus on other technologies such as solar cells. The size of production compared to local consumption may result in derived needs in the form of larger transmission capacities in the network.

3.2 Potential for Wind Turbine Capacity

The technical potential for utilisation of wind power in the Nordic countries has been estimated at more than 250 TWh when results from national studies are combined [5, 9, 10, 11]. These estimates are based on wind statistics, charts and maps, nature conservation plans, etc.

Great uncertainty is associated with the technical potential, but there is no doubt that the potential is significant as seen in relation to total consumption within Nordel.

Provided that the economic assumptions are all right, the realisable potential will depend on how wind power can be incorporated into the environment. If "mountain turbines" and "offshore turbines" are accepted, the realisable potential is expected to amount to about 75-150 TWh (25,000-50,000 MW). This corresponds to 20-40 per cent of the electricity consumption within the Nordel area today.

However, this does not necessarily imply an increase in the number of wind turbines in the Nordic system. Today, there are more than 7,000 turbines in Nordel with a total capacity of about 2,000 MW. The majority of turbines are smaller than 250 kW.

Today, turbines of 2 MW are being built (wing diameter 75 m) and in year 2005 turbines of 5 MW are expected to be a reality. Before 2020 turbines of 10 MW (wing diameter 160 m) are likely. So, in the long run the realisation of e.g. 50,000 MW of wind power could probably take place by means of approx. 5,000 turbines.

Seen in this perspective, wind turbines should rightly be called wind power stations. Here the design of visionary connection specifications is an essential prerequisite for a reasonable interaction between production and transmission, cf. section 7.1. Control and regulation of wind power stations are still virgin soil, but the technological development opens up new prospects.

Today, wind turbines produce at a cost of DKK 0.25-0.35 per kWh (EUR 0.04-0.05 per kWh), depending on location and utilisation time. It is not unrealistic to expect costs below DKK 0.20 per kWh (EUR 0.03 per kWh) in the long run for production at offshore and mountain turbines, not least due to the high utilisation times.

3.3 Scenarios

Two scenarios have been set up for the expansion by non-dispatchable production. The scenarios are both set up for year 2020 and are characterised by:

- A considerable amount of installed wind power
- Local CHP totalling 9,200 MW
- Consumption increase of about 1 per cent per annum in the period 2000-2020
- Decommissioning of primary units that are older than 40 years in year 2020.

The difference between scenarios 1 and 2 is the amount of installed wind power. In scenario 1 10,000 MW is installed for the Nordel area, in scenario 2 20,000 MW.

With the national targets and results [5, 6, 7, 10 and 12] everything seems to indicate that Nordel will comprise at least 10,000 MW of wind turbines in 2020. Seen in that perspective, scenario 1 is no extreme scenario at all. On the other hand, scenario 2 implies a strong increase in wind power expansion compared to present national targets. As a result, the scenario implies technological leaps in the turbine field and/or international co-ordination of framework conditions.

Year 2020	**Consumption Winter**		**Consumption Summer**		**Wind power, MW**		**Local/ industrial CHP MW**
	Max. MW	**Min. MW**	**Maks. MW**	**Min. MW**	**Scenario 1**	**Scenario 2**	
Norway	26,000	22.700	17,100	13,800	1,000	4,000	250
Finland	16,500	10,600	10,900	7,400	500	2,000	3,200
Sweden	32,000	23,000	15,000	9,800	4,000	8,000	3,000[3]
Denmark	7,500	3,000	6,000	2,500	5,400	7,000	2,550
Total	82,000	59,300	49,000	33,500	10,900	21,000	9,000

Table 2 *Variations in consumption summer and winter compared with installed non-dispatchable production. As regards electricity consumption, the figures are approximate figures intended are to illustrate the order of magnitude.*

Scenario 1 comprises a total non-dispatchable production of 19,500 MW, including 9,000 MW of local CHP. Scenario 2 comprises a total non-dispatchable production of 30,000 MW, including 9,000 MW of local CHP.

[3] Only part of this power is non-dispatchable, as some Swedish local CHP units can produce heat independently of the power production.

In comparison with this, non-dispatchable production in the Nordel system today accounts for about 10,000 MW, including about 8,000 MW of local CHP.

Enclosure 1 shows the geographical location and size in terms of MW of non-dispatchable production capacity as well as variations in electricity consumption in 2020. The Enclosure illustrates that the imbalances between wind power and regional consumption are unevenly distributed geographically in the total Nordic system, resulting in potential transport requirements. Likewise, it appears that non-dispatchable production is concentrated in the southern part of the Nordel area. However, as will be known, the regulating capacity is mainly located in the northern part of the Nordel area.

Nuclear power stations are difficult to regulate, but they represent reliable base-load units. As a result, decommissioning of nuclear power stations has a great impact on the risk of power shortage, unless the nuclear power stations are replaced by new production units.

4. Characteristics of Non-dispatchable Production

Non-dispatchable production is to be understood as production that is controlled by other factors than electricity consumption and is not one of the immediate regulating options of the system control. As a result, non-dispatchable production is not assumed to supply ancillary services to the electricity system, but can, on the contrary, increase the need for such services, cf. chapter 5.

However, non-dispatchable production can be divided into two types: a stochastic production given by wind turbines and a controlled production caused by local CHP units, including industrial CHP.

This section describes the production value of the two types of non-dispatchable production and looks at the gradients caused by the stochastic production in particular. Finally, the stochastic production is assessed in a large geographical area.

4.1 Production Values – Simultaneousness with Consumption

The production from local CHP units is characterised by the bond to the local area heating requirement. Therefore, the production from CHP units also coincides with the large electricity consumption in the winter months. In Denmark measurements have demonstrated that local CHP units (including industrial units) produce at least 75 per cent of the installed capacity when electricity consumption is between 80 and 100 per cent.

Besides, measurements have shown that wind turbines produce approx. 50 per cent more in the winter months than in the summer months [13]. However, as cold winter days are often characterised by calm weather there is only a small match between maximum consumption and wind power production.

The utilisation time for geographically dispersed onshore turbines is approx. 2,200 hours. Offshore or mountain turbines will be able to achieve utilisation times of up to the double value, cf. **Figure 3**. When the utilisation time approaches 4,000 hours, the production from wind turbines will become more stable, increasing the simultaneousness with the consumption maximum, all other things being equal. However, the combination of maximum electricity consumption and zero wind power production will still occur at a regional level. The larger the geographical area is, the smaller the probability of this match is, cf. section 4.3.

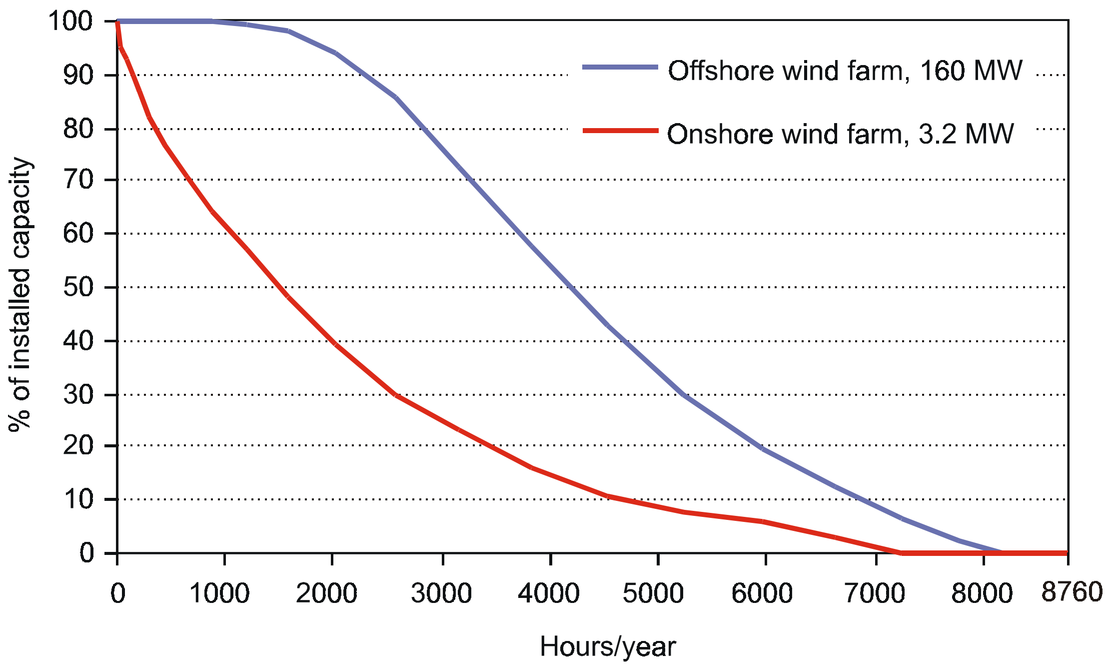


Figure 3 *Duration curves for a 160 MW offshore wind farm with a utilisation time of approx. 4,000 hours and a 3.2 MW onshore wind farm with a utilisation time of 2,125 hours.*

Offshore wind farms will be characterised by zero production less than ten per cent of the time. About 50 per cent of the time production will exceed 50 per cent of installed capacity. In particularly windy years production will be up to 15 per cent larger than medium production, in particularly windless years 15-20 per cent lower than medium production.

4.2 Power Gradients Caused by Wind Turbines

Wind power production will be stochastically determined and thus always associated with some uncertainty. Today wind production cannot be forecasted sufficiently precisely, neither in terms of time nor in terms of size, to be included in the operational planning on equal terms with other types of production.

Forecasting systems for wind power are likely to be substantially improved in the future, enabling 12-hour, 24-hour and 36-hour forecasts for the energy content of wind power to be included in trade on the power exchange, and so in the actual operational planning.

Nord Pool’s exchange product “Elbas”, meeting Swedish-Finnish needs to trade up to two hours before the 24-hour operation period, will be applicable in connection with trade of large amounts of non-dispatchable production.

However, short-term power variations cannot be predicted. These power variations are handled by the primary regulation and are seen on the a.c. co-operation links and must, according to current practice, be counterbalanced via secondary control in the local area or by purchasing exchange, possibly via the co-operation links.

The size of the power gradients depends partly on the wind power capacity in the system and partly on the geographical dispersion of the turbines. **Figure 4** shows an example of constant wind capacity (1,000 MW), but where the turbines are integrated into the system in three different ways.

Geographical dispersion reduces the size of power gradients substantially, the gradients for 1,000 MW of onshore turbines only account for about 30 per cent of the gradients from an offshore wind farm of 1,000 MW. However, if the 1,000 MW of offshore turbines is distributed on three sites instead of one, the power gradients are reduced by 50 per cent.

The figures for the power gradients are estimated on the basis of measurements from Danish onshore and coastal wind farms. As no sufficient number of wind measurements at sea is available as yet, the estimated power gradients for offshore turbines are subject to some uncertainty.

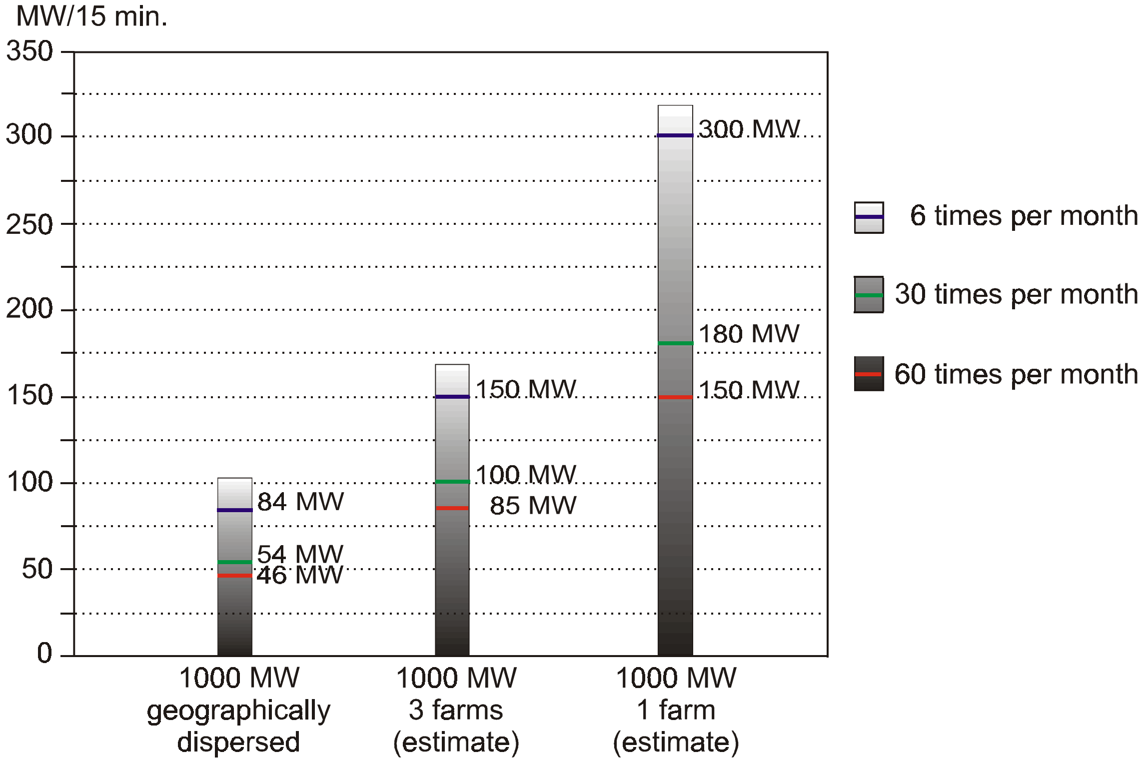


Figure 4 *Numerical sizes of power gradients for three different implementations of 1,000 MW of wind power. The gradients are distributed equally on upward and downward regulation.*

If the number of turbines in the system is large, there will be large power gradients to be equalled out between the areas. Whereas large consumption gradients always occur at the same time in the morning, the power gradients from wind turbines will occur irregularly. This puts entirely different requirements on the regulating ability of the power system. The electricity system must also be able to correspond to the regulation on mornings when consumption increases and wind production decreases.

Depending on the formulation of the specifications for connecting wind turbines to the network, it will be possible to regulate new turbines located in large farms at sea or in the mountains. Nordel should identify the realistic regulation potential, as it may strongly influence the necessary network expansion.

A special problem arises in strong wind when many wind turbines trip simultaneously and the gradients may exceed the dimensioning outage in the system. This is further described in chapter 5.2.

A possible scenario is that in future the network will have to be expanded in areas with many wind turbines due to power gradients and power shortage/overflow. In this connection it is important to decide whether network expansion by new overhead lines in one country can be justified and carried out locally with a view to satisfying regulating needs in another country.

4.3 Equalisation in a Nordic/Northern European Perspective

An investigation based on all measurements of wind speeds several places in Northern Europe [13] sheds light on the correlation between electricity production from wind turbines in the individual countries. **Figure 5** shows that the cross-correlation between the production from two wind farms is practically exponentially decreasing with the distance. This means that when the distance between the two wind farms exceeds 1,000 km the cross-correlation is usually less than 0.2.

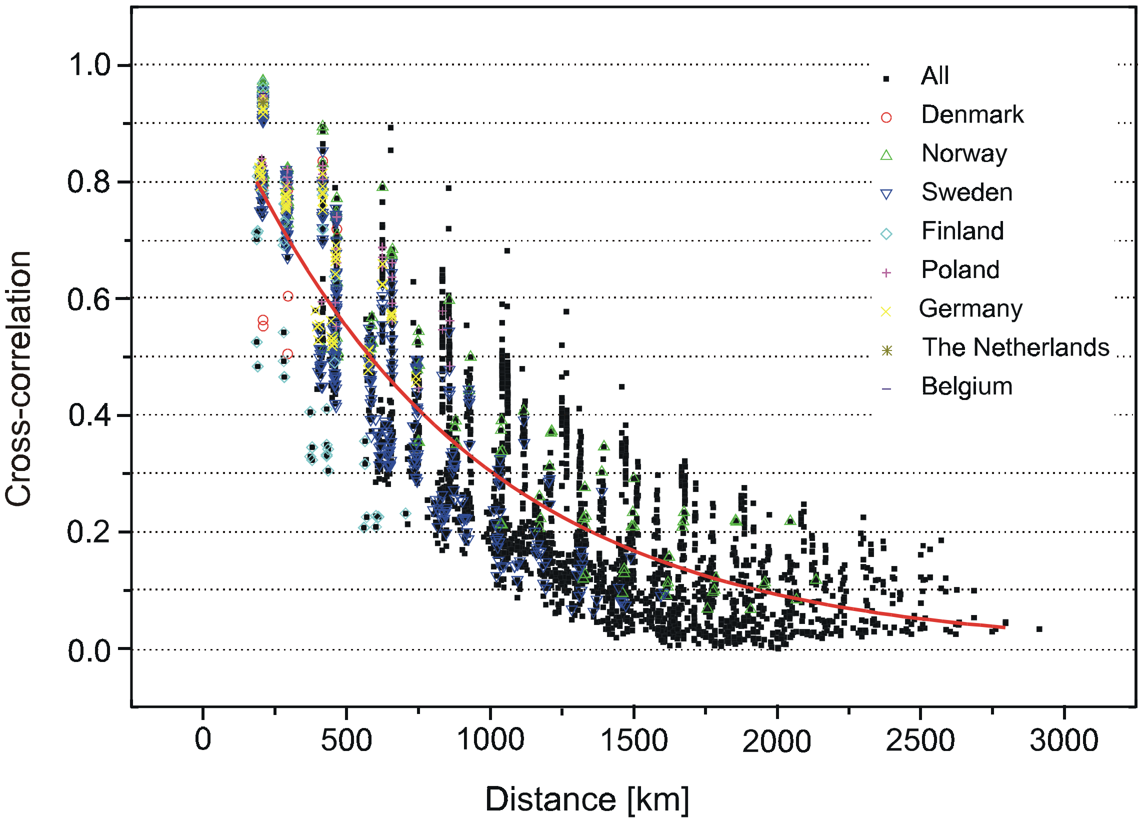


Figure 5 *Cross-correlation as a function of the distance between wind farms in Northern Europe*

The results vary somewhat from country to country. For instance, the cross-correlation for turbines within Norway is generally larger than the cross-correlation for turbines within Sweden. A reason could be that Norway is more exposed to uniform weather than Sweden.

If Northern Europe is considered together, variations in electricity production based on Figure 5 will not take place within the individual hour, but over several hours. This will influence transports in the network.

5. Ancillary Services

Ancillary services are understood to mean technical services necessary to maintain a coherent electricity system and to ensure a sufficient quality of the electricity supplied. The quality parameters are operational reliability (how strong is the system towards incidences) and requirements on maximum voltage and frequency variation.

Ancillary services cover, inter alia, services necessary for technical reasons to be able to carry out the production variation fixed by the market. Ancillary services are used in the operational phase. The long-term planning is to ensure that the ancillary services are available for use in future operations.

Establishment of large amounts of non-dispatchable production will strongly influence the need for regulations and reserves in the remaining production facilities. These are needs that can be covered by ancillary services. The following chapters will take a closer look at this.

5.1 Operational Reserves

To create balance between production and consumption, Nordel has formulated a set of regulations for reserves, of which some are common to the entire area. The reserves are primarily distributed according to the time requirement for activation.

In Nordel there are the following types of reserves concerning active power:

Automatically regulated reserves:

- Frequency control reserve
- Instantaneous disturbance reserve

Reserves activated by the operators:

1. Forecasting reserve
2. 15-minute reserve
3. 4-hour reserve

Besides, Nordels “Recommendations for Frequency, Time Deviation, Regulating Power and Reserves” establishes that any expansion by production capacity must cover its share of the need for ancillary services and reserves through own investments or by purchases in the market.

Appendix 1 illustrates the expected impact of non-dispatchable production on different types of reserves.

The conclusion is that the technology applied in the Nordic electricity system today to control the production and consumption balance is not suitable to handle large amounts of wind power and other non-dispatchable production in the electricity system. As a result, a new technology for control of the electricity system must be developed that is:

- Adapted to the technology applied at wind power and other non-dispatchable production units.
- Adapted to the technology applied in the existing production system.
- Adapted to Nordel's market system.
- Adapted to the non-dispatchable production in terms of size.

The problem of regulating production is easily divided into two; a part that can be forecasted some hours in advance and is naturally handled by the market and a part that varies so quickly that it should be balanced by an automatically regulating reserve. The most important thing in the automatic part of the reserve is to get a control signal that soon registers changes in the non-dispatchable production and can be applied in an automatic control without too frequent intervention from the system operators.

Appendix 2 presents some thought about a future regulation concept.

5.2 Network Reserves and Maximum Production Outage

When the wind power is collected in large farms in a relatively small geographical area, there will be a risk of production outage for the entire farm.

There are two aspects of this problem. Partly the amount of production that the power system can bear to lose at a time in rare "non-dimensioning but not unlikely" disturbance situations without extensive cascading in the network. Partly the consequence of normal n-1 disturbances of network connections to offshore wind turbines, as Nordels instantaneous disturbance reserve is determined on the basis of "disturbances that statistically occur more than once every third year".

Outage of a network line leading to a large group of offshore turbines will be able to activate the maximum power reserves. Therefore, network connection of large offshore farms must be planned with this in mind. However, reserve cables for offshore farms are extremely expensive and as the utilisation time is also low, expansion of interconnections must be an alternative. The problem becomes decisive for when the network lines are expanded to ring connections.

However, for offshore wind farms the “cut-out” effect must also be taken into consideration. “Cut-out” means that all wind turbines in the wind farm stop within a short period because of too high wind speeds (usually about 25 m/s as a ten-minute mean value). An operating situation like this will also be able to activate the maximum power reserves, but it may be assumed that by virtue of preceding wind forecasts the system control will be attentive when the risk is highest. Future system analyses must determine the actual extent of the “cut-out” effect.

5.3 Regulating Power

Non-dispatchable production puts heavy demands on the regulating ability and so on the regulating power.

A common feature of non-dispatchable production is that it requires separate regulating reserves in the system. Wind turbines make heavier demands than local CHP units, which are more predictable in their production and to some extent can be controlled by means of tariffs. Besides, there is a coupling to the local heating requirement in a local CHP unit, which ensures a geographical dispersion of the plants and a location close to the consumption.

However, as far as wind turbines are concerned, the best locations are found in windy and scarcely populated areas where consumption is low, which puts heavy demands on the main network.

Which Units can be Regulated?

Previously, the problem of regulation would be solved centrally by finding the units that regulate in the best and least expensive way. In the market the selection and minimisation of costs has been left to the market players.

However, from a planning point of view it is important to have an overview of the best suitable units for the necessary regulation to avoid that the competitive regulating power is constrained by bottlenecks in the network.

Another essential condition is that for many years yet to come, network constraints will be normal in the Nordel network. That is, optimum operation in these situations implies that regions with large amounts of non-dispatchable production procure regulating power at units in their own area, even though they may not be particularly suitable for this.

Besides, one cannot rule out that the market could find a competitive form of consumption control reducing the requirements on production regulation created by non-dispatchable production.

Usually, hydropower stations are regarded as extremely suitable for regulation. However, in practice there are also limits to how much the hydropower stations can regulate without waste of water. There are bonds between the production at power stations along the same river. The regulating ability of the power stations depends on the size of the hydropower reservoirs and there are also minimum limits to the water flow in a river with several power stations. Pumped storage power on a daily basis, as it is known from the Alps, is not installed in the Nordic countries where pumped storage power typically occurs on a seasonal basis.

In Nordel a study of the suitability for regulating the various types of units is pending.

Is there Sufficient Regulating Power?

The current trend in the Nordel system is that the regulation properties are weakened as condenser units are scrapped. However, the need for regulating power is increased in line with the expansion by non-dispatchable production. Wind power can only contribute by upward regulation if the production has been limited in advance to a level that is lower than the current wind promises. Such a reduction influences the profitability of the turbines to a considerable extent.

Previous Swedish studies have assessed that fast power variations (< 15 minutes) constitute up to 3 per cent at 3,000 MW of installed wind power in Sweden. This corresponds to 90 MW. Whether 3 per cent is the correct figure is very uncertain. The Danish studies, **Figure 4**, rather point to 6-8 per cent for geographically dispersed turbines, but the geographical dispersion is smaller here. If these assumptions are transferred to assessment of the need for regulating power in the scenarios, the need is 300-800 MW in scenario 1 and 600-1,600 MW in scenario 2.

In a Nordel context the problem can be summed up to say that in the southern part of the Nordel network there is non-dispatchable production and in the northern part regulating production such as the Eidfjord station of 1,000 MW divided on four six-beam Peltonturbines. If this power station is controlled by automatics regulating continuously and controlling the number of units and beams in operation, it will take the sting out of the regulating problem in scenario 1, that is, in a way where the water is utilised at a reasonable efficiency. Even though there is no reason why exactly that station is to be speeded up and down and even though the non-dispatchable production is expanded in other parts of the Nordel network, the example illustrates that there are sufficient resources and that the expansion by non-dispatchable production is primarily a network problem in a Nordel context.

Unfortunately, some of the operating situations in which non-dispatchable production needs balancing power coincide with operating situations in which the network from the hydropower areas towards consumption-intensive parts of the Nordel network is already constrained. As experience shows that expansion of the network is difficult, the example also illustrates that the network constraints become decisive for the need for local regulating power.

6. Transport Requirements

The transport requirements arising as a result of non-dispatchable production occur when local production exceeds local consumption. In a transitional period the solution is to be found in network reinforcements in the distribution network, but if the expansion by non-dispatchable production continues, the need for transport will soon be seen in the transmission network. And then it will not be long before the production influences the utilisation of interconnections with neighbouring systems.

This chapter describes assessments of a number of problems and looks into how non-dispatchable production influences the risk of power shortages. Finally, various measures are described that can help reducing the transport requirement.

6.1 Assessments of Transport Requirements

The result of the assessments in each country is divided according to subjects. The result will form the basis for the Grid Group's future activities concerning transmission capacities in the Nordel network in year 2010.

Power Constraints Seen in a Local/Regional Perspective

Local CHP units are common in Sweden, Finland and Denmark, cf. **Table 1**. From a network point of view the power stations limit the transport requirement in the transmission network, as production takes place locally and to a high extent coincides with consumption. As the local CHP units represent a reduction in consumption at local level, they reduce the transport requirement in the transmission network, all other things being equal.

However, the electricity production at local CHP units simultaneously reduces the electricity consumption in the region to such an extent that expansion by wind turbines, as has taken place in Denmark, results in considerable export from the region.

Enclosure 2 illustrates how the expansion by wind turbines in Denmark has increased the need for transport capacity – first at distribution level, not at transmission level. It must be expected that a similar development will take place in Norway, Sweden and Finland.

To meet the unpredictability of wind power it is often necessary to increase the operational margins in the transmission network. With unchanged transmission capacity this means reduced trade capacity and so advancing of a need for reinforcements.

Influence on Geographical Transmission Cross-section

The operational margin expresses the transmission capacity in a cross-section that is reserved to meet changes in power flow following from the fact that hydropower outbalances variations in electricity consumption. Today, the operational margins in the Swedish system are 100-150 MW.

Scenarios 1 and 2 probably result in a need to increase the operational margins as a result of the unpredictable power gradients and especially in cross-sections 2 and 4 as well as the interconnections to Denmark. This means that the transmission capacity that is available to the market must be reduced. The costs are thus connected to larger expenses in connection with counterpurchase at bottlenecks in the cross-sections. This may result in an advanced reinforcement need. This issue could be a theme in the next issue of “Transmission Capacities in the Nordel System”.

However, the utilisation of the constraining cross-sections in the Swedish transmission network and on interconnections to Denmark will also be influenced by the slow changes in the network flow. Particularly in cross-sections 2 and 4, as a major part of the wind power is expected to be established in Denmark and Southern Sweden. As regulating power is primarily collected in the Northern part of the area, transport in all Swedish cross-sections will vary in line with wind power production.

Power Constraints Seen in a Nordic Perspective

The transmission requirement in cross-section 4 will be influenced by scenarios 1 and 2. A combination of low load and strong wind results in a production surplus in Southern Sweden and Denmark, which will go towards north in certain cases. This is a capacity direction that the cross-section is not designed for, and reinforcements may be relevant.

So, non-dispatchable production creates an increasing need for transports from south towards north in the Nordel area. At other times and particularly in wet years the transport will still go from north towards south and further on to the Continent. In these situations the non-dispatchable production will increase the transport requirement in the entire Nordel main network.

The question is whether there is sufficient transport capacity in the network in wet years, or whether large amounts of RE energy are prevented from reaching the European market. For instance, will turbines in Western Norway be able to produce if the local network is constrained by the production from hydropower stations? Here the network constraints may arise both locally, nationally and internationally.

An overall structure analysis of the Nordic network should include this question.

6.2 Power Shortage

The risk of power shortages may be influenced by large amounts of non-dispatchable production, but only to the extent that the non-dispatchable production displaces primary power stations [14]. Where the expansion by wind power takes place in other areas than where power stations are scrapped, there is a special need to revise the assumptions behind power shortage studies. To the extent that power shortage situations must be prevented by network reinforcements, it will often be insufficient just to reinforce the network towards neighbouring areas, as also this area may have production shortages and internal network constraints.

6.3 Measures towards Non-dispatchable Production

As appears from previous chapters, non-dispatchable production results in derived costs in the form of ancillary services, larger operational margins and possible network extension. However, the need for ancillary servies, network extension, etc., can obviously be limited if all measures improving the integration of non-dispatchable production are included in the considerations on a Nordel level.

Examples of measures:

Control by means of Tariffs

Well-known method to control local CHP units.

Control of Consumption

Electric boilers are common in Sweden, Norway and Finland. Heat pumps also represent a regulating potential.

Control of Wind Turbines

New turbines represent a significant regulating potential, but there is a need for in-depth investigations.

Energy Storage

New types of electricity stores are being developed. In the long run it must be expected that it will be possible to store energy from wind turbines within 24 hours. This will increase the regulating ability in the 24-hour operation period considerably, but will probably not change the need for transport in a windy month.

Financial Incentives

For market participants, wind turbine owners, existing and new producers with a view to reconstruction or construction of new plants with the demanded properties within active as well as reactive power.

These measures must be seen in the light of the alternative, which may be network reinforcements.

7. Derived Requirements on the Main Network

The non-dispatchable production increases the requirements on the main network. As it is primarily located in the southern part of the Nordel area, the energy flow in the main network is changed in many situations. Besides, the unpredictability of wind power means that a need for larger operational margins, and so lower transmission capacities to the market, must be foreseen.

It is thus decisive that the connection specifications for non-dispatchable production are taken into consideration to ensure a reasonable balance between the requirements on production units and on the main network.

This chapter describes the initiatives concerning connection specifications and assesses the consequences to design and planning of the main network.

7.1 Connection Specifications

The planning is to ensure that the necessary reserves are available in the operating situation, but it also has to ensure that connection specifications for non-dispatchable production are worked out, so that there is a basis on which to assess the quality of the necessary reserves.

Denmark has just worked out a set of specifications for connecting large wind farms to the network [15]. As offshore wind turbines are grouped in large farms and are connected to the transmission network, they are rather “wind power stations” than wind turbines. The specifications reflect this, as requirements are e.g. put on the regulating properties of the offshore farm during network disturbances and on the farm’s production gradients, etc. under intense network conditions. However, this does not change the fact that it is mainly a matter of stochastic non-dispatchable production, but this contributes to reducing the need for ancillary services. In certain cases the offshore wind farm itself will act as a supplier of services.

Preparation of specifications lays down an important framework for design and planning of the main network.

7.2 Design and Planning Criteria

Expansion by wind turbines implies expansion by networks. First locally, then regionally and internationally. Both scenario 1 and scenario 2 will radically change the production distribution and so the transport requirement in the southern part of Nordel’s main network. However, it is impossible to estimate today to which extent the 400 kV network and interconnections should be expanded.

The market is also to function even though the production facilities cover large amounts of non-dispatchable production.

The Grid Group estimates that there is a need for a set of supplementary planning criteria that take into account that the Nordel system covers large numbers of wind turbines. However, these criteria must be set up in parallel with the consideration of the requirements that must be put on the wind turbine manufacturer.

7.3 Market Influence

Already today, non-dispatchable production exerts influence on the market. For example, the wind power production in Denmark means that Swedish players experience difficulties when making operational forecasts and entering deals for part of their production facilities, due to the partly unpredictable presence of wind power electricity at Nord Pool.

Further expansion by non-dispatchable production would increase the requirements on the market and so the requirements on the main network.

Appendix 3 refers to a Danish study of the possibilities provided by the market for balancing further wind power in the western Danish system. It appears that the capacity on connections to neighbouring systems has a great impact on the size of the residual power overflow, understood as the part of the electricity overflow (the difference between bound production and consumption within the area) that must be handled by special regulation of the system: For instance decommissioning of CHP units and heat production at pure heat units and/or decommissioning of wind turbines. Another regulating possibility is increased electricity consumption, e.g. for heat pumps.

8. Conclusions

A number of problems relating to non-dispatchable production in the Nordel system have been identified that must be dealt with in co-operation. There is both a need for transmission capacity, regulating capacity and not least reserves in case of outage of the largest unit.

Non-dispatchable production is understood to mean the part of the production facilities that cannot be load-dispatched. At the moment it accounts for about 10,000 MW, of which wind turbines account for 2,000 MW and local CHP units account for 8,000 MW. The non-dispatchable production is expected to boost as a result of wind power expansion.

In principle, nuclear power stations are non-dispatchable, but they constitute a reliable base-load resource that feeds into the transmission network and cannot be compared with other non-dispatchable production. However, scrapping of nuclear power stations can reduce the regulating ability of the system to the extent that dispatchable units must take over base-load production.

Nordic wind resources are significant, and in the long term they will be able to cover 20-40 per cent of the electricity consumption in the Nordic countries. Today, turbines can produce at EUR 0.04-0.05 per kWh. A further price decrease is not unrealistic, and production becomes competitive with coal, nuclear power, etc., but the properties are not the same.

Two scenarios have been set up, featuring minor and major expansion of wind power, respectively. This results in a non-dispatchable production of 20,000 MW and 30,000 MW, respectively.

However, both of the scenarios increase the demand for regulating power and transport in the network. The need for regulating power for the fast power variations alone is estimated to be 300-800 MW in scenario 1 and 600-1,600 MW in scenario 2.

As the wind power in both scenarios is mainly placed in Denmark and southern Sweden increased pressure on the interconnections between Denmark and Norway/Sweden and on cross-sections 2 and 4 in Sweden must be foreseen. Therefore, the expansion by non-dispatchable production is a network problem to some extent, but as overhead lines is a scarce resource other measures have to be included. In this context it is a question whether it is possible to carry out an overhead line project in one country justified by power and regulating needs in another country.

The risk of power shortages will be influenced by large amounts of non-dispatchable production, but only to the extent that non-dispatchable production displaces primary power stations.

The Grid Group has identified the problems without taking into consideration whether they originate from the production facilities or the network. In the next phase the solution models must further clarify to which extent it is a network problem and to which extent the technological possibilities in control and regulation of the turbines can solve the problems directly in the production facilities.

The following proposals have been made for further initiatives:

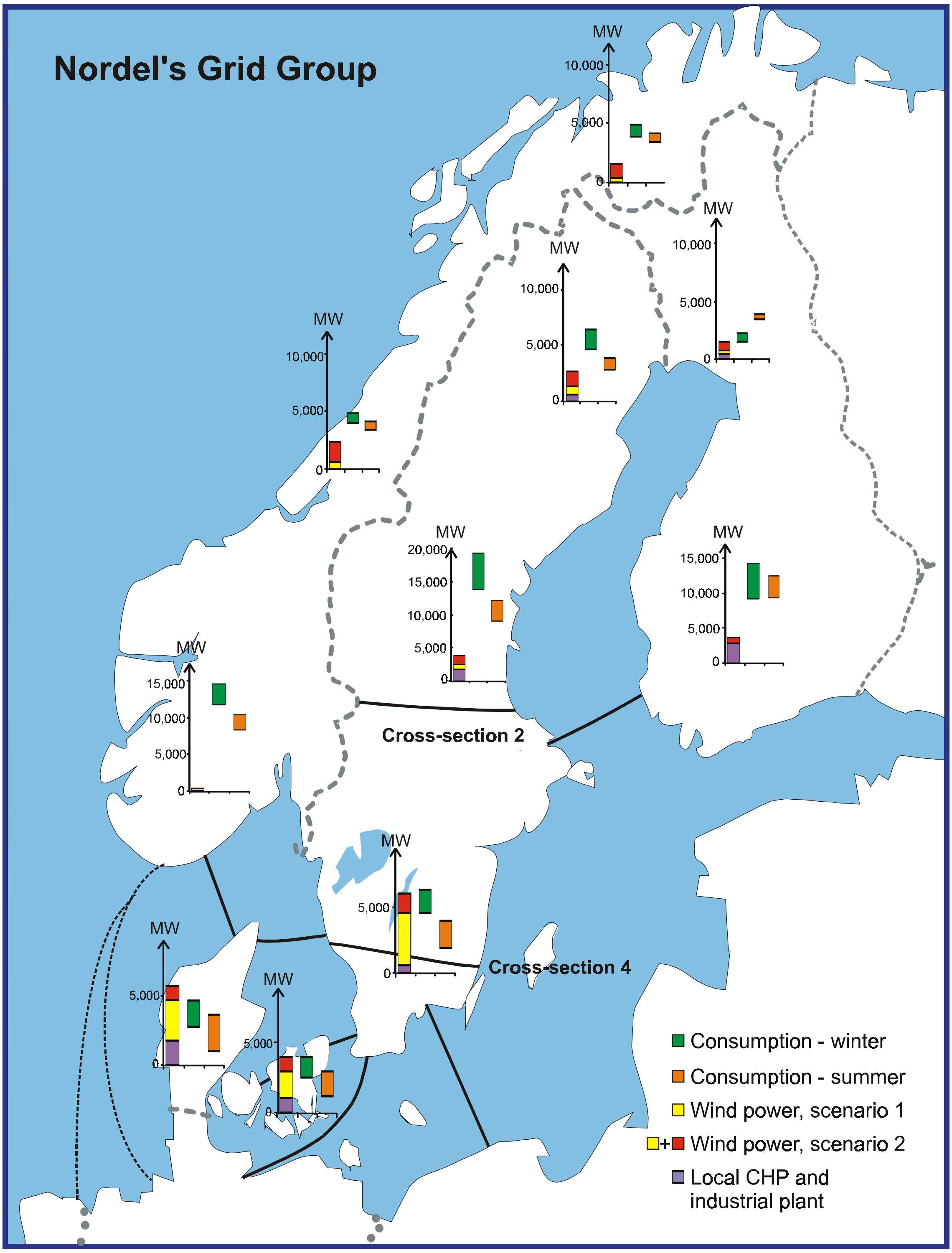
- Study of the correlation between wind power and hydropower in the Nordel area.
- Nordic analysis of consequences to the market in connection with large amounts of non-dispatchable production.
- Analysis of the regulating capacity of the system and its geographical location. Which units in the existing system will best meet the need for regulation?
- It will be possible to regulate new turbines located in large farms offshore or in the mountains, depending on the specifications. There is a need to map the realistic regulating potential of these farms, as it may have a spillover effect on the necessary network expansion.
- General analysis of measures improving the integration of non-dispatchable production in the Nordel system.
- In-depth analysis of the impact of non-dispatchable production on the risk of power shortages.

The Grid Group will apply the result of the future work as a basis for the work on transmission capacities in year 2010.

It is important to ensure inter-disciplinary co-operation between the Operations Committee and the Planning Committee in the future work.

References

1. “Consequences of Large Amounts of Non-dispatchable Production Capacity in the Nordic Electricity System” (in Danish), status document for Nordel’s Annual Meeting 1999, Nordel’s Grid Group 1999.
2. “Green Paper on Renewable Sources of Energy”, European Commission, November 1996.
3. “RE in Denmark and other EU Countries” (in Danish), Danish Energy Agency, June 1999.
4. “Energy 21”, Danish Ministry of Environment and Energy, 1996.
5. “National Program for Wind Power in Sweden”, Kjell Jonason, Göteborg Energi AB, March 2000.
6. “National Wind Energy Activities in Norway”, Harald Birkeland, NVE, NWPC'2000 Trondheim, 13-14 March 2000.
7. “Wind Energy Activities and Policies in Finland”, Jonas Wolff, VTT Energy.
8. “Analysis of the RE Certificate Market” (in Danish), Danish Energy Agency, December 1999.
9. “Energy and Power Balance towards 2020” (in Norwegian), NOE report 1998:11.
10. “Action Plan for Offshore Wind Farms in Danish Waters”, Danish Energy Agency, June 1997.
11. “Action Plan for Renewable Energy Sources” (in Finnish), Ministry of Trade and Industry, Energy Department, Publications 4/1999. Edita, Helsinki, 1999.
12. “Wind Power in Denmark, Technology, Policies and Results”, Danish Energy Agency, Danish Ministry of Environment and Energy, 1999.
13. “Equalizing Effects of the Wind Energy Production in Northern Europe determined from Reanalysis Data”, Risø National Laboratory, May 2000
14. “Power Shortage, Updated Calculations” (in Danish), Nordel’s Grid Group, May 2000.
15. “Specifications for Connecting Wind Farms to the Transmission Network”, Eltra and Elkraft System, July 1999.
16. “IRP99” (in Danish), Elkraft System and Eltra, April 2000.



Consumption variations, wind power, local CHP and industrial plant, year 2020

Wind turbines - Production in relation to area consumption	**Technical problem**	**Requirement**	**Time** **Number of wind turbines in Eltra's area**
The turbine production reduces consumption in the local area	Voltage quality with the consumers	Specifications for connecting turbines to the distribution network	1988 100 MW
The production of the turbines in the local area is expanded and comparable to consumption in the local area	Constraints in the existing 10 kV network	Separate 10 kV networks for collection of wind turbine production	~ 1992 300 MW
Some of the production of the turbines must be sent out of the region	Overload of local transformers in low-load periods	New 60/10 kV transformers	~ 1994 400 MW
The production of the turbines in one region often exceeds consumption	Constraints in the existing medium-voltage network	New 60 kV lines	~ 1996 650 MW
The production of the turbines in one part of the country often exceeds consumption considerably	Overload of transformers and lines in the transmission network in low-load periods	Reinforcement of transmission networks and international interconnections	1999 1,350 MW
Offshore turbines	"Wind power stations" – large production collected in one node	Specifications for connecting turbines to the transmission network (1998)	2002 1,900 MW of onshore turbines 150 MW of offshore turbines

Example of wind turbine and network expansion in a relatively small geographical area (Eltra) with a maximum consumption of less than 4,000 MW and a minimum consumption of approx. 1,500 MW.

Reserves

This appendix sheds light on Nordel’s existing rules for reserves based on the problem of non-dispatchable production.

Frequency Control Reserve

The purpose of Nordel’s frequency control reserve is to keep the network frequency within ± 0.1 Hz in connection with the small unpredictable changes taking place in consumption. The control signal is the network frequency.

Today, this reserve is 600 MW with 6,000 MW/Hz distributed between the countries in the synchronous Nordel network according to annual energy consumption. In Denmark, only Elkraft’s area (Eastern Denmark) is included in the Nordel reserve, because Eltra’s network has UCTE frequency. The distribution of the reserve is based on an even distribution of the small unpredictable changes in consumption over the entire synchronous Nordel network. As a result the frequency control reserve should/must normally also be evenly distributed. In contradiction to this, the non-dispatchable production tends to be located in certain geographical locations and the counterregulation caused by it should therefore be geographically optimised based on where the resources for regulation are found and what constraints exist in the transmission network.

The network frequency is not a very good signal to control the regulation necessary in consideration of wind power, because changes in the network frequency are small and because it is a delayed signal, as the network frequency reflects the integrated imbalance between production and consumption.

However, it should of course be noted that if nothing special is done to the non-dispatchable production, the imbalance from it will naturally influence the network frequency and so the frequency control reserves, which is controlled by the network frequency.

Instantaneous Disturbance Reserve

The instantaneous disturbance reserve must be activated if a production outage has created an imbalance. It is decided on the basis of the largest rolling unit[4] in the Nordel network and distributed between the countries according to certain rules. As the wind turbines consist of units that will not exceed a few MW in the near future, and the local CHP units are also of a limited size, Nordel’s instantaneous disturbance reserve is unaffected by the installation of wind turbines.

When several offshore farms are connected by a main cable, outage of the main cable will correspond to outage of the largest power station unit. This will be decisive for the time of ring connection of the offshore wind farms.

However, again it should of course be noted that if nothing special is done to the non-dispatchable production, it will of course influence the network frequency and thus the instantaneous disturbance reserve, which is controlled by the network frequency.

Forecasting reserve, 15-minute reserve, 4-hour reserve and adjustments of production schedules

Forecasting reserve, 15-minute reserve, 4-hour reserve and adjustments of production schedules may of course be used to control imbalances due to wind power.

The problem is, however, that it is unpractical, because part of the wind power production fluctuates too much to be controlled manually. Furthermore, in a market system there must be some time to organise supply and demand. However, for the part of the variations that can be predicted some hours in advance manual control based on the market is an obvious possibility.

Like downward regulation of other production units, downward regulation of wind power does not constitute any technical problem. It is the possibility of upward regulation that is difficult and costly. The sharing of the burden as regards the possibility of upward regulation is defined in Nordel's recommendation for reserves, etc. If wind power were to contribute to upward regulation, it would imply that maximum production had been reduced in advance. If, for instance, production had been produced by 15-20 per cent of maximum power, a similar upward regulation could be made. This would, of course, influence the profitability of the wind farms. The order of magnitude of the amount can, if nothing else, illustrate the value of the services that can be bought from the remaining system.

[4] A fault that statistically occurs more often than once each third year.

Regulation Concept for the Interconnection Network

This appendix introduces some considerations concerning a regulation concept for a system with large amounts of non-dispatchable production.

The purpose of a regulation concept is usually efficient utilisation of all the resources of the power system. However, this can be done in many ways, and what is appropriate in certain situations may not be in others, so the solutions must be flexible enough to meet different purposes. Furthermore, the distribution of responsibility and costs must be transparent. Finally, solutions must be non-discriminatory towards all players in the Nordic electricity market.

The problem must necessarily be based on international co-operation. The following three solutions are further described:

1. The entire Nordel area co-operates on solving the problem
2. Nordel and UCTE co-operates on solving the task
3. Denmark co-operates bilaterally with the Northern German area

The most simple Nordel solution to the problem is naturally to apply a Nordel network regulator regulating the faults of the entire Nordel network. This actually corresponds to what is being done today for the synchronous Nordel network, because it is an isolated network that according to nature will always balance. The new thing is then that also Eltra is covered by the network regulator, and this will result in some new technology.

Besides, the fact that the UCTE network applies requirements on power balance on a 15-minute basis, whereas Nordel applies “Indstillingsfejl” on an hourly basis makes it natural to include Eltra in Nordel’s network regulation.

Whether regulation of the interface between the Nordel and UCTE networks must take place on a 15-minute basis or hourly basis must depend on negotiation between the parties bearing the operational responsibility for the two networks.

However, a single Nordel network regulator regulating unit in the Nordel network is not a suitable solution. The reason is that network constraints are rather the usual thing than the exception in the Nordel network. The solution may be to us a “distributed network regulation”, implying that the sub-areas that often experience network constraints, have their own network regulator. This network regulator will usually be inferior to Nordel’s network regulator; but if network constraints arise seen from the area in question, the regulator will instead regulate on the network constraint, and the regulation of the Nordel network will be left to other areas that are not exposed to network constraints in the relevant situation. In the regulation concept maximum utilisation of the network is first priority and then Nordel's network regulation.

The principle is that non-dispatchable production is considered to be a joint task in a large geographical interconnection network. In this way wind power, which is particularly in focus here, become a more constant type of production from the point of view of the individual participant.

Actually, the principle is a step away from the old operational culture based on load-dispatchable units. This production technology resulted as a natural thing in an area control with tight tolerances for the area's deviations from the schedule. Non-dispatchable production leads as a natural thing to an operational culture that permits free exchange of power over the interconnection network.

Control Signals Made Necessary by the Non-dispatchable Production

The regulation task under Nordel auspices is to regulate the units which are not isolated as regards networks and which are suitable for and willing to regulation in order to maintain power balance; a task that has become substantially larger after the introduction of non-dispatchable production.

Two control signals are immediately applicable to maintain the power balance after introduction of non-dispatchable production:

- Measure the immediate production from the non-dispatchable units directly. However, for many small wind turbines and local units it must take place by means of estimates, for practical reasons.
- Establish a measuring ring around the entire Nordel network. The sum of all these MWs is the total deviation from the schedule. The principle (network regulator) is well-known in other interconnection networks and is today applied in the UCTE network.

The most simple and most commonly applied principle is network control or area control, where a measuring ring covers the entire Nordel area.

Possibilities of Using the Market for Regulation of Non-dispatchable Production

Power overflow in a given area is defined as the difference between the bound production and the consumption in the area. Important measures to handle power overflow are strong transmission links to neighbouring systems and a well-functioning spot market for electricity, so that a potential overflow can be transformed to sales in the market.

To shed light on the possibilities of using the market for regulation of non-dispatchable production an analysis has been carried out for Eltra's area [16]. The problem has been illustrated by estimating how an additional production of 3.5 TWh from 1,050 MW of offshore turbines can be regulated.

It is assumed that 1,000 MW of foreign capacity is available, which e.g. corresponds to the exchange potential on the Konti-Skan (600 MW) and Skagerrak (1,000 MW) interconnections less the transit agreement's 400 MW and 200 MW for ancillary services. It is not assumed that there is enough capacity on Eltra's German interconnection for Danish regulation of non-dispatchable production. The same applies to the Great Belt interconnection: Where there is overflow in Western Denmark, the same will probably apply in Eastern Denmark.

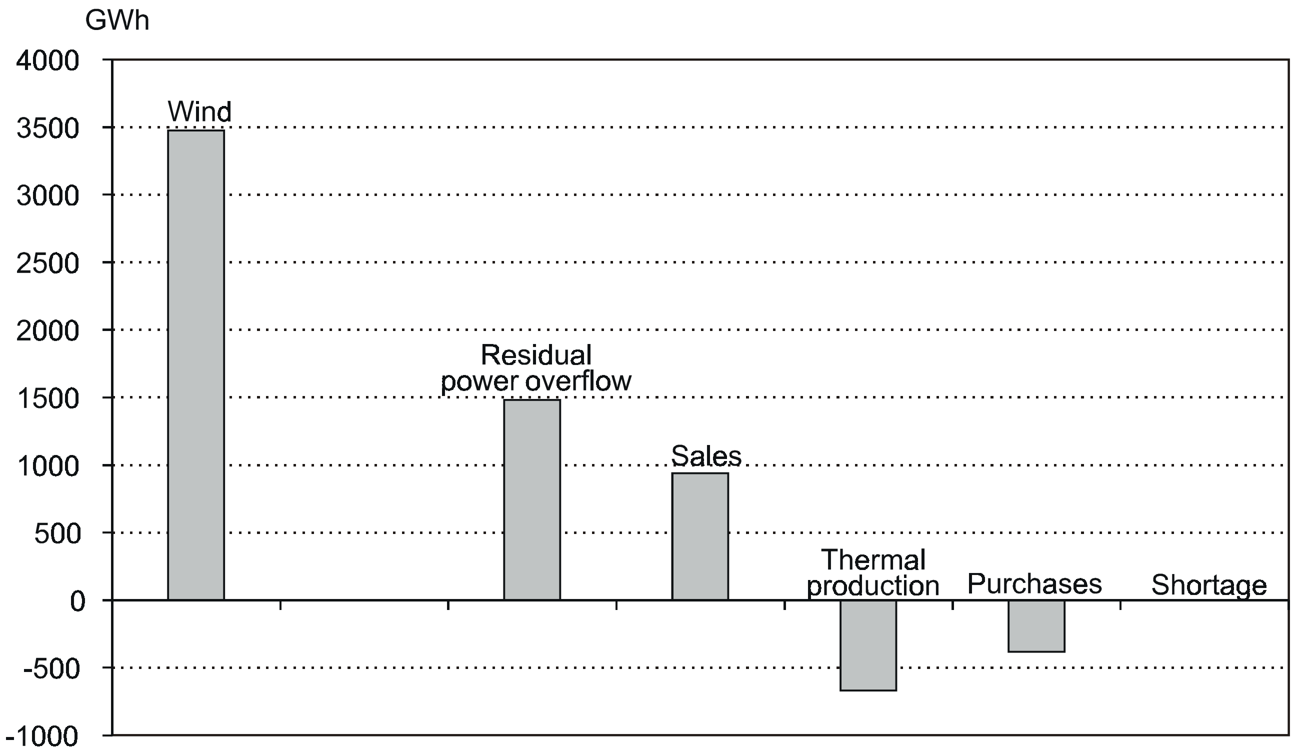


Figure 6 *Regulation of additional 3.5 TWh of offshore wind production in Eltra, 1,000 MW foreign capacity available.*

Figure 6 describes how the additional production of 3.5 TWh from the offshore wind turbines is regulated: Approx. 1.5 TWh becomes residual overflow, 0.9 TWh is regulated by increasing sales to the market (export at an average price of DKK 0.12), approx. 0.7 TWh is handled by regulating thermal production and approx. 0.4 TWh is regulated by less purchases in the market (import). Residual power overflow is here defined as the part of the overflow left when the possibility of exporting is depleted.

Furthermore, to shed light on the importance of the size of the foreign capacity a calculation has been done with 1,400 MW of available foreign capacity for a market regulation, see **Figure 7**. The additional wind power of approx. 3.5 TWh is regulated by approx. 1.1 TWh residual power overflow, approx. 1.4 TWh increased sales, approx. 0.4 TWh regulation on thermal units and approx. 0.6 TWh less purchases in the market.

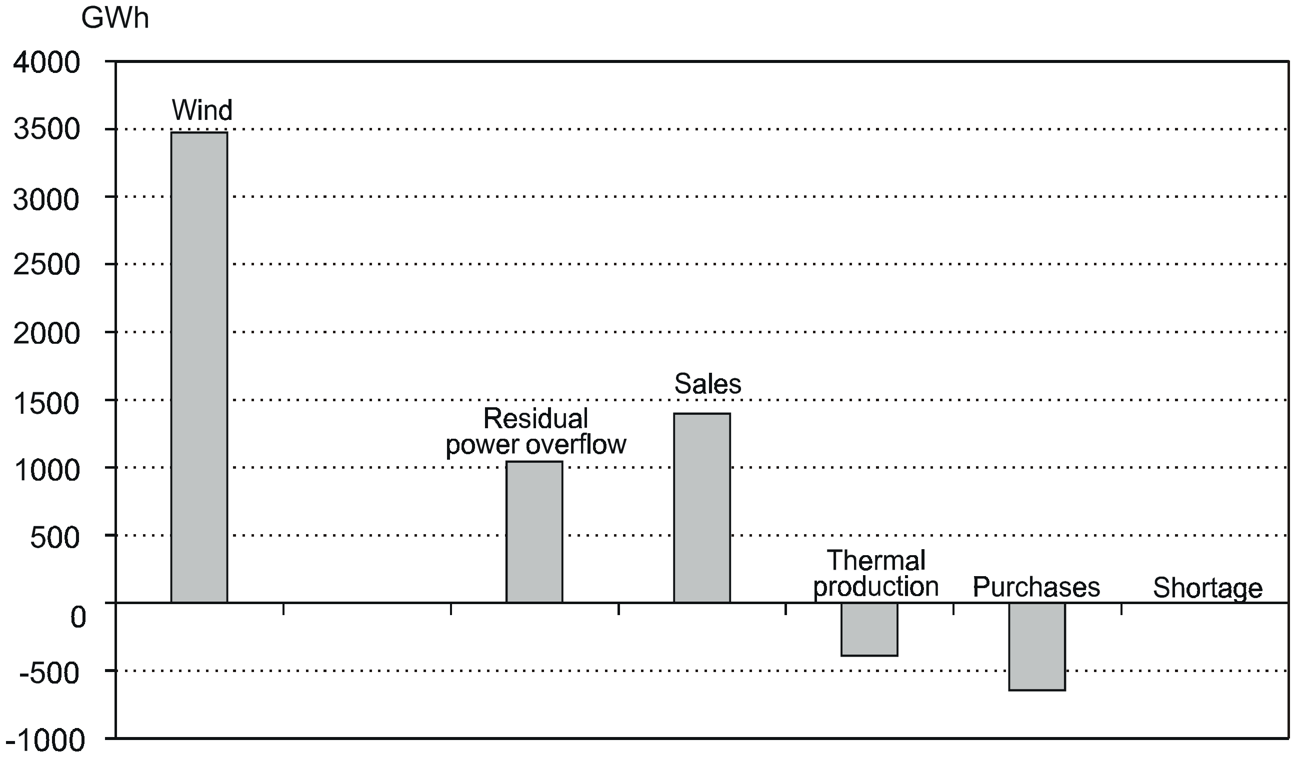


Figure 7 *Regulation of additonal 3.5 TWh of offshore wind production in Eltra, 1,400 MW foreign capacity available.*

It should be noted that the residual power overflow must be handled by special regulation of the system, e.g. closing-down of power units and heating production at pure heating units and/or closing-down of heating pumps.

The problem of overflow also exists in Elkraft's area – however, with other values for foreign capacity, overflow, etc. Elkraft has a larger foreign capacity than Eltra towards the Nordic hydropower system and less wind power, which means that there should be sufficient exchange capacity for a number of years. However, internal Swedish transmission constraints have several times resulted in substantial reductions in the transmission capacity between Sweden and Zealand, hindering exchange.