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Vulnerability of the Nordic Power System
Executive Summary

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RESULT (summary)

The objective of the analysis is to identify the vulnerability of the Nordic power system, identify barriers to reduce vulnerability in a Nordic context and to propose possible actions. The study focuses on vulnerability with respect to energy shortage, capacity shortage and power system failures.

Vulnerability is defined with respect to the unwanted situations “High prices”, “Curtailment” and “Blackouts”. The main tool of the study is risk analysis, where risk is a result of the probability of an event ant its consequences.

With respect to energy shortage, the system is in a medium risk state. For the present system the probability of a situation like the 2002/03 winter or considerably worse is once every ten years. Under the assumption that power production increases with increasing demand, the situation will be similar towards 2010. In the opposite case, the risk of extremely high prices increases. With respect to capacity shortage, the system is in a low risk state. This is partly due to actions already taken by the TSOs. The risk state will slightly deteriorate towards 2010. With respect to blackouts, the system is in a medium risk state. This is due to the fact that large blackouts in Southern Scandinavia cannot be completely ruled out. Such blackouts involve many consumers resulting in major or potentially even critical consequences. However this is not different from the situation before deregulation. There are no indications that the situation will become worse towards 2010, but there is uncertainty with regard to the effect of changed maintenance routines. Reductions in qualified technical personnel also gives reason for concern.

The study identifies significant differences between the Nordic countries with respect to the framework for transmission system investment, system balancing, rules and price setting in the case of curtailment, congestion management and the handling of import and export. Recommended actions include reduction of regulatory uncertainty with respect to generation investment, improving demand elasticity, reducing the impact of high prices on specially exposed consumer groups, improving the framework for grid expansion, improve system monitoring and protection and operator training and increased research and development within power systems.

KEYWORDS

SELECTED BY AUTHOR(S)		
	Nordic Power System	Energy Shortage
	Security of Supply	Capacity Shortage

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1 INTRODUCTION

This is the Executive Summary of Technical Report TR A5962 “Vulnerability of the Nordic power system” by SINTEF Energy Research.

In recent years Nordic electricity market cooperation has increased. The importance of a more binding cooperation has been accentuated by the strained power situation in the winter of 2002/03. Moreover, the blackouts in the autumn of 2003 have directed the attention towards the common Nordic vulnerability. A statement from the minister meeting in Gothenburg in the autumn of 2003 expressed that: “The Nordic energy ministers acknowledge the need to carry out a vulnerability analysis of the Nordic power market to reveal common challenges related to questions around the security of supply. The analysis shall include investigations on what can be done to avoid power cuts like those that occurred in September 2003. As soon as the causes of the problem are known, this shall be followed up and afterwards discussed by the meeting of the energy ministers in Brussels in December.”

The meeting of the Nordic energy ministers in December 2003 agreed that the Nordic power market generally functions satisfactory, but that society’s increasing vulnerability for power system failures makes it desirable to carry out a comprehensive analysis of the vulnerability of the Nordic power system to identify specific actions to improve the security of supply.

Control and improvement of the Nordic vulnerability requires coordination at the political level, between regulators and between system operators. An important principle is the use of market-based solutions.

The present report is the result of a study by SINTEF Energy Research with the objective to analyze the vulnerability of the Nordic power system and to propose actions to reduce this vulnerability. The budget for the study was increased by EBL Kompetanse on behalf of the Norwegian Electricity Industry Association (EBL). It is the intention of EBL to continue the present study with two additional studies to evaluate the proposed actions and to contribute to increased harmonization and coordination of system operation respectively.

2 OBJECTIVE OF THE STUDY

The objective of the present vulnerability analysis is to
1) Identify incidents, situations and scenarios leading to critical or serious consequences to the society and the power system
2) Identify barriers to handle and reduce the vulnerability
3) Identify possible countermeasures and actions to handle and reduce the vulnerability

The terms incidents, situations and scenarios comprise the following three aspects as well as combinations of the three:

- Energy shortage
- Capacity shortage
- Power system failures

Definitions

Energy shortage is associated with the power system's ability to cover the energy consumption. It is characterized by reduced generation of electrical energy due to either scarcity of primary energy (water, fuel) or long-term outage of major plants. In an import dependent area it can also be caused by unavailability of major interconnections. Energy shortage is a long-term problem with a time horizon of, say one month up to several years. It is a question of price and volume rather than a physical supply attribute: In a free market there is in principle no lack of goods. It is a question of how high the price should be to balance supply and demand. Situations may however occur where the supply of electrical energy is so low that the authorities will not accept a market clearing by price but take measures to perform a controlled rationing or energy curtailment.

Capacity shortage is associated with the power system's ability to cover instantaneous demand, characterized by lack of available generation capacity or in the transmission networks. This is normally a short-term problem, with a time frame of a few hours, possibly over several consecutive days. Contrary to energy shortage situations, capacity shortage may occur so fast that there is no time for a market clearing, and the market may not be able to set a price.

Power system failures are incidents where a power system component's ability to perform its function is interrupted or reduced. The failure leads to a fault that is a condition where a component has a missing or reduced ability to perform its function. The fault may further lead to a power system forced outage. Faults may be caused by deficiencies in power system components (generation or transmission), system protection or inadequate routines and procedures.

The vulnerability analysis is a methodical examination of the Nordic power system with the objective to determine the system's ability to withstand threats and survive unwanted situations by the identification of threats, quantification of risk and evaluation of the ability to stabilize the system. The Nordic power system in this context comprises the power system in Finland, Sweden, Denmark and Norway at the voltage levels 110 – 420 kV. The vulnerability analysis is carried out for the present situation (2005) and for the future Nordic power system in 2010.

The study does *not* comprise vulnerabilities due to the following aspects:

- Threats due to sabotage, terror, acts of war or international political conditions outside the Nordic countries or EU
- The local effects (as opposed to the effects on the entire transmission system) of events such as transformer explosions or fire in transformer stations
- Incidents in the distributions networks even if they may have critical impacts on a local level
- Floods and dam break

3 METHODOLOGY

The methodology of the study is illustrated in Figure 1:

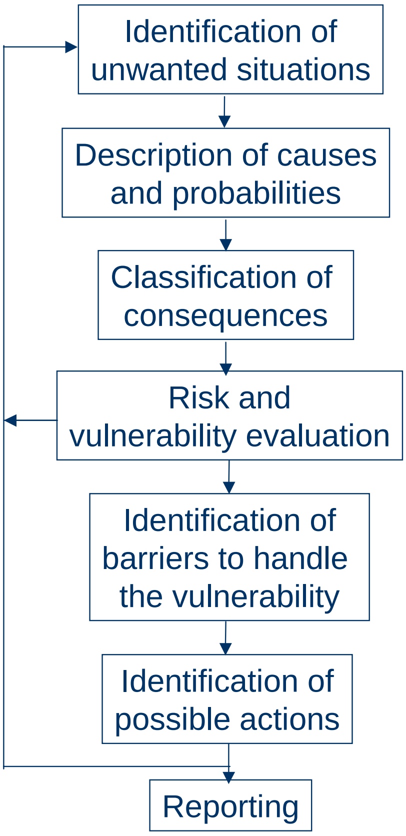

Figure 1: Flow chart for the vulnerability analysis

Identification of unwanted situations involves a systematic evaluation of vulnerabilities. The most important factors for the electricity supply are **price** and **availability**. The types of consequences are grouped in three different categories describing the unwanted situations: "High price", "Curtailment" and "Blackout".

Definitions

High price-situations relate to an Elspot price significantly higher than the normal level for a long period. Such situations are mainly related to energy shortage.

Curtailment-situations involve controlled rationing or load curtailment. There is not necessarily a clear distinction between "high price" and "curtailment". These aspects are related in the sense that curtailment might be necessary if the high price situation does not lead to a sufficiently decrease in demand to clear the market, or if the price level that clears the market is socially or politically not acceptable. Curtailment may occur in the long run caused by energy shortage or in the short run, caused by capacity shortage.

Blackout-situations refer to extensive interruptions involving that larger geographical areas are affected more often and for longer periods than normally can be expected.

Probabilities are expressed as frequencies and ranked according to how often the situations are assumed to occur. The categories and scale used are shown in the table below:

Table 1: Description of probability categories

Probability category	Description
Unlikely	Less than 1 per 100 year
Infrequent	1 per 100 year or more
Occasional	1 per 10 year or more
Probable	1 per year or more
Frequent	10 per year or more

The consequences are described and ranked according to the degree of seriousness for each of the three categories of unwanted situations: "High price", "Curtailment" and "Blackout".

High prices and their relation to vulnerability involve methodological challenges. If electricity is regarded as a commodity, there should be no reason why high prices for this good would give special reasons for concern. However, electricity has some special characteristics that distinguish it from other goods:

- It is generally regarded as a necessity
- In Norway and to some extent Sweden it represents a significant share of some households' expenditure
- At least in recent years, price variations have become relatively large

In this context, we shall not forget the underlying rationale for a market-based organization of the power sector, which is to increase economic efficiency. In a market, supply and demand adjust dynamically to the market price. Fluctuating prices are therefore not something "bad" that has to be avoided, but a necessary element in a well-functioning market. Moreover, to make investments in new capacity profitable in a market environment, it is necessary that average prices cover all fixed and variable generation costs, including a risk premium to cover uncertainty. With the inherent significant variability of hydro generation, prices have to be high in some years to compensate for the low prices in wet years. Of course, extreme prices can be problematic and may indicate deficiencies in the market structure. But occasional moderately high prices are a natural ingredient in markets, especially markets with large variations in both supply and demand, like the Nordic electricity market.

Several analyses from Statistics Norway conclude that the economic damage to Norway from the high prices in 2002/03 was small. For the Nordic area as a whole it is even smaller, because e.g. Denmark actually increases its gross domestic product due to increased generation. However, there are distributional problems, meaning that certain low-income groups are especially exposed. On this background this study focuses on the increased expenses for Nordic consumers caused by energy shortage and the resulting high prices, which for 2003 is estimated to 4.8 billion Euros. Based on the experience from 2002/03 and certain assumptions about society's or the authorities' level of acceptance the following classification of high price situations is used in the study:

Table 2: Classification of High-price situations (excl VAT)

Direct economic loss to Nordic households	**Corresponding loss to *all* Nordic consumers**	**Average spot price increase**	**Classification**
< 1.0 billion Euros	< 2.2 billion Euros		None
1.0 – 2.5 billion Euros	2.2 – 5.5 billion Euros	25 €/MWh in one year	Moderate
2.5 – 4.0 billion Euros	5.5 – 8.8 billion Euros	36 €/MWh in one year	Major
> 4.0 billion Euros	> 8.8 billion Euros	> 36 €/MWh in one year, curtailment	Critical

Curtailment is necessary when either there is a physical shortage of energy or capacity that is not solved by high prices or when the prices that are necessary to balance the market become so high that they are seen as unacceptable.

Definition
Curtailment is a planned reduction of demand other than through market prices. Curtailment can be realized in several ways. A distinction can be made between physical curtailment by rotating disconnection or quota allocation. The latter must be combined with penalty fees for quota exceeding to enforce compliance.

In the case of energy shortage on a Nordic basis it is probable that a market balance can be obtained by letting prices become high enough long enough. (In some local areas in Norway physical shortage that cannot reasonably be cleared by prices may occur, but this is outside the scope of this study.) However, the authorities may decide to take in use curtailment because the resulting prices are seen as unacceptable. A curtailment situation due to energy shortage is deemed critical in this study, cf. Table 2.

The need for curtailment may also occur in the case of capacity shortage. This is the situation where demand is very high due to low temperatures, and available generation resources and import are insufficient to cover demand. In such situations a market balance may not be obtained even with extreme prices, because price elasticity of demand is insufficient in the short run. It is important to observe the difference between *medium* term (weeks, months) demand elasticity, which exists if only prices become high enough, and *short*-term demand elasticity, which is limited due to lack of hourly metering and direct load control. Curtailment caused by capacity shortage is classified in the same way as blackouts below.

Blackouts are in this study classified according to:

- Magnitude of the disturbance in terms of power interrupted (MW).
- Duration of the outage (Hour).

The classification used in this study in shown in Figure 2:

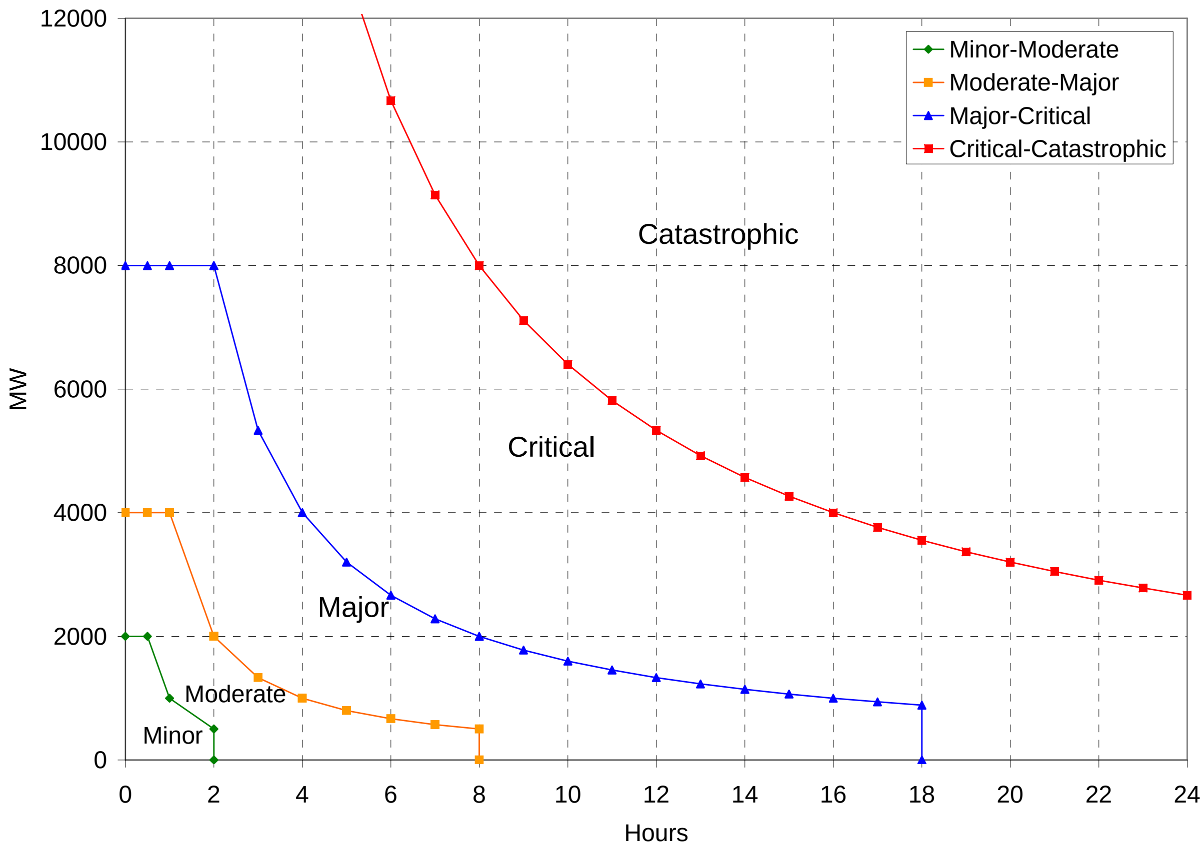

Figure 2: Consequence classification and intervals for “Blackout”-situations

The figure is interpreted in the following way: a blackout that lasts less than 2 hours *and* involves less than 2000 MW of interrupted demand *and* less than 1000 MWh of interrupted energy is classified as a minor event, and correspondingly for the other classes.

The risk evaluation is summarized in a risk graph that shows the relation between frequency of occurrence as shown in Table 1 and severity of the events high prices, curtailment and blackouts. The quantified risk should be evaluated according to specified acceptance criteria. The criteria are typically divided in low, medium and high risk. A tentative division is indicated in the tables and graphs using the different degrees of shading as described in qualitative terms below:

	Low risk	Acceptable. No action requirements.
	Medium risk	Evaluation of needs and possibilities for risk reducing actions.
	High risk	Not acceptable. Risk reducing actions necessary

4 ENERGY SHORTAGE

Analysis of energy shortage is carried out with a multi-area power market simulation model, the EMPS model. For the present system, Figure 3 shows the simulated loss to Nordic consumers for all historical inflow alternatives, together with the borders between the classifications shown in Table 2.

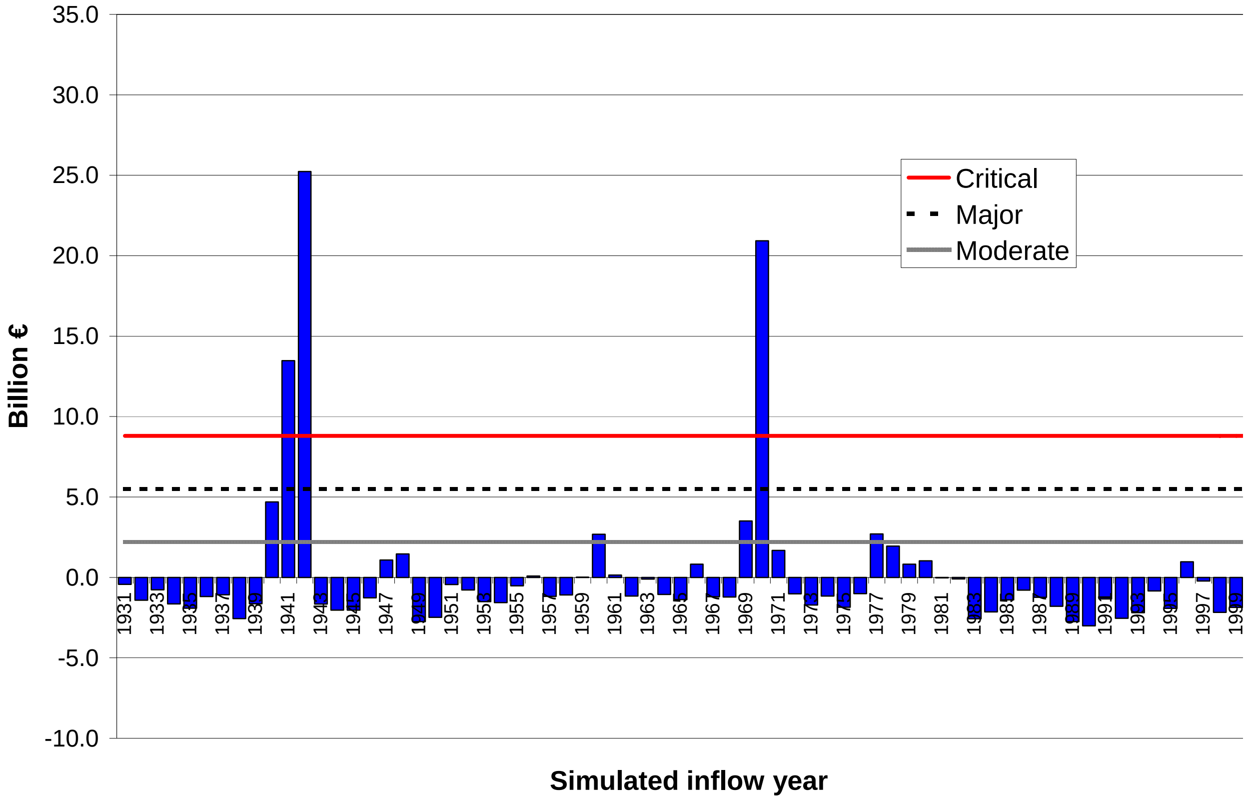

Figure 3: Consumer loss caused by high prices, present system (2005)

Based on these simulations the number of scenarios characterized as “unwanted events” are:

Scenarios	**Number**	**Probability**
Moderate or worse consequences	7	10 %
Major or worse consequences	3	4 %
Critical consequences	3	4 %

This means that a situation like in 2002/03 *or worse* can be expected once every 10 years.

For the analysis of future vulnerability for energy shortage in 2010, three scenarios were used. The most likely scenario has a balanced development of supply and demand, resulting in a vulnerability very similar to the present system. To assess an “under balanced” situation, a scenario without 800 MW of gas plants in Norway was defined, while a situation with more supply was simulated by assuming that Barsebäck 2 stays in operation. Figure 4 shows consumer losses in the case without gas plants in Norway.

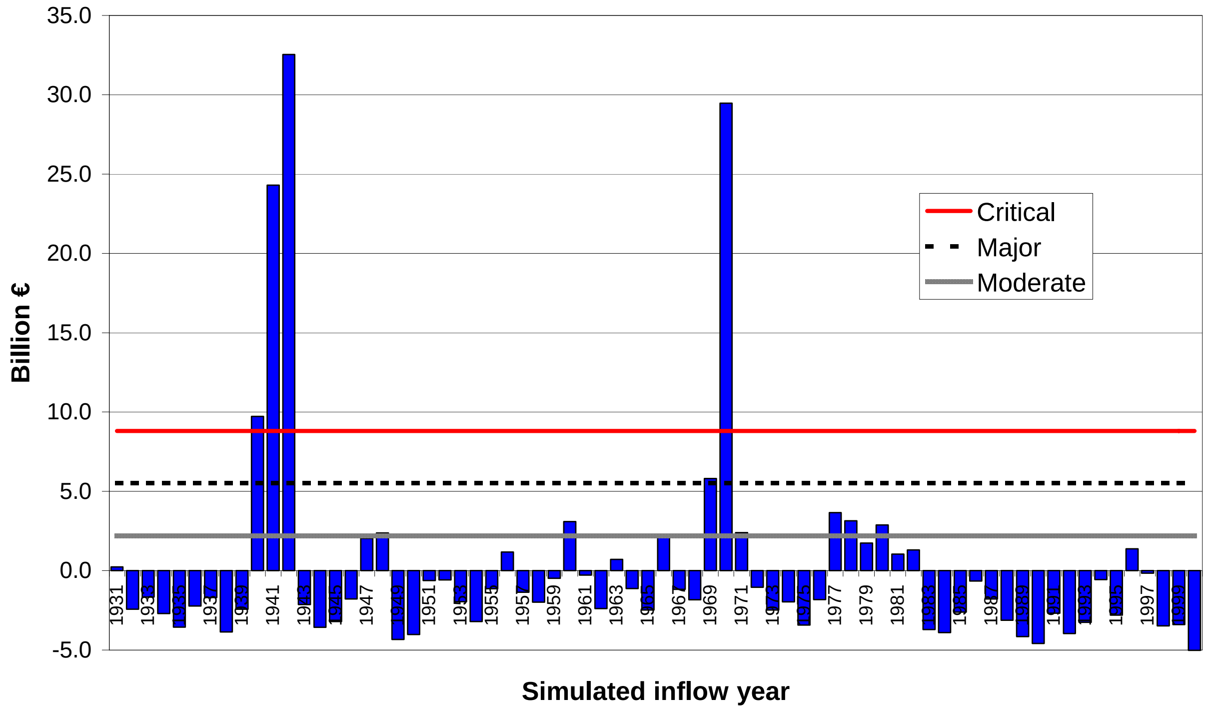

Figure 4: Consumer loss caused by high prices, future system (2010), no gas plants in Norway

A similar situation can also occur in the case of delay of the commissioning of the 1600 MW Oikiluoto 3 nuclear power plant in Finland. For this case the occurrence of "unwanted events" is:

Scenarios	Number	Probability
Moderate or worse consequences	12	17 %
Major or worse consequences	5	7 %
Critical consequences	4	6 %

Roughly speaking, price increases like in 2002/03 *or worse* would be seen every 6 years.

A permanent state of under balance like simulated in this scenario leads to considerably higher prices on average. Probably this would suppress demand, resulting in less severe effects of inflow deficits and a reduction in vulnerability.

If Barsebäck 2 stays in operation and gas plants are built in Norway, the situation is slightly better than for the present system.

Figure 5 shows the energy shortage risk graph for the present and future system.

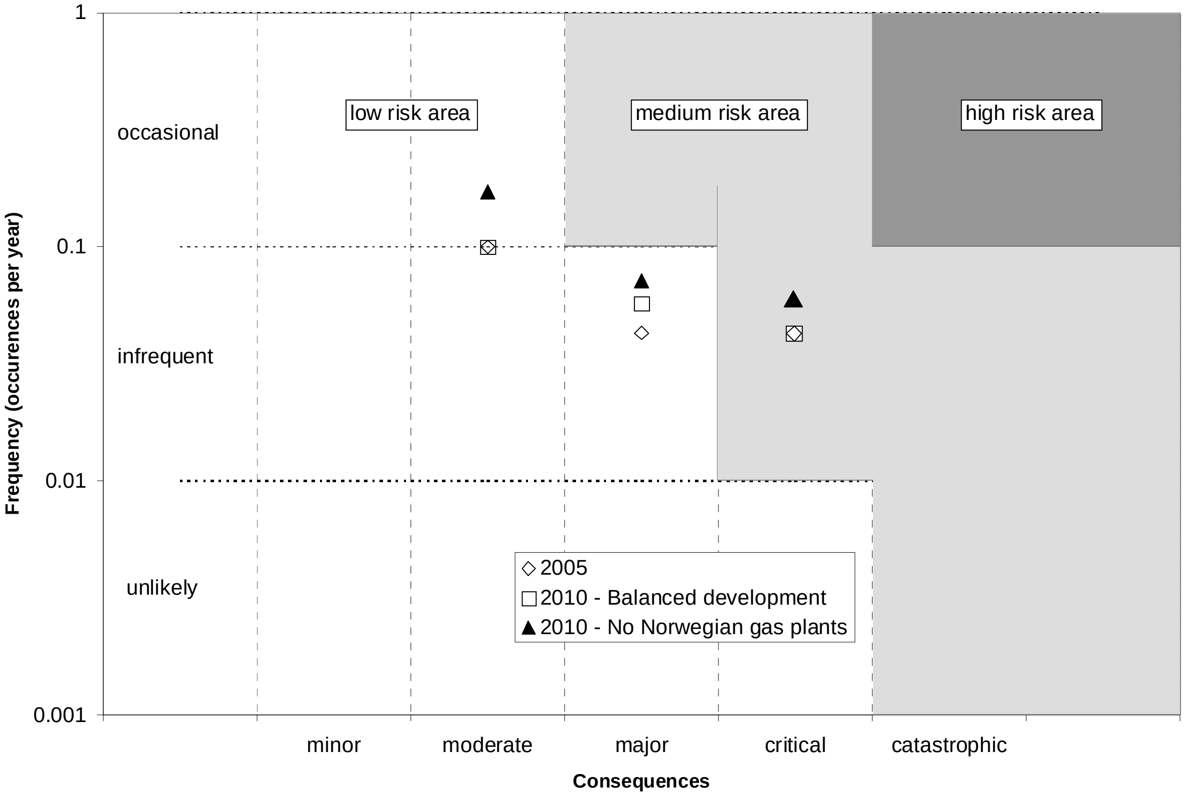

Figure 5: Risk graph energy shortage

The risk graph shows a medium risk state, caused by the significant consequences of extremely dry years. Note that the scale of the vertical axis is logarithmic.

Uncertainty in these calculations is primarily related to two issues: demand elasticity and model philosophy. As already mentioned, demand elasticity at very high prices may be underestimated. An underestimation of demand elasticity implies that real prices during critical events are lower than the model estimates, and this reduces the highest outcomes in Figure 3 and Figure 4. This would not reduce the *number* of critical events, because prices would have to be very high to trigger this price elasticity. The model philosophy assumes that the system is run from a single-owner optimization point of view. This probably results in a better utilization of resources than obtained in the real interplay of independent market participants. As a result, the model may obtain a more favourable energy balance and lower prices than is seen in the real world. The result of this may be a certain underestimation of the number of unwanted high-price events.

Another type of uncertainty lies in the possibility that the EU Water Framework Directive 2000/60/EC will reduce hydro generation in the Nordic countries, but if this will be the case and what the size of the reduction would be is impossible to know presently. Implementation of the Directive is planned between 2010 and 2012.

5 CAPACITY SHORTAGE

In the context of the present study, capacity shortage is defined as a situation where available generation capacity and imports together are insufficient to serve demand without violating the constraints of the grid, while keeping satisfactory reserve levels.

With respect to *vulnerability*, the important issue is what happens under special conditions, and what kind of special conditions can lead to situations with serious consequences. Special conditions occur when generation availability is reduced or when import availability is less than expected. The study therefore considers three scenarios:

- reduced import availability
- reduced availability of hydro generation
- outage of one nuclear unit

The outcomes in 2005 are mainly within the low risk area, but the probability of a critical shortage is higher than desirable, and is within the medium risk area. A *normal winter peak* (every two years) will have a positive capacity balance for all outcomes, also with reduced imports, low hydro availability and one nuclear unit out of operation. In the case of a *cold winter* (every ten years), the Nordic countries have a need for imports exceeding the assumed realistic import capability in some cases. However, the need for import never exceeds *physical* import availability. In the case of an *extreme winter* (every thirty years), the need for import to the Nordic countries exceeds assumed realistic import for all outcomes. Unless normal availability of hydro, the need for import will exceed physical import capacity. The probability of this scenario is however extremely small.

Figure 6 shows the risk graph for capacity shortage for 2005 and 2010.

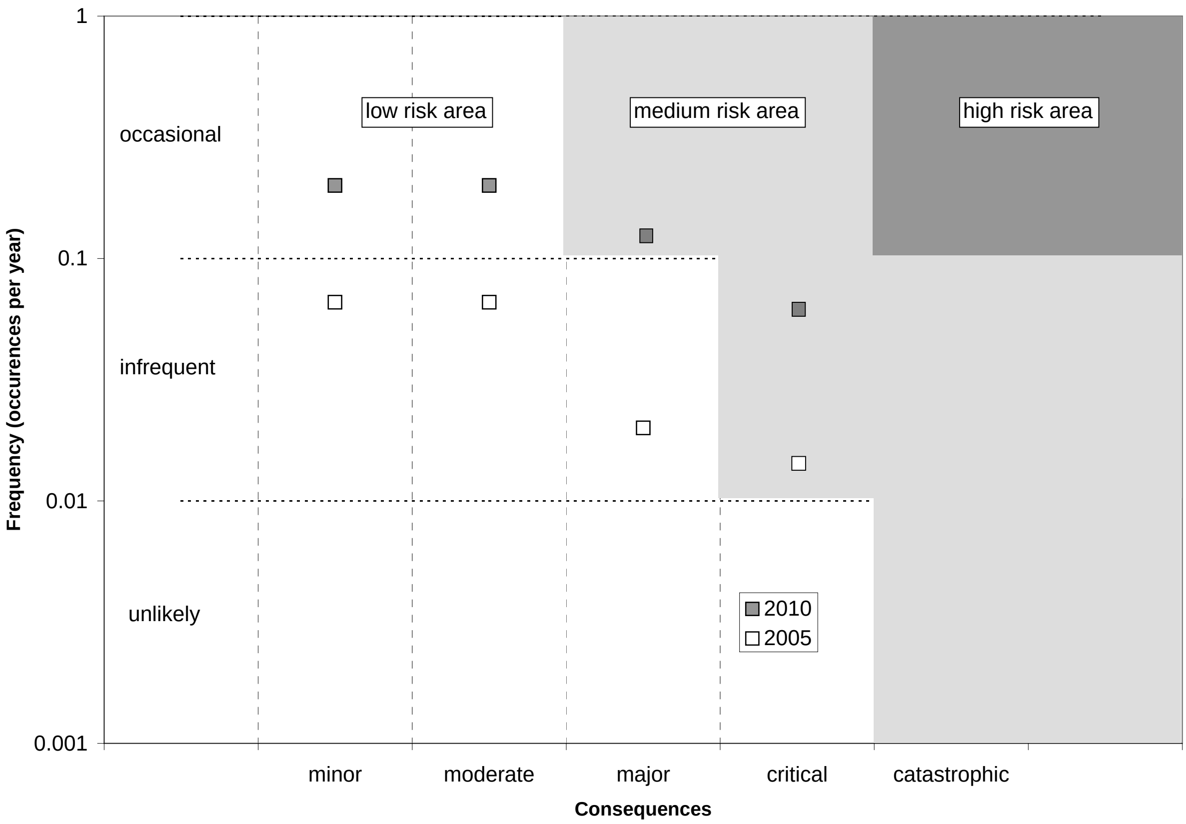

Figure 6: Risk graph capacity shortage

The risk situation for capacity shortage deteriorates between 2005 and 2010, and in 2010 the system is in a medium risk state with the assumptions used in the present study. The probability of major or critical consequences is higher than desirable. It is however quite possible that real demand elasticity is higher than assumed, which will improve the situation.
The deterioration of the capacity balance between 2005 and 2010 is caused by the fact that the major share of new resources consists of base load options (gas, nuclear, wind), contributing less to peak generation than to energy supply.

6 POWER SYSTEM FAILURES

The risk of power system failures depends on the probability of the combination of faults and disturbances that lead to a system collapse and the consequence of the interruption in terms of power and energy not supplied, duration of the outage and other factors such as serious damage or injuries caused by the blackout. Failures and disturbances in the power system can never be completely avoided. Still, the probability of critical blackouts is low. This is closely related to the way the system is designed and the operating security criteria that are applied.

The various blackout scenarios analyzed in the study are related to certain geographical areas. Each scenario is presented with a description of the critical situations and events that can lead to a blackout, and a discussion of the probability and the consequence involved.

The areas chosen are as follows:
1) Finland, import case
2) Finland, export case
3) Helsinki area
4) Northern Sweden
5) Southern Sweden
6) Gothenburg area
7) Stockholm area
8) Eastern Denmark and Copenhagen
9) Western Denmark
10) Southern Norway and Oslo
11) Western Norway and Bergen area
12) Stavanger area
13) Southern Scandinavia

The following figure shows the results for the present system:

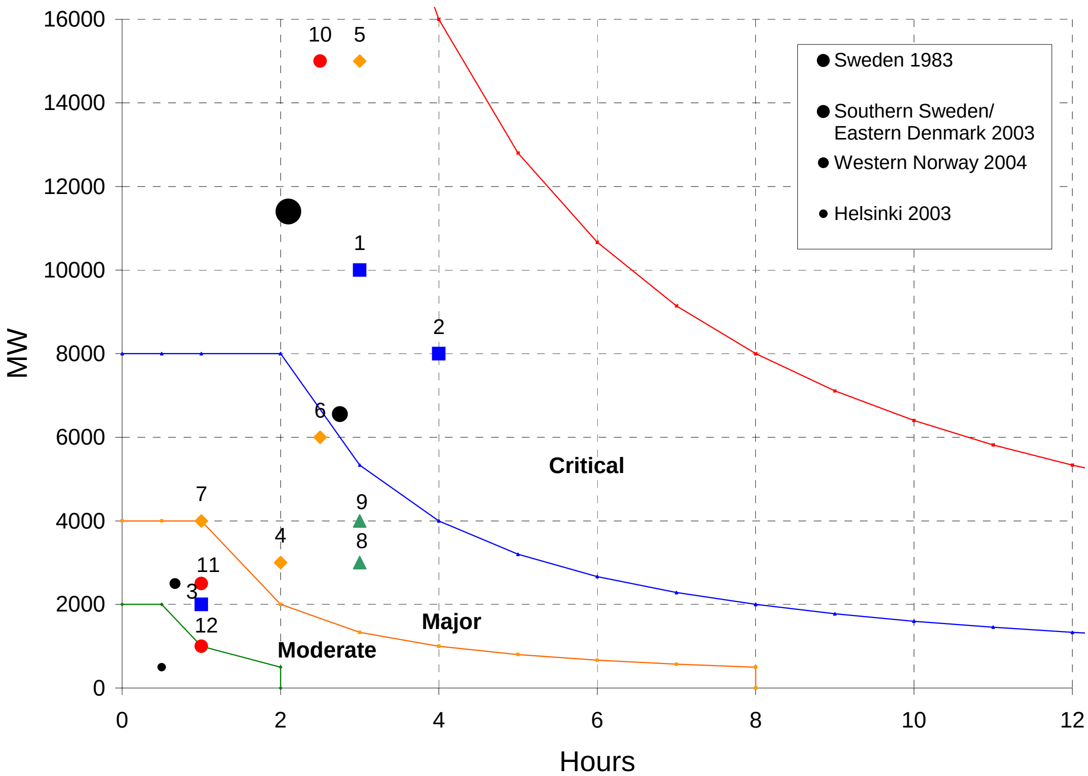

Figure 7: Consequence assessment of power system failures for the present system. The numbers refer to the areas given above. Blue coloured markers (squares) are used for the Finnish scenarios, orange colours (diamonds) for Sweden, green (triangles) for Denmark and red (circles) for Norway. Some historic blackouts are also shown.

Figure 8 shows the corresponding risk graph.

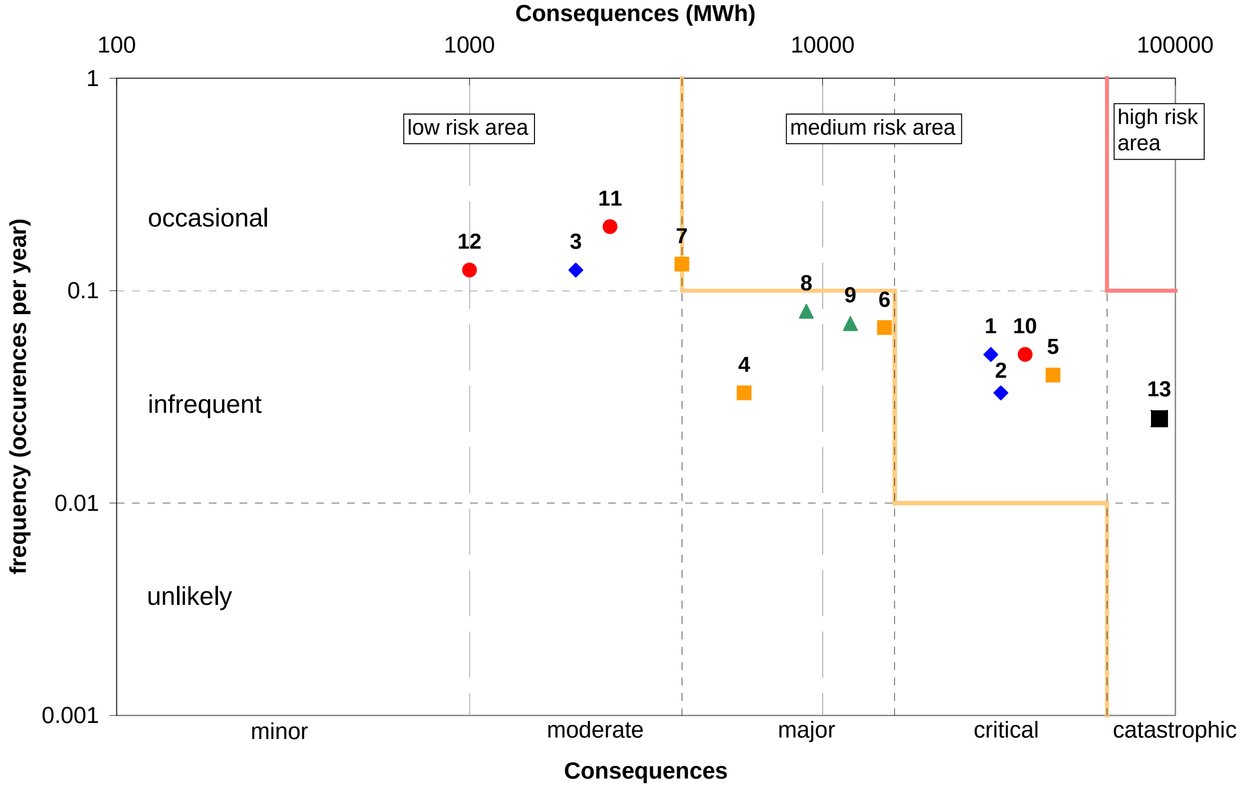

Figure 8: Risk graph of blackouts for the present system. The numbers refer to the geographical areas described above.

There are five scenarios that can be characterized as critical or worse. All these events are expected to happen infrequently, i.e. with frequency of occurrence less than one per 10 years. Thus, they come in the category *medium risk*.

It is noted that all the scenarios in this category involve the blackout of either Southern Norway, Southern Sweden or Southern Finland or a combination. This is mainly due to the high load concentration in these areas, and does not imply that the reliability of the power system in these areas is lower in any way. With the exception of the scenario with high import to Finland, the analysis suggests that the most critical situations arise in operating conditions with very high power transfer from east to west or from north to south.

Towards 2010 the probability of failure in a number of areas might increase due to increased demand and a resulting more frequent occurrence of operation conditions with high power transfers. On the other hand, the TSOs will be aware of this and probably take the necessary countermeasures. Taking this into account, there is no reason to believe that the risk situation will change significantly in the near future. Factors and developments that could adversely influence the probability and consequences of power system failures are:

- Uncertainty is related to how the probability of blackouts changes as the power system and the operating conditions change in the future. One reason for this can be the location of new generation resources, which has become less predictable than previously because of a lack of integrated planning of generation and transmission. New generation capacity and changes in the mix of generation can lead to occasional power flow patterns with higher risk. If the frequency of bottlenecks due to very high demand for power transfers from east to west and from north to south increase in the future, this will be of particular concern.

- High focus on cost reductions and possible changes in maintenance routines are factors that nay increase the probability of failures. The fact that investments in the transmission grid have been low during the last decade may also lead to increased failure rates, as the components in the power system grow older. On the other hand, it is also a fact that maintenance work in itself is a factor that tends to increase the probability of failures. The total consequence of this is therefore somewhat uncertain.
- Competence and education of power system engineers are of paramount importance. Lack of staff with necessary technical competence within power system operation, planning and maintenance is a possible threat to future risk of power system failures.

7 CHALLENGES IN HANDLING VULNERABILITY IN A NORDIC CONTEXT

The analysis so far has presented a broad picture of the present and expected future vulnerability of the Nordic power system. With respect to energy shortage there is concern regarding very dry years and their impact on hydro generation, especially in Norway. With respect to shortage of generation capacity during peak demand, the present situation is broadly within the low risk area. To a considerable extent this is the result of actions already taken by the TSOs. Towards 2010 the balance will weaken towards medium risk with the assumptions that were used in the study. Vulnerability due to power system failures is in the medium risk area, both presently and in the future. This is a result of the possible consequences of large blackouts in the Southern parts of Finland, Sweden and Norway with a probability of occurrence once every 10-20 years.

In the following, some important areas that represent challenges at a Nordic level with respect to improving the vulnerability of the power system are presented.

Investments in transmission

Over time, investments in new transmission capacity are necessary to maintain a transmission grid that is optimally adapted to the requirements of the power market. When it comes to investment in transmission, the regulatory frameworks under which the TSOs are operating are of vital importance. It appears that regulation of the TSOs is very different in the Nordic countries. Norway has a formal revenue cap regulation, where the incentives of Statnett in principle are given through the economic impact of decisions on the company’s economic result. Still Statnett has to apply for concession, and NVE will review an application and quite possibly deny concession when they find investment unprofitable for the society as a whole. In Denmark, investments in the main grid are explicitly subject to cooperation between the TSOs and the Danish Energy Authority. Svenska Kraftnät decides on investments that can be justified from technical and socio-economic aspects within a three-year financial framework approved by the government. In Finland investments in the main grid are more closely coordinated with the authorities.

Balancing
The TSOs are responsible for the balancing markets, which are used when imbalance occurs in the operational phase. Although the TSOs in the Nordic system operate individually in the operational phase, there is close cooperation with regard to secondary frequency regulation, and from 2002 a common Nordic balance market was introduced. The various balancing markets work well in handling imbalances during system operation, but this clearly assumes that there are sufficient bids in these markets to handle conceivable imbalances. During periods with very high spot prices, it is more attractive for producers to sell power on the spot market, and the situation might occur where there are insufficient resources available for the balancing markets. The Nordic TSOs have chosen different solutions to cope with this potential scarcity of reserves. The differences in the handling of the balancing markets can have detrimental effects on the long time ability to secure resources on market based conditions. Especially subsidizing basic capacity that might eventually be used in the spot market should be avoided, with the possible exception of the case where the Elspot does not clear. In the latter case, prices should be very high and known in advance, to create a credible threat for market participants in case they cannot comply with their obligations.

Curtailment
Norway has regulations for energy curtailment with a criterion for effectuation (real danger of rationing), but no explicit rules for pricing in such cases. The Swedish Electricity Act authorizes the TSO to execute load shedding in situations where it is necessary to sustain the system balance and integrity and no other resources are available. West-Denmark defines a force majeure situation, but this is only implicitly directed towards a generation capacity shortage that is not caused by major system disturbances. Fingrid clearly defines a power shortage, but pricing rules do not reflect the severity of the situation.

The pricing rules in the case of load curtailment differ substantially between the Nordic countries. It is not clear what happens with the exchange between countries if one country unilaterally interferes in the market and sets administrative prices. Because curtailment situations affect the vulnerability of the Nordic power system, there is an evident need for harmonization in this area.

Transmission congestion
Transmission congestion means that available transmission capacity is less than desired by the market participants through their bids and offers to the spot market. Congestion is resolved in different ways within the Nordic power market. The fact that congestion is handled in different ways within the same integrated market is in principle a disadvantage, which can lead to a sub-optimal utilization of the total transmission and generation resources in the system. As such, it causes losses to all market participants and to society as a whole, compared with a unified way of handling transmission congestion. As a result, it is quite probable that prices on average are slightly higher than they could be, but to our belief the impact on average prices is marginal. Although a unified solution clearly would benefit the Nordic power market, it is hard to argue that the different procedures of congestion management will lead to substantially increased vulnerability.

Import/export limitations

Power that is transferred into or out of the Nordic market area is administrated by different sets of rules than those governing rules within the Nordel area. As long as there is no real single integrated European power market with a common set of rules, this is a reality that must be faced. However, the rules that control the exchange between areas with different sets of rules should be as transparent as possible, securing an optimal exchange between such areas.

The import/export capacities to countries outside the Nordic area might, under present arrangements, be used in a way that worsen conditions of energy shortage or scarcity of power in the Nordic countries, although there is no reason to believe that this has happened so far. In general, it is better to avoid such situations through a strict separation of ownership. A failure to do so may sooner or later have impacts on the vulnerability of the power system, leading to increased probabilities of high prices or curtailment.

8 PROPOSED ACTIONS

At this stage it is appropriate to remind of the scope of the study, which is limited to the vulnerability of the Nordic power system, as related to generation, demand and the main transmission grid. The vulnerability at the distribution grid level is outside the scope of the study. Although according to statistics the dominating share of demand interruptions is caused by faults at the distribution level, this is primarily a national concern in the individual countries. With this in mind, it is important to point out that the Nordic power market generally has performed well. Although there have been some blackouts recently, the analyses in this report do not indicate that the vulnerability of the Nordic power system has become unacceptable.

Still there are obviously reasons for authorities to supervise security of electricity supply, given the importance for virtually all aspects of a modern society. Although the present study does not reveal severe deficiencies in the present Nordic power market, there is clearly room for improvements in several fields. The vulnerability of the Nordic power system is in the medium risk area, and actions should be evaluated to reduce the risk.

The study identifies a number of potential actions to reduce the potential increase in vulnerability of the Nordic power system that may occur in the course of the coming years. Actions can be taken by the authorities, including the regulators, the TSOs or the market participants. Actions taken by the authorities can either be direct actions, targeting specific issues, or they can be indirect, influencing the TSOs or the market, e.g. by providing information to the TSOs or market participants. Similarly the actions of the TSOs can be either direct or indirect by motivating market participants.

Potential actions are divided in four groups:

- Actions that improve the conditions for investment in generation by market participants
- Actions that improve the framework for decisions on expansion of the main grid
- Actions that increase the efficiency of the market
- Actions that reduce consequences of unwanted events

A final action of a slightly different character is research and development.

The first two groups are aimed at reducing the frequency of occurrence of unwanted events, they are *preventive* actions. Actions that reduce consequences of unwanted events are *corrective* actions, while increasing market efficiency and research and development include both preventive and corrective actions.

Actions in either of these groups can have an impact on energy shortage, capacity shortage and blackouts. In this Executive Summary, only the actions that are deemed to have most impact are included:

Reduction of regulatory uncertainty

Uncertainty is a major impediment for new investments. In general, uncertainty is inherent to almost every investment decision in all markets, and the uncertainty related to investments in new power generation is a logical consequence of the decision to restructure the power market. However, apart from the uncertainty with relation to future prices, demand and external shocks, which is seen in all markets, there is a considerable additional regulatory uncertainty in the power market, caused by the unpredictability of future political decisions in this highly sensitive area. In this area, there are clearly considerable differences between the Nordic countries. While, on the one hand, it is possible to invest in new nuclear power in Finland, investment in gas-fired plants in Norway is held back because of the uncertainty with respect to potential future limitations and/or taxation of CO_2 emissions. Governments could reduce this uncertainty for example by guaranteeing that future political decisions e.g. with respect to taxation would not be given retrospective force before a period of five to ten years.

> **Reduction of regulatory uncertainty**
> Target: improving conditions for investment
> Responsible: authorities
> Impact: energy/capacity shortage

Improving demand elasticity

Our analysis clearly shows that increased price elasticity of demand in the short run can reduce vulnerability for shortage of generation capacity and in the long run for energy shortage. This confirms once again numerous other results. The question is of course *how* to reach this goal. Realization is probably a national concern, but stronger commitment and cooperation at a Nordic level could facilitate the process.

> **Improving demand elasticity**
> Target: increase the efficiency of the market
> Responsible: "The Market" (authorities)
> Impact: capacity shortage, energy shortage

Reducing the impact of high prices on consumers

The major problem with high prices is their distributional effect. Arrangements to compensate vulnerable groups in the case of a prolonged period of very high prices would probably increase the acceptability of high prices, and therefore improve the efficiency of the market. It is important that such arrangements are implemented in a way that does not reduce demand flexibility.

> **Reducing the impact of high prices**
> Target: reducing consequences
> Responsible: authorities
> Impact: energy shortage

Improving the framework for grid expansion

Grid expansion generally can reduce vulnerability. Increased interconnections with areas outside Nordel and partly within Nordel can reduce vulnerability for energy and capacity shortage. Strengthening of certain areas of the grid can also reduce the probability of blackouts. A great deal of work in this area is done within the Nordel cooperation. But when it comes to investment, the individual TSOs are constrained by national regulatory frameworks. There are considerable differences between these frameworks, and the result can be sub-optimal national decisions when seen in a Nordic context. Although there is probably no judicial basis for a common Nordic regulatory framework, harmonization with respect to the regulation of the TSOs would result in closer-to-optimal investments in the Nordic grid.

> **Improving the framework for grid expansion**
> Target: optimal grid expansion
> Responsible: authorities
> Impact: all areas

System monitoring and protection

Improved state of the art tools for system monitoring and protection increase the possibilities to discover and recognize problematic situations at an earlier stage, thus reducing the probability that such situations develop in a blackout. Even if a blackout situation develops, the geographical extent can be limited. With respect to the areas with medium risk for blackouts, use of such tools can both reduce the probability and the consequences, moving the respective points down and to the left in the direction of the low risk area in the risk graph.

> **System monitoring and protection**
> Target: reducing consequences
> Responsible: TSOs
> Impact: blackouts

Operator training

> **Operator training**
> Responsible: TSOs
> Impact: blackouts

In the case of cascading blackouts, a major challenge is the lacking experience of operators in handling such situations because of their very low frequency of occurrence. Training on realistic simulators could provide such experience, comparable with pilots' training in flight simulators. Establishment of a common Nordic training simulator and regular training sessions for system operators could be a cost-effective way to implement this action. A development in this direction is already under way through Svenska Kraftnät's Aristo simulator.

Research and development

> **Research and development**
> Target: improving power system operation and protection
> Responsible: Authorities, TSOs
> Impact: blackouts

Research and development in power transmission system planning and operation require specialized competence, models and equipment. The industry activity in this area has declined during the last decade due to reduced investments and globalization of the power industry. This has again affected the activity level in universities and research institutions. Decreasing competence within power systems and power technology is indicated as a source of increased vulnerability. Considerable synergies can be obtained by coordinating the R&D effort undertaken by the Nordic TSOs.

The study identifies a number of additional actions. Of these, the action "Improving incentives for renewable power generation" may have high impact in the longer term. With respect to each area of concern, the actions deemed to have high impact in the short term can be grouped as shown in the tables below. These tables sum up the actions, also indicating if they can be implemented at a Nordic (as opposed to national) level.

Table 3: Preferred actions to reduce vulnerability with respect to energy shortage

Responsible	**Actions**	**Nordic level**
Authorities	Reduce investment uncertainty	
Authorities	Reducing the impact of high prices on consumers	
Authorities/The Market	Improving demand elasticity	X

Table 4: Preferred actions to reduce vulnerability with respect to capacity shortage

Responsible	**Actions**	**Nordic level**
Authorities	Reduce investment uncertainty	
Authorities/The Market	Improving demand elasticity	X

Table 5: Preferred actions to reduce vulnerability with respect to blackouts

Responsible	**Actions**	**Nordic level**
Authorities	Improving the framework for grid expansion	X
Authorities/TSOs	Research and development	X
TSOs	System monitoring and protection	X
TSOs	Operator training	X

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