Twenties

Transmitting wind

Task 16.2.2
Hydro potential and barriers
Deliverable nº: 16.2

EUROPEAN COMMISION

SEVENTH FRAMEWORK PROGRAMME

EC-GA nº 249812

Project full title: Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions

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Document info sheet

Document Name:	Task 16.2.2. Hydro Potential and Barriers
Responsible Partner:	SINTEF Energy Research
WP:	WP #16
Task:	Task 16.2.2
Deliverable nº	16.2
Version:	FINAL DRAFT
Version Date:	January 23th , 2012
Author:	D. Huertas-Hernando

Diffusion list

All Partners

Approvals

Draft approved by TC. TC comments implemented.

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Documents history

Revision	Date	Main modification	Author
V01	27.05.2011	First draft	SINTEF Author/s
V02	02.06.2011	Comments from P. Meibom Risø DTU	P. Meibom
Final Draft	23.01.2012	Final version after TC comments	D. Huertas-Hernando H. Farahmand

EXECUTIVE SUMMARY

This report is written within subtask 16.2.2 in the TWENTIES project, and constitutes the background report for further analysis of the flexibility of hydropower in the Nordic power system. It presents an overview of the Nordic electricity system and attempts to shed light over its existing and future flexibility i.e. the system's capability to export power for the purpose of balancing wind power variability in Northern Europe.

Hydro generation has ideal characteristics for providing real-time balancing energy in comparison to thermal generation. This is because of its high regulation speed and low operating cost. Therefore, hydro generation can add good flexibility to the power system production in order to compensate for the uncertainty introduced by uncontrollable renewable power generation. This report serves a first discussion of the existing and future flexibility in the Nordic system. The flexibility will be further analysed in the following subtasks 16.2.3 and 16.2.4.

<u>The existing flexibility of the Nordic system</u>

The existing flexibility in the Nordic system is based on import from adjacent countries in periods with low prices and export in periods with high prices such that the total energy exchange over a period is approximately zero. Since there is hardly any pumping capacity in the Nordic system, the import to the region must be balanced with reduction of the hydro production. The flexibility will vary a lot from winter to summer, from working-day to weekend and from peak hours to off-peak hours. Due to such uncertainties, the 'flexibility' of a system is rather difficult to quantify, but some frames are possible to calculate. The maximum theoretical flexibility in the Nordic system based on hydro power is about 35 000 MW. The number is based on 25 000 MW capacity in Norway and about 10 000 MW (16200 MW installed capacity – 5825 MW run-of-river) in Sweden. Finnish hydro power is not included because it is mainly run-of-river. Thus, in periods with low prices in other countries, up to 35 000 MW hydro power production, in theory, could be reduced and *stored* and electricity corresponding to the real demand can imported to the Nordic region.

This theoretical potential is limited by the maximum available production capacity and the consumption, at given times and during the system's peak hours.

The total expected available capacity in the Nordic system in 2012 is **78 000** MW, excluding the allocated reserves in the system. These reserves are of about 5850 MW plus an additional 800 MW which Norway reserves for forecast errors.

The expected peak load on an average winter day is **68 150** MW. This is 1700 MW lower than the sum of the peak values for all the Nordic countries because of the so-called coincidence factor.
Thus, in an average peak hour in the winter it may be possible to export electricity from about 10 000 MW production from the Nordic region to adjacent countries. The number will off course be lower in very cold periods when the peak consumption is higher than in average winters.

These estimations do not consider bottlenecks in the transmission system within the Nordic region or between the Nordic region and other countries or other limitations like requirements for minimum production etc.

The future flexibility

In the future, the flexibility of the Nordic system can change as a result of various factors:

- Changes in the hydro power system like increase of production capacity or installation of pumping.
- Changes in capacity for other sources than hydro power. Substantial increase in wind power production in the Nordic region will require more short term flexibility (within the hour and in a few hours perspective), but will increase the available energy in the system.
- Increase in transmission capacity both within each Nordic countries and between the Nordic region and other European countries.
- Major changes in the Nordic electricity demand, e.g. increase due to the large-scale electrification of transport or decrease because of large-scale deployment of heat pumps in regions where electricity is used for heating.
- Changes in demand or production because of climate change.

Norway has about 30-35 TWh of hydro power potential which is not already developed or not protected. About 16.5 TWh are categorized as small power stations with probably limited ability for regulation. Thus about 11-18 TWh could be developed and contribute to increase of the flexibility. As an example 14 TWh with a use of 4000 hours per year requires a capacity of 3500 MW. It is not likely that a substantial increase of the hydro power capacity in the Swedish and the Finnish systems will be possible in the next years.

The existing production could be upgraded with increase of production capacity. The Norwegian regulator has done a rough calculation for the potential and estimated it to be about 16 500 MW in Norway where about 11 500 MW is located in the south and east parts of Norway.

There is very limited documentation of the potential for installation of pumping capacities. Norwegian largest production company Statkraft, has estimated it to be about 10 – 25 000 MW in the south of Norway. The only estimate found from Sweden is the possibility of pumping between Vänern and Vättern and the installation of 50 000 MW capacity. It is a huge volume, but since it is not found included in any political document from Sweden it must be considered to be discussions or ideas at the moment.

At the completion of this report, a recent study appeared [42] where the potential of increased hydro capacity in Norway is further refined based on some of the above restrictions. It is found that an increase of 18.2 GW is feasible through a combination of pumping and expansion upgrades in 13 existing plants.

Table of Contents

1 INTRODUCTION

This report is written within work package 16 of the project Twenties, which is a project funded by the 7th Framework Program of the European Commission. TWENTIES looks at Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions.

With present and future offshore grid development, there will probably be a growing demand for the Nordic hydro balancing capability. The objective of subtask 16.2.2 is to assess the potential and barriers for increased hydro power flexibility in the Nordic and continental Europe grid system. The flexibility can be on dynamic response, but the main issue will be to assess potential for future increase in power capacity and for pumped storage options.

This report documents background information for further work and more in-depth analysis. A review of previous assessments of the hydropower system in the Nordic region is presented in chapter 2. In chapter 3 the existing Nordic power system is described. Chapter 4 contains a description of possible future development of the Nordic power system. Finally, in chapter 5 the barriers for increased hydro power flexibility are described. Chapter 6 presents the conclusions.

In this report, the Nordic region shall be understood as Finland, Denmark, Sweden and Norway. Iceland is not included.

2 REVIEW OF PREVIOUS ASSESSMENTS

In this chapter previous assessment of the flexibility of the hydropower system in the Nordic region are reviewed. Most of the reviewed work in this chapter has a Norwegian focus.

Assessment from the Norwegian Regulator (NVE) [1]
NVE is currently (spring 2011) working with an assessment of the potential for increased capacity in the existing Norwegian hydropower system. The regulator has made a rough calculation based on their database of the system with detailed information about every power plant and reservoir, *e.g.* installation, production, head of water, capacity of reservoir and outlet (sea, river, reservoir, and lake). They have only evaluated increased capacity in the existing system, and installation of pumping is not considered.

The following criteria are used for selection of power stations:

- Installed capacity of at least 50 MW (Covers about 80% of the total capacity)
- The power plant must to some degree have a reservoir
- There must be outlet to lake, reservoir or sea

89 of the 143 power stations with capacity of at least 50MW fulfilled the criteria.

The average time of use for Norwegian hydro power plants is approx. 4200 hours. The average for the selected plants was about 3900 hours per year. In calculations for possible capacity increase an average time of use of 2000 hours per year was used. The estimates showed a possible increase of capacity of 16 500 MW, situated mainly in the West, South and East parts of Norway.

Estimation of potential for balancing power, Statkraft [2]

The largest power producer in Norway, Statkraft, is also actively investigating possibilities and the potential for balancing power. Statkraft looks at mainly three alternatives for increasing the flexibility in the hydro power system:

- Change the operation pattern in existing plants
- Increase installed capacity
- Build pump storage in connection with existing reservoirs

Based on installation of pumping, the technical potential for balancing power is estimated to 10 000 – 25 000 MW in the south of Norway. In addition the potential for increased capacity in existing installations has been calculated to be 6000 – 7000 MW [2]. The results are described in more detail in section **Error! Reference source not found.**.

CO_2 values from the hydro power system [3]

This report, commissioned by NVE, discusses how installation of larger aggregates in the Norwegian hydropower system will impact the CO_2 emissions. The most relevant result for the Twenties project is that it is shown by rough calculations that the lack of transmission capacity between Norway and other countries is the main system-related barrier for export of balancing power. The calculations are based on data from 2005 and 2006. In those years the highest average consumption was in January (17.6 GW) and the lowest in July (10.5 GW)

Since the maximum production capacity is 29 GW, there will be a lot of available capacity in the production system during major parts of the year. The maximum transmission capacity from Norway to other countries is 5000 MW in 2011. The study however does not consider the location of production capacity versus transmission capacity to other countries [3].

The KMB-project “Balance Management” [4].

The objective of the KMB-project “Balance Management” is to design the scientific foundation for a framework for efficient, market-based balancing of power systems that can be implemented in multinational power markets [4].

In this project, balancing resources available for exchange are defined. The security of supply (SoS) in each TSO’s power system is the most important aspect that must be taken into account when exchanging balancing services. One way to ensure SoS is to make sure that only reserves beyond the defined reserve requirement for each part of the system are available for sale to other areas. This implies that reserves covering both loss of the largest production unit and the expected forecast error with regard to consumption and wind production shall be kept for local purposes. It is also anticipated that only reserves bid into the Balancing Market are available for sale. This means that for the next operational hour the following resources are available for export:

$BR_{export} = BR_{Bid} - BR_{SoS} - BR_{FE}$

BR_{Bid} = Resources bid into the Regulation Power Market
BR_{SoS} = Resources kept for Security of Suply (SoS), referring to dimensioning fault
BR_{FE} = Resources kept for potential Forecast Error

The uncertainty with regard to the real level of consumption the next day is by the Norwegian TSO, Statnett, estimated to about 800 MWh/h in winter time due to uncertainty in the temperature and other causes. This volume, BR_{FE}, is therefore added to the dimensioning fault as basis for the reservation of reserves in the Statnett RKOM (Reserves Option Market) market.

The Nordic synchronous system has since 2002 been operated as one control area. The Nordic system has a total Frequency Controlled Disturbance Reserve of 1160 MW and a Fast Active Disturbance Reserve of 4680 MW. In addition Norway uses 800 MW of forecast error reserves. The amount of reserves is related to the ENTSO-E “principle of responsibility” which states that each control area is responsible for restoring its own balance within a certain time [5].

3 PRESENT HYDROPOWER FLEXIBILITY

3.1 THE NORDIC POWER SYSTEM

In the Nordic countries the production systems differ greatly from one country to another. Denmark uses conventional power and an increasing proportion of wind power. Norway has hydropower, while Finland and Sweden have a mix of different systems, mostly hydro power and nuclear power. The total power generation in the Nordic region reached 370.5 TWh in 2009 – a decrease of 5% compared to 2008- with a distribution by source as in Figure 1.

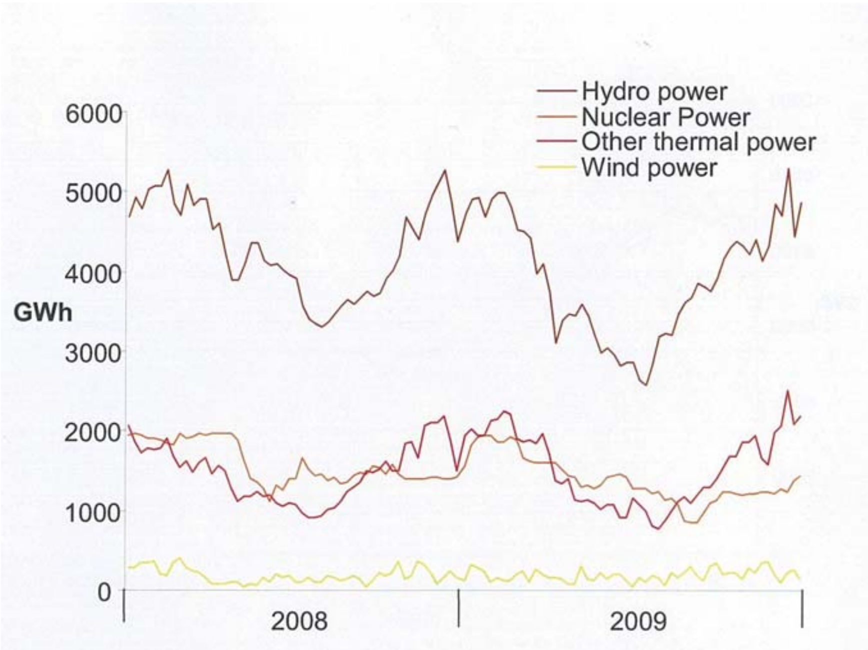


Figure 1 Power generation by source in the Nordic region, 2008-2009 [6]

For 2012, the expected electricity balance (TWh) in the Nordic region is estimated as shown in Figure 2.

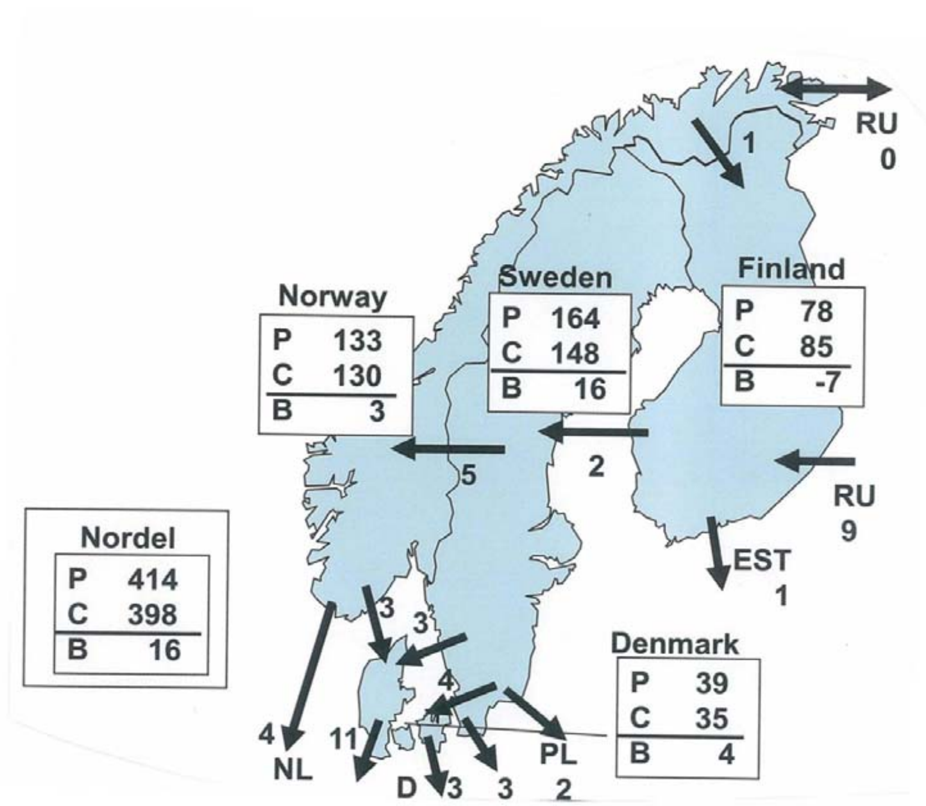


Figure 2 Expected electricity balance in 2012 (TWh) [7]. P=Production, C=Consumption, B=Balance without energy exchange. The estimations consider an average inflow.

The expected available power capacities and the peak demands in each country, in 2012 are shown in Figure 3. The numbers are estimated based on average winter temperatures and show total Nordic values with coincident factors for both wind and demand.

The peak load in the Nordic system may reach 73 000 MW, in a very cold winter (1 out of 10). A prerequisite for such a high consumption is that it is cold in the whole region at the same time. The expected generation capacity available in 2012 is nearly 78 000 MW, thus the Nordic region will be self-supplied in very cold periods.

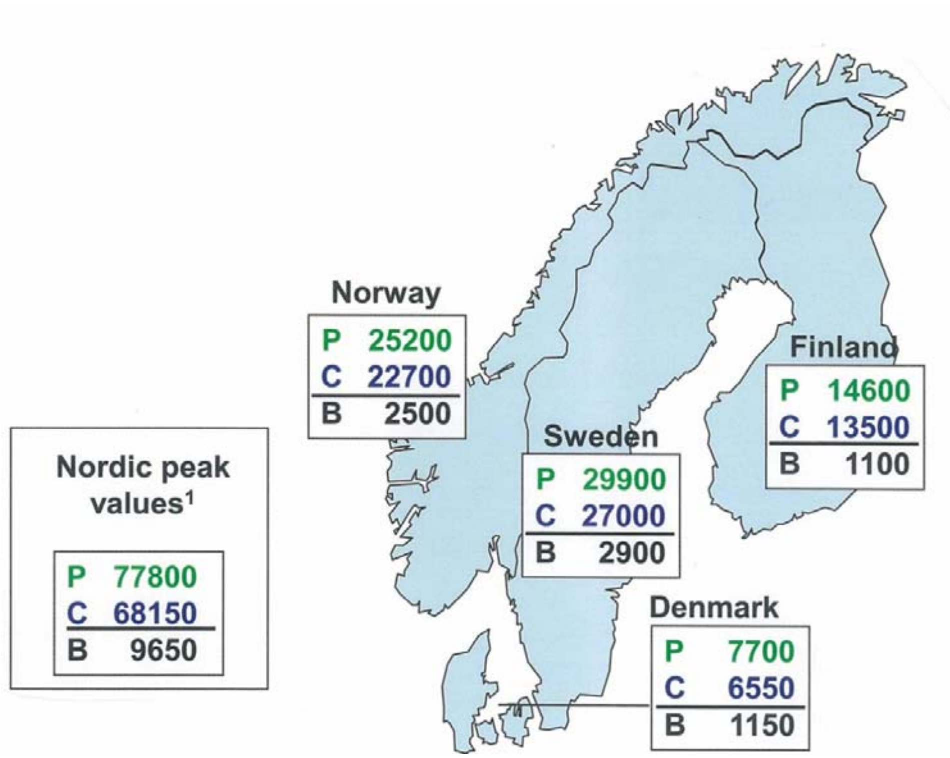


Figure 3 Expected available power capacity and peak demand 2012/13 (MW) [7]. P=Production, C=Consumption, B=Balance without energy exchange.

The main regions for production of hydro power in the Nordic region are Southwest and North of Norway and North of Sweden. The largest hydro reservoirs are also located in the same regions. The main inflow to the reservoirs occurs during the spring when the snow in the mountains melt and during the rainy autumns. The inflow to the Nordic water reservoirs in 2008 and 2009 is shown in Figure 4 and the reservoir levels are shown in Figure 5.

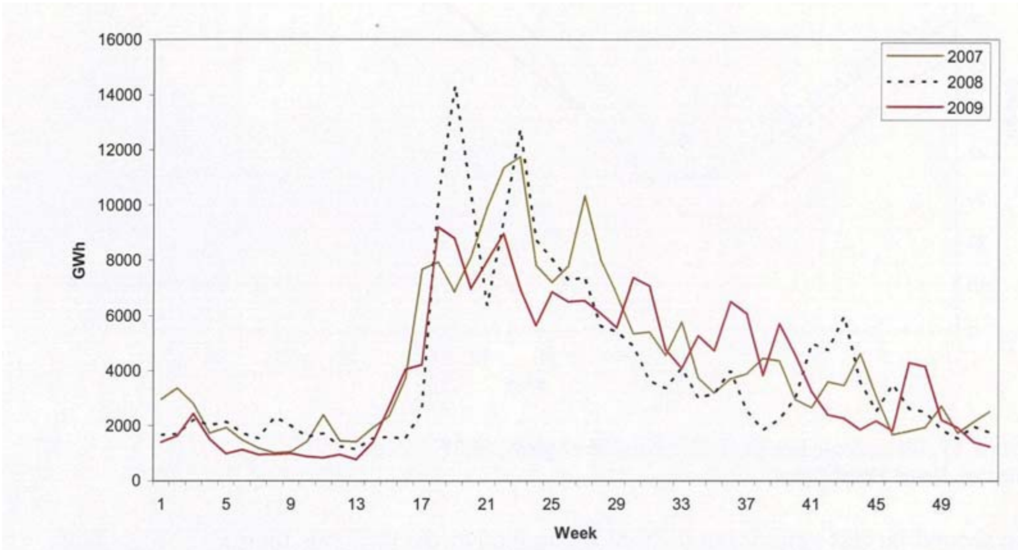


Figure 4 Effective inflow to the Nordic water reservoirs, 2007-2009 [6]

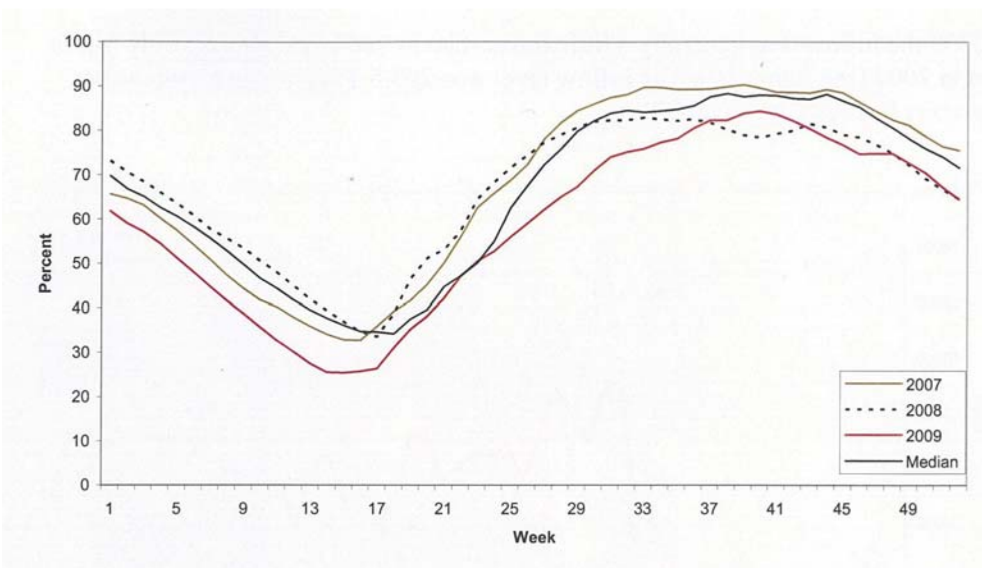


Figure 5 Reservoirs levels in the Nordic region, 2007-2009 [6]

Today, the Nordic grid comprises the national electricity power systems of Denmark, Sweden, Norway and Finland, as well as several interconnections between the countries which tie the national grids together into a coherent system. The system constitutes a single area with a common frequency, with the exception of Western Denmark, which is interconnected with the grid that falls within the ENTSO-E continental European region. The Nordic transmission system with relevant constraints is shown in Figure 6, and the expected available trading capacities are shown in Figure 7.

The subsystems in Finland, Norway, Sweden and eastern Denmark are interconnected synchronously. The subsystem in Western Denmark is connected to Norway and Sweden via HVDC links. As a result of expansion of transmission capacity between the subsystems, the interconnected Nordic electricity power system operates increasingly as a single entity. The common system reduces the need for reserves [8].

Interconnectors also link the Nordic market to Germany, Poland, Estonia and Russia and the Netherlands. In November 2010 the European Market Coupling Company (EMCC) started operations. This connection combined the German and the Nordic power markets into one market, where the prices and capacities are calculated in a coordinated fashion. Since the beginning of 2011 the NorNed cable has made possible the coupling between the interregional markets of France, Belgium, the Netherlands, Luxembourg and parts of Germany on one side and Norway, Sweden, Finland, Estonia and Denmark on the other.

Increased integration with Europe gives opportunities for exchange of electricity and balancing services, but it also introduces new challenges. To avoid imbalances in the Nordic synchronous system, the changes on the flow on the HVDC-cables must be followed by corresponding changes in production. For system operation and production control (involving manual actuations), it is crucial that the flow on the cables do not changes too quickly. Consequently a restriction for flow gradient is set to max 30 MW/min per connection. With six relevant connections (2011), this means a total gradient for the synchronous system of 180MW/min [9].

The share of renewable in the Nordic system is already very high (about 61 %) and is expected to increase considerably among other because of EUs 20-20-20 targets. Further utilization of onshore and offshore wind resources is expected to be important for increase of the renewable production.

The power systems in Norway, Sweden, Finland, and Denmark are described in more detail in the following chapters.

Figure 6 The transmission system in the Nordic region with relevant transmission constraints [5].

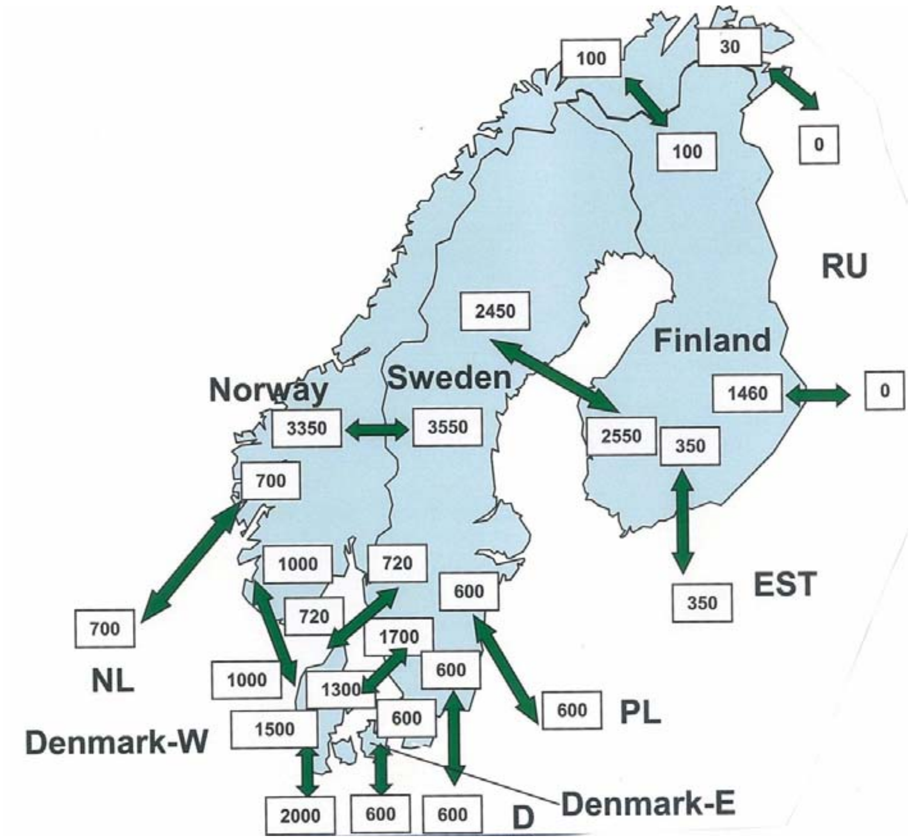


Figure 7 Expected cross border available trading capacities in 2012 (MW) [7]

3.2 NORWAY

3.2.1 GENERATION

Norway's electricity generation comes almost exclusively from hydropower (96%). The total installed hydro generation capacity is **29 600 MW** (2011), with a maximum available winter capacity of approx. 25 000 MW [10]. The hydropower generation in Norway depends on the annual precipitation and can vary greatly from year to year. The average yearly energy generation is of approx. **123.5** TWh/year (with an average utilization time of 4,200 hours). There are 1250 hydro power plants currently in operation in Norway. The installed power plant capacity varies from 1240 MW (Kvilldal power station) to less than 1 MW.

Table 1 Number and capacity of hydropower plants in operation, in Norway, per 01.01.2008 [10]

MW	Number	Total capacity (MW)	Average yearly generation (GWh/year)
0 – 0,1	201	8	41
0,1 – 1	231	110	490
1,0 – 10	638	1 247	5 640
10 – 100	253	9 223	41 348
100 -	78	18 440	74 345

The 10 largest power plants cover, in average, 25% of the annual generation (Table 2).

Table 2 The 10 largest power plants in Norway – location, max. capacity (MW) and average yearly production (GWh)[10]

Power Plant	**Region**	**Max. capacity (MW)**	**Average yearly prod. (GWh)**
Kvilldal	Rogaland	1 240	3 517
Sima	Hordaland	1 120	3 441
Tonstad	Vest-Agder	960	4 169
Aurland 1	Sogn og Fjordane	840	2 419
Saurdal (pump and storage)	Rogaland	640	1 300
Rana	Nordland	500	2 123
Tokke	Telemark	430	2 221
Holen	Aust-Agder	390	805
Tyin	Sogn og Fjordane	374	1 398
Svartisen	Norland	350	1 996

Norway has both run-of-river and reservoir power stations. Most run-of-river power stations are situated in lowland areas in Eastern and Central Norway. Run-of-river and small scale generation have a total installed capacity of **6 255** MW [11].

3.2.2 ENERGY STORAGE AND PUMPING CAPACITIES

Reservoir power stations usually have a larger installed capacity than run-of-river stations, but a shorter utilization period. The total installed capacity in reservoir power stations is 23 405 MW. High-head power stations are often built inside the mountain, near the reservoirs – the power station and reservoirs are connected by tunnels and pipes down the mountainside. The total reservoir capacity[1] in Norway is 85 TWh (or 62 bill. M^3) and this accounts for about 70% of the average yearly electricity generation capacity [12].

In Norway, there are 9 pumped-storage units in operation with a total capacity of approx. **1336** MW and approximately 24 pumping units (located around the largest reservoirs in the South-West) with a total capacity of approx**. 87** MW. The existing pumped-storage units are mostly used for seasonal energy storage.

Table 3 summarizes the information about the existing power plants in Norway emphasizing the capacity share of run-of-river versus reservoir and pump-storage plants.

Table 3 Types of hydro power plants in Norway

Type	**Total capacity (MW)**
Run-of river	6 255
Reservoir	23 405
Pumped-storage	1 336
Pumps	87

3.2.3 GEOGRAPHICAL DISTRIBUTION OF HYDROPOWER STATIONS

Most hydropower is generated in the South-West and North of Norway. The largest reservoirs and pumps are located in the South-West.

Figures 8 and 9 show the geographical distribution of the largest power plants and pump-storage units in the South-West of Norway. Figure 9 (which is an excerpt of the NVE's hydropower Atlas [13]) also show all existing hydropower plants in the center and south of Norway with a capacity larger than 10 MW (see all black dots).

[1] Norwegian reservoir capacity is approximately 50% of total hydro power reservoir capacity in Europe [3]

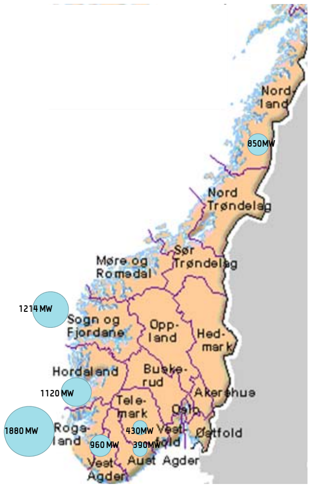


Figure 8 Geographical distribution of the largest hydropower plants in South-West Norway

Figure 9 Geographical distribution of the hydro and pump storage units

3.2.4 HISTORICAL USE OF HYDRO STORAGE: INFLOW PATTERN AND RESERVOIR LEVEL VS. CONSUMPTION

The Norwegian power generation, based almost entirely on hydropower, depends on the yearly precipitation and water inflow to reservoirs. Typically, the reservoir levels follow a seasonal variation, increasing during late spring, summer and early autumn (due to snow melting and rain) and decreasing during late autumn, winter and early spring, as shown in Figure 10. The figure illustrates that there are significant differences in reservoir levels from wet years (Max. (1990-2007)) and dry years (Min. (1990-2007)), which when correlated with cold winters, will have a significant effect on energy and power import levels and market prices.

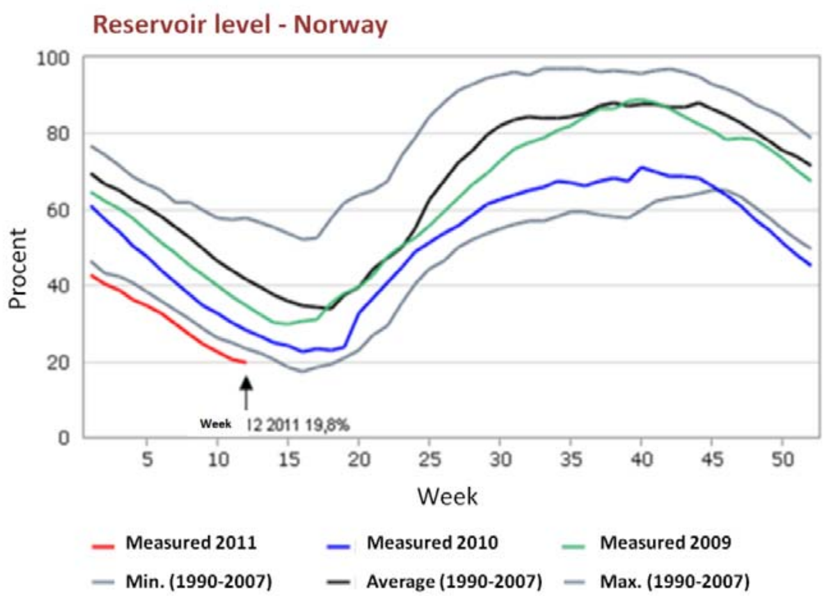


Figure 10 Yearly variation of reservoir levels in Norway, based on historical data for the last 20 years [14]

The amount of electricity that can be generated throughout the years depends thus on water inflow through the year but also on the allowed changes reservoir levels.

In an average year (like for example 2007) the water inflow and energy output, can vary, during a year, as shown in Figure 11. Normally, water is used during the autumn and winter when electricity demand is reached the highest level. Demand reaches its lowest level in spring and summer, periods in which the snow melting and when the precipitation is highest, allowing the reservoirs' refill.

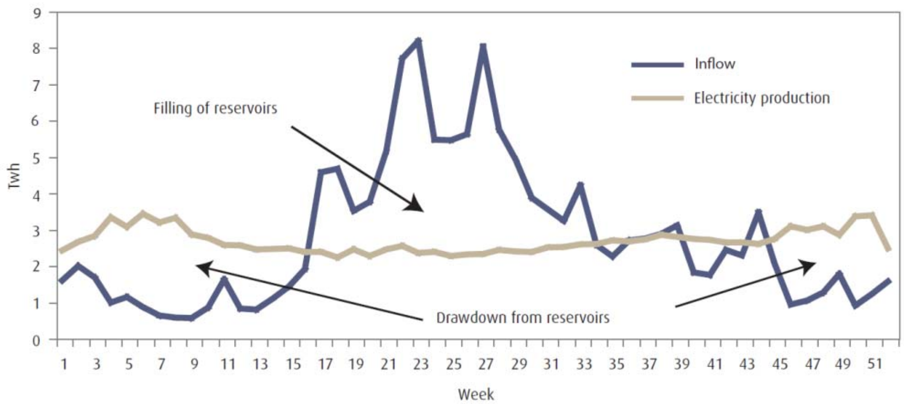


Figure 11 Water inflow and energy output in 2007 [15]

Reservoirs in Norway are used for:

- Short-term regulation – a daily or weekly filling and emptying cycle.
- Seasonal regulation – storing water in summer for use in winter months, when the demand for power peaks (most common practice).
- Multi-year regulation (dry-year) – also possible due to the large reservoirs that can store water in wet years for use in years when precipitation is low.

3.2.5 LIMITATIONS ON MINIMUM PRODUCTION

The use of the Norwegian hydropower potential is limited by various restrictions. When a watercourse is used for hydropower development, conflicts may arise between a number of user groups and environmental interests. Extensive legislation relating to hydropower provides requirements for obtaining licenses for various purposes. The most important elements in the framework for hydropower development are the protection plans for water resources, the Master Plan for Water Resources, the Industrial Licensing Act, the Watercourse Regulation Act and the Water Resources Act – see Figure 12.

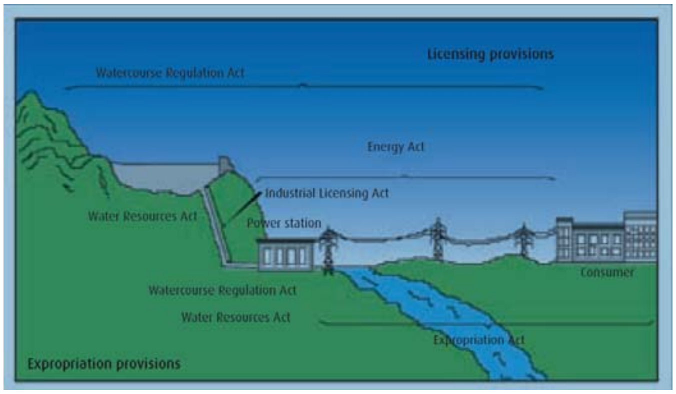


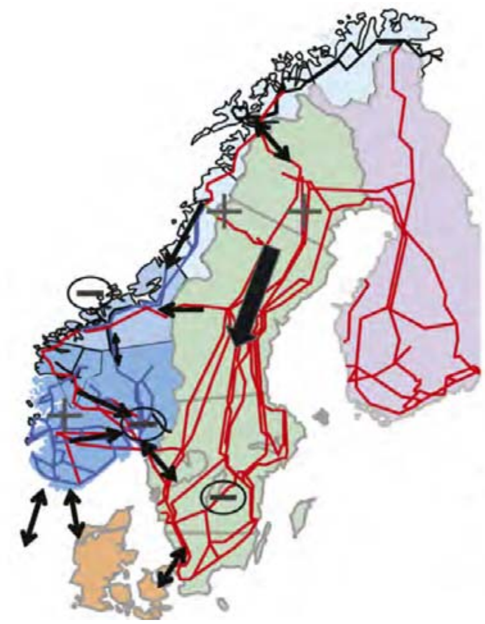
Figure 12 Legislation governing the licensing in the hydropower sector [16]

For example, the difference between the highest and lowest permitted water levels in a reservoir is stipulated in a watercourse regulation license and takes into account factors as topography and environmental considerations.

In the future, more strict rules are likely to be imposed, due to local environmental concerns. This may have a substantial effect on how much of the remaining hydropower potential in Norway can be utilized.

3.2.6 GRID CAPACITY

Figure 13 Typical power flows in the North [17]



Currently, the power in Norway (and in the Nordic grid), is transported on two main axes: North – South and West – East, see Figure 13 [8]. The North – South flow consists of to parts: the transport of power form the North to Central Norway and the power exchange between Norway and the continent. The West – East flow consists of the transport of power from the West of Norway (where the largest power plant and reservoirs are situated) towards Eastern demand centers (Oslo) and the exchange between Southern Norway and Southern Sweden and between Sweden and Finland.

The main transmission network in Norway was divided by Statnett (the Norwegian TSO) in several regions, based on the power and energy balance situation (surplus and deficit) in each region.

For each region, Statnett also gives an estimation of the currently available network capacity to connect, for example, new renewable generation units in different regions – see Table 4

Table 4 The available capacity in the Norwegian transmission network (2010) [17]

Area	Available capacity in today's network (MW)
1	100-150
2	600
3	500
4	400
5	1500
6	300
7	400
8	1000-1200

The existing transmission capacity out of South of Norway is of 3700 MW. This corresponds to 2050 MW transmission connections with Sweden, 1000 MW with Denmark and 700 MW towards the Netherlands [8]. In addition, there are connections between Central Norway and Sweden, summing up 1400-1700 MW, and between North Norway and Sweden (120 MW) and Russia (50 MW).

The transmission capacity between Norway and its neighbouring countries is likely to increase in the future. The Norwegian TSO Statnett has included in its investment plan (2010) a number of new possible cable connections with Denmark, Germany, UK, Sweden and The Netherlands – see Table 5 and Figure 14. However, there is significant uncertainty related to these plans, with respect to both cost estimations as well as the actual possibilities for realization of these connections. Regarding the latest uncertainty issue, several aspects have yet to be clarified, as for instance: ownership of the cables, stakeholder's opposition, and not the least the available transmission capacity inland.

Table 5 Overview of future possible transmission connections between Norway and the continent [17]

Project	Capacity (MW)	In operation	Comments
Skagerak 4: New cable to Denmark	**700 MW**	2014	Concession received in June 2010. Project in collaboration with Energinet.dk
NORDLINK: Cable to Germany	**1400 MW**	2016/18	Concession application April 2010
NorGer: Cable to Germany	**1400 MW**	2016/18	Concession application 2009. Collaboration project between Agder energi, Lyse, EGL and Statnett
NorNed2: New cable to Netherland	**700 MW**	2016/18	Concession application 2010
NSN: Cable to UK	**1600 MW**	2017/20	Collaboration project with National Grid
South-west link New DC connection with Sweden	**1200 MW**	2016/17	Intention announced 201, concession application 2010. Collaboration project with Svenska Kraftnätt

Figure 14 Possible transmission connections between Norway and the continent [17]

3.3 SWEDEN

Ref [18] describes the electricity production in Sweden in 2010. The figures are estimated figures from 2009.

Table 6 The electricity capacity in Sweden in 2010 [18]

Primary Energy	Installed capacity [MW]	Annual Production [TWh]
Nuclear	9570	71.9
Fossil Fuel Fired	5000	4.4
Hydro	16200	67.0
Conventional Hydro	5430	
Pumped and Mixed		
Other Renewables	42380	12.5
Wind	1600	3.0
Biomass	1800	5.5
Not Specified		
Total	**35050**	**155.7**

The total installed hydro power capacity in Sweden in 2011 is about 16200 MW and the average yearly production is approx. 65 TWh. The yearly inflow variation is between 50-80 TWh. Run-of-River is about 5825 MW.

Approximately 700 power stations are larger than 1.5 MW and 1800 are smaller. Hydro power plants with installed capacity smaller than 10 MW produce ~ 4.3 TWh yearly. There is hardly any pumping installed (43 MW in 2010).

The installed reservoir capacities are about 33.7 TWh. Table 7 shows the largest reservoirs in million m^3. Table 8 shows the installed capacity in the river systems and Table 9 shows the production in the largest river systems [19] , [20].

Table 7 Largest hydro power reservoirs in Sweden [19]

Reservoir	Watercourse	(Million m^3)
Vänern	Göta älv	9 400
Suorva	Luleälven	6 000
Tjaktjajaure	Luleälven	1 675
Storsjön	Indalsälven	1 250
Satisjaure	Luleälven	1 260
Torrön	Indalsälven	1 180
Storuman	Umeälven	1 100

Trängslet	Dalälven	880
Gardiken	Umeälven	870

Table 8 Installed capacity in watercourses in Sweden [19]

Watercourse	Installed capacity in 2009 (MW)
Upper Norrland	**7143**
Lule älv	4 196
Pite älv	50
Skellefte älv	1 026
Rickleån	10
Ume älv excl. Vindelälven	1 758
Öreälven	6
Gideälv	70
Moälven	6
Nätraån	12
Small rivers	9
Central and lower Norrland	**6122**
Ångermanälven	2 586
Faxälven	2099
Indalsälven	2 094
Ljungan	600
Delångersån	16
Ljusnan	817
Small rivers	4
Gästrikland, Dalarna and Mälardalen region	**1292**
Gavleåen	24
Dalälven	1148
Eskiltunaån	9
Arbogaån	33
Hedströmmen	8
Kolbäcksån	57
Nyköpingsån	5
Small rivers	8
Southeastern Sweden	**420**
Western Sweden	**1226**
Entire country	**16,203**

Table 9 Electricity production in the largest rivers systems in Sweden [19]

Watercourse	**Production (Twh)**
Lule älv	16.9
Skellefte älv	4,9
Ume älv	7.4
Ångermanälven	6.9
Faxälven	3.4
Indalsälven	9.1
Ljungan	2.0
Ljusnan	3.7
Dalälven	5.1
Klarälven	1.8
Göta älv	2.1
Övriga älvar	5.1
Totalt	**68.4 TWh**

Figure 15 shows the inflow together with the hydro power production and the development of the reservoir levels over a 10-year period from 1997 to the end of 2006. The curves in the upper part of the figure are results of the sum for 52 weeks.

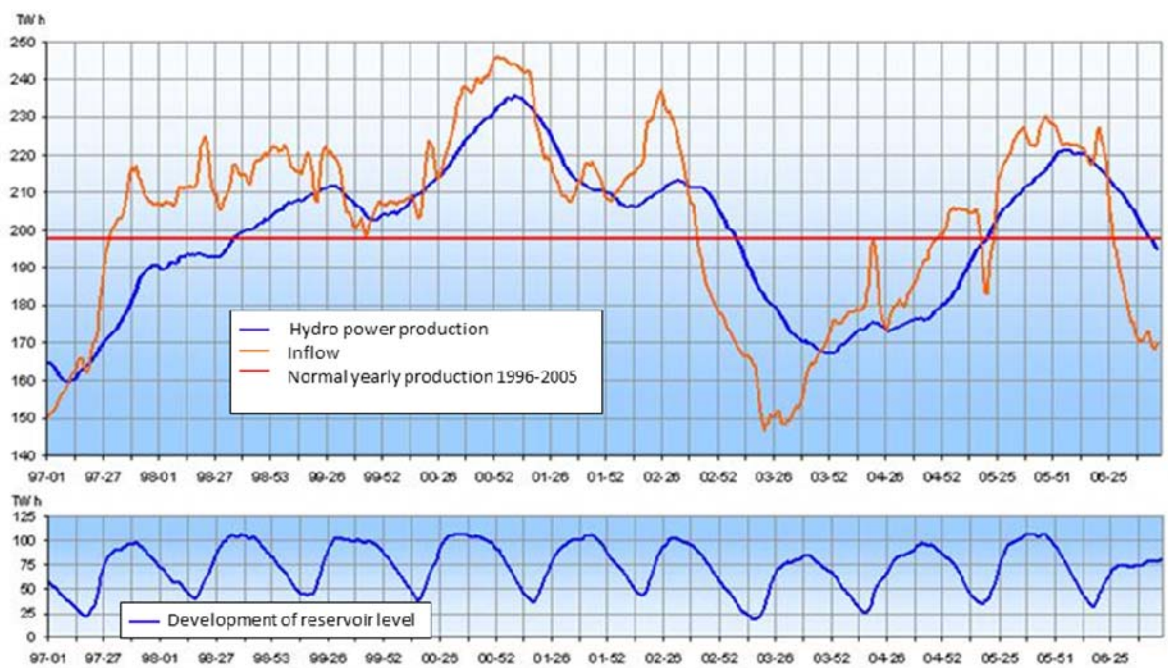


Figure 15 Inflow, hydro power production and development of reservoir levels in Sweden from 1997-2006 [19]

About 80% of the hydro power production is located in the northern part and about 20% in the southern and the middle parts. While the main part of the hydro power production is in the northern part of the country, the largest shares of the consumption are located in the middle and the southern parts. As shown in Figure 6, there are large transmission lines from north to south in Sweden for transmission of the electricity.

The Swedish national grid is often strong enough to allow both transmission between generation and consumption and export and import to and from neighbouring countries. Figure 6, shows the main bottlenecks in the Swedish transmission system. These bottlenecks may in some periods limit the flow of electricity from the northern to the southern part. There used to be one common market area for the whole country, but from November 2011 Sweden has splited in 4 prices areas reflecting the different production/consumption situations.

3.4 FINLAND

Table 10 describes the electricity production in Finland in 2010. As shown in the table the production capacity has a high share of fossil fuels (51.1%) and considerable shares of renewables (32.6%) and nuclear (15.6 %) [18]. 17.3% production capacity is based on hydro power. There is no pumping in the hydro production system.

Table 10 The electricity production in Finland 2010 [18]

Primary Energy	Installed capacity [MW]	Annual Production [TWh]
Nuclear	2,696	22.5
Fossil Fuel Fired	8,817	29.9
Hydro	3,124	13.5
Conventional Hydro	3,124	
Pumped and Mixed	0	
Other Renewables	2,500	11.0
Wind	240	0.8
Biomass	2,246	
Not Specified	157	1.5
Total	**17,269**	**78.4**

According to [18] Finland had a yearly production of 78.4 TWh, a net import of 7.1 TWh and a demand including losses of 85.5 TWh. The peak demand was 16 800 MW.

The annual output of hydropower in Finland is approximately 3,000 MW which equals 13 TWh of electricity generation. Most of Finland's rivers are relatively short length and shallow. The longest river in Finland is the

Kemijoki, which begins in northeast Finland near the border with Russia and flows southwestward to the Gulf of Bothnia. Other major rivers include the Muonio, which begins in far northwest Finland and flows southward to the Gulf of Bothnia (forming part of Finland's border with Sweden) and the Oulujoki, which begins in central Finland and flows westward to the Gulf of Bothnia.

Figure 16 Map of Finland with the largest rivers, lakes and reservoirs [21]

The most significant areas of hydropower development in Finland are in the Kemijoki River in northern Finland, in the Oulujoki River basin in central Finland and in Vuoksijoki which flows between the lake Saimaa and the lake Ladoga in Russia, see Figure 16.

There are presently about 200 hydroelectric power plants in Finland. However, most of these are small – only eight have generating capacities of at least 100 MW with none more than 200 MW. The eight largest of Finland's hydroelectric power plants is shown in

Table 11 [22].

Table 11 Hydroelectric Power Plants in Finland (100 MW and greater) [22]

Power Plant	**River**	**Capacity (MW)**
Imatra	Vuoksijoki	170
Petäjäskoski	Kemijoki	135
Taivalkoski	Kemijoki	133
Pyhäkoski	Oulujoki	122
Rouhiala	Vuoksijoki	120
Pirttikoski	Kemijoki	110
Isohaara	Kemijoki	106
Seitakorva	Kemijoki	100

The total reservoir capacity in Finland is about 5 TWh [23]. The largest reservoirs are in the Kemijoki river, see Table 12 and Figure 17.

Table 12 The largest reservoirs in Finland [22]

Reservoir name	Area [km^2]	Regulated volume [m^3]
Kemijärvi area	130–285	1,067 million
Lokka reservoir	216–417	1,444 million
Porttipahta reservoir	34–214	1,097 million

Most of the hydro power plants in Finland are run-of-river plants and their electricity generation can be regulated only for a short period of time [24].

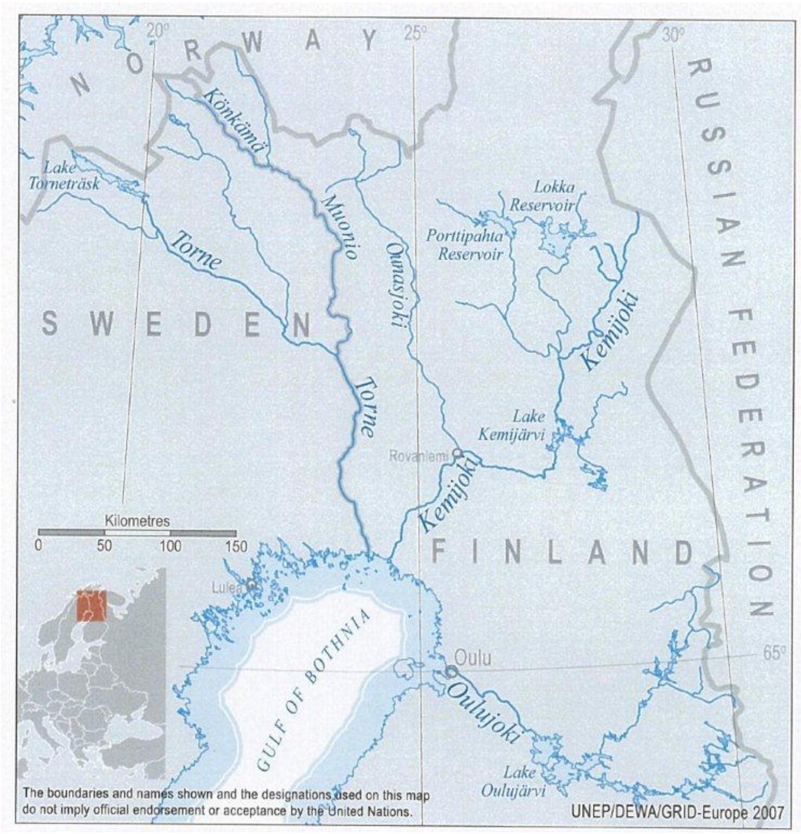


Figure 17 Map of the Kemijoki water system [25]

A map of Finland's high voltage electricity transmission grid is shown in Figure 18 [22]. The existing transmission capacities between Finland and its neighbouring countries are shown in Table 13 [7].

Table 13 Transmission capacities between Finland and its neighboring countries [7]

[MW]	Norway north (NO5)	Sweden north (SE2)	Sweden middle (SE1)	Estonia	Russia
From FI	100	1050	800	350	0
To FI	100	1650	800	350	1300

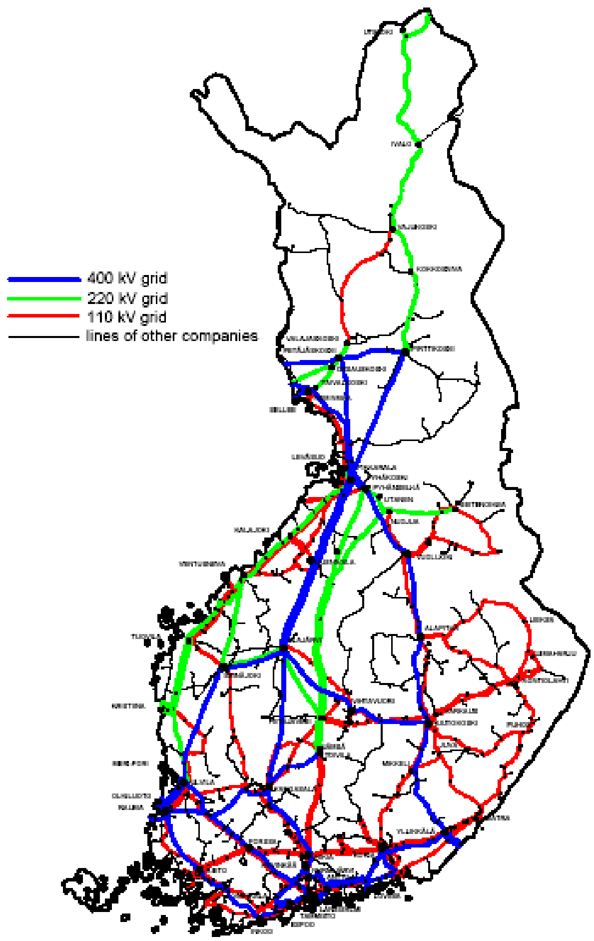


Figure 18 Finland's High Voltage Electricity Grid (as of December 2001) [22]

4 FUTURE HYDRO POWER FLEXIBILITY

4.1 NORWAY

Among Scandinavian countries, Norway is perhaps the country with the largest potential for increasing its hydropower and pump and storage capacity. This potential lies, primarily, not in building new reservoirs and generation capacities, but in increasing the generation capacity of the existing power plants, improve the use of existing reservoirs and building additional pumps (between existing reservoirs).

Most of Norway's approximately 370 storage hydroelectric power stations comprise multi-lake systems whose various lakes are often interconnected by underground tunnels and pressure shafts. Such systems can theoretically be converted to pump storage systems at relatively low cost. However to obtain a significant increase of power production for balancing purposes, the turbine capacity in Norwegian power plants (currently 22 GW) will have to be expanded, apart from stepping up the pumping capacity. This implies the construction of additional inflow tunnels, pressure shafts, pumps and turbines whose realization would require long term planning and sufficiently long lead times.

A recent (unpublished) NVE study [12] estimates that the potential for *increased capacity in the existing hydropower* plants in Norway can reach **16 500** MW (see Table 14). The estimation was done based on a simple screening of NVE's information about existing hydropower plants in Norway. 89 power plants with a total capacity of 17 000 MW and 66.4 TWh averaged annual production are included in the study. The power plants were selected based on: the size of current installation (> 50 MW), reservoir capacity and type of outlet (sea, reservoir, large lake, river – with possible new tailrace to sea, reservoir or lake).

Table 14 The potential for capacity increase in the existing power plants in Norway (source: NVE)

	Number	Capacity	Prod.	Utilization	Reservoir	New total	Increase
		MW	TWh	hours	%	MW	MW
> 50 MW	143	23000	95	4150			
"Possible"	89	17000	66.4	3910	82	33500	16500
Region							
East	13	2000	8.1	4050	73	4100	2100
South	18	4900	17.0	3480	92	8600	3700
West	30	6100	23.3	3800	64	11900	5700
Middle	8	1000	4.6	4660	60	2300	1300
North	20	3000	13.4	4520	93	6700	3700

This estimation is rather 'theoretical' and does not include details about the types of power plants to be built and technical solutions (beyond some general considerations), cost evaluations, environmental impacts, and transmission and market impacts.

Figure 19 presents an overview of Norway's hydropower capacityin 2010 including: developed hydropower plants, plants under construction, plants that applied and plants that received concession form NVE, potential for upgrading existing power plants and building new capacities over 10 MW, potential for development of small power stations (under 10MW), and sites that are permanently protected.

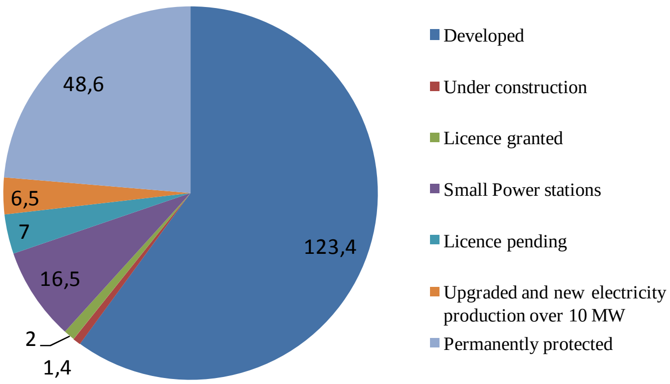


Figure 19 Norway's hydropower potential, per 1 Jan. 2010 [TWh/year] [10]

To give an indication of the pumped storage potential, we refer to a presentation (unofficial study) made by Statkraft [26]. The study discusses that there are significant possibilities for capacity increase and new pumped storage plants (between existing reservoirs) and gives an example of using Lake Blåsjø (7.8 TWh reservoir capacity) in South-West Norway. For instance, the potential for 1 day pumping can reach 85 GW (assuming a ½ m/hour reduction in reservoir level), for 5 days pumping – 30 GW for and for 60 days pumping – 2.6 GW (see Table 15).

Table 15 Pumping potential at Lake Blåsjø

Upper limit on reservoir reduction level	Pumped power (MW) on periods with different duration		
	1day 24 h	5 days 5 x 24h = 120h	60 days 60 x 24h = 1440h
0,50 m/hour	85 500	30 000	2 600
0,10 m/hour	30 000	16 000	2 600
0,01 m/hour	3 200	3 200	1 500

4.2 SWEDEN

Table 17 and Table 17 show Eurelectric's expectations for the development of the Swedish power system up to 2030. It is expected a high increase in renewable production, especially wind production which increases from 1.9% to 15.1% of the total production. At the same time the nuclear production is expected to decrease from 46.1% to 31.9% of the production.

Table 16 The expected development of electricity production in Sweden to 2030 [18]

	Installed capacity [MW]			Annual Electricity Production [TWh]		
Primary Energy	2010	2020	2030	2010	2020	2030
Nuclear	9570	10030	7030	71.9	75.4	52.9
Fossil Fuel Fired	5000	2870	2870	4.4	4.1	4.1
Hydro	16200	16400	16600	67.0	68.4	69.7
Conventional	5430	3970	4220			
Pumped	0	0	0			
Other Renewables	4280	9350	12600	12.5	26.3	39.3
Wind	1600	6000	9000	3.0	15.0	25.0
Biomass	1800	2300	2500	5.0	7.0	9.5
Not Specified						
Total	35050	38650	39100	155.7	174.3	166.0

Table 17 The expected development of electricity balances and peak demand in Sweden to 2030 [18]

	2010	**2020**	**2030**
Electricity production [MWh]	155.7	174.3	166.0
Net import [MWh]	-18.2	-30.3	-18.5
Demand (incl losses) [MWh]	137.5	144.0	147.5
Peak demand [MW]	23300	24000	24200

According to [27] there is not expected any considerable increase in hydro power installed capacity in Sweden in the period to 2020. Neither is there foreseen any increase in pump capacity. This opinion is confirmed by [28].

However, the Swedish Energy Agency has assessed a potential for a moderate increase in this period to about 0-5TWh/year, within the existing regulatory framework to promote the development of renewable energy within the Swedish power system. The economic potential is assessed to be about 30 TWh/year of extra production. Note that from January 2012 Norway and Sweden have a common green certificate market.

Besides the official estimations there are some discussions [28b] about building pumping capacity between the lakes Vänern and Vättern in Southern Sweden. The difference in altitude is 44 meters between these lakes. The utility in Mariestad, Mariestads Kraftverk, is evaluating a pump capacity of 50 000 MW. Another site in Sweden evaluated for installing nearly the same pump capacity is Vattenfalls Suorvadamm in Lappland. The consequences of the possible pump production need to be analysed for both alternatives, and the start of any project is probably years ahead.

The potential for increase of small scale hydro power (capacity 10 MW or lower) production is about 7 TWh compared to the existing 4.3 TWh [20].

4.3 FINLAND

Table 19 and Table 19 show Eurelectric's expectations for the development of the Finnish power system up to 2030.There is expected a more than doubling of the nuclear production, while the hydro production is nearly constant. The wind production is expected to increase considerably. However, since current production level is low (less than 1 TWh), wind production will have a share of about 6% of the total production in 2030. The annual electricity production is expected to increase about 42 TWh from 2010 to 2030, while the demand is increasing about 23 TWh. Thus, Finland will go from being an importer of electricity to be an exporter.

Table 18 The expected development of electricity production in Finland to 2030 [18]

	Installed capacity [MW]			Annual Electricity Production [TWh]		
Primary Energy	2010	2020	2030	2010	2020	2030
Nuclear	2696	5901	7501	22.5	47.4	56.4
Fossil Fuel Fired	8817	8150	8150	29.9	30.9	27.2
Hydro	3124	3385	3489	13.5	13.9	14.4
Conventional	3124	3385	3489			
Pumped	0	0	0			
Other Renewables	2500	3883	5015	11.0	17.1	13.0
Wind	240	1500	2500	0.8	4.5	7.5
Biomass	2246	2342	2474			
Not Specified	157	221	219	1.5	1.8	1.8
Total	17269	21540	23270	78.4	111.1	120.6

Table 19 The expected development of electricity balances and peak demand in Finland to 2030 [18]

	2010	**2020**	**2030**
Electricity production [MWh]	78.4	111.1	120.6
Netto import [MWh]	7.1	-9.8	-7.4
Demand (incl losses) [MWh]	85.5	101.3	108.7
Peak demand [MW]	16200	16800	18000

About 60% of Finland's rivers have been developed for hydroelectric energy and about 20% are protected against development. As a result, few new hydroelectric projects are being planned.

However, the use of hydropower can still be increased in Finland. According to the study made by The Ministry of Trade and Industry in 2005, there is still 663 MW hydro potential left in the already constructed and unprotected watercourses. Construction of hydro has been greatly restricted by the Rapid Protection Act of 1987 and other nature conservation acts and measures. There is 1,467 MW of new hydro potential in the protected watercourses, so the techno-economic hydro power potential in Finland is altogether 2,130 MW. In terms of annual energy production it equals less than 10 TWh of electricity production. Upgrading made in connection with refurbishment is the most advantageous way to increase potential. Some increase – but limited – can be achieved by construction of new power plants and auxiliary machineries. The annual amount of diversion energy – due to inadequate storage capacity – is approximately 750 GWh, of which only 7 GWh is included in the above mentioned increase plans [29].

According to Finland's national action plan for promoting energy from renewable sources a limited increase in hydro power production is expected to 2020. They expect hydro power capacity to increase with 50 MW from 2010 to 2020. The capacity for pumping is expected to be 0 also in 2020 [30]

4.4 CONSEQUENCES OF CLIMATE CHANGE

The consequences of climate changes in the period 2020-2050 have been analysed for the Nordic power market in [31]. The analysis is based on an assumed 2020 system configuration that is simulated with three different climate scenarios (i.e. hydro inflow and temperature).
The reference climate scenario is based on observed climate variables from the period 1961 to 1990, whereas the remaining two scenarios are forecasted climatic variables for the period 2020-2050, provided by partners in the Nordic research project on Climate and Energy [33].

The two climate scenarios are denoted Hadam and Echam. In Hadam and Echam there is a general increase in temperature over the year with 1-2 degree Celsius. The increase is largest in the winter period. The difference between Hadam and Echam is relatively small. Inflow for the scenarios was prepared by scaling the observed inflow in the reference period by factors calculated from the analysis by the project partners and their forecast for the period 2020-2050. The predicted average annual inflow represents an increase of 12-13% compared to current situation. Further description of methodology for establishing the scenarios and the resulting scenarios is given in [31].

The system simulations are carried out using the EMPS-model. EMPS simulates the optimal operation of the Nordic system and interconnections to continental Europe. Simulations give detailed results for power production for different technologies, demand, prices and exchange between the Nordic areas and with the connected European countries [32].

The system is modelled as the current system modified with expected changes for 2020. Among others, the model includes 1108 hydro power modules with a detailed description of reservoirs, discharge and relevant constraints.

The demand is expected to decrease somewhat in the climate scenarios compared to the reference case due to the temperature increase. For the NordPool area, demand is reduced with 1.9% for Echam and 2.5% for Hadam. The reduction is relatively stronger in the winter than in the summer.

According to the analysis results the predicted annual inflow represents an increase of 10-12% in the climate scenarios compared to the reference conditions. A significant part of the increase stems from more inflow during the winter season. Hydropower production is expected to increase with 9-10% for the NordPool region. Reservoir handling is expected to change towards less variation in reservoir levels over the year. The main reason is that reservoirs will be less empty during late winter/early spring.

The inflow, the reservoir levels and the hydro power production for the NordPool region are shown in Figure 20.

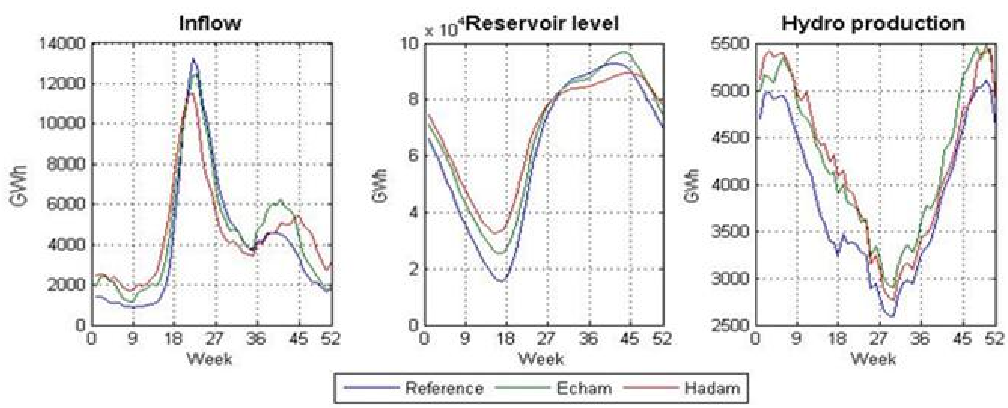


Figure 20 Average annual properties for the NordPool region (GWh)

Assuming everything else kept constant (thermal production, changes in demand for other reasons than climate changes etc), the climate changes will to some degree increase the flexibility of the Nordic hydropower system. Since the hydro power production increases and the demand decreases, will there in average over the year be more production "available" than without climate changes. The expected hydro production and demand for the summer and winter period in 2020 is shown for the three different scenarios in Table 20. In the climate scenarios the hydro system is covering about 30 TWh more of the demand in the NordPool region than in the reference scenario. The corresponding number for Norway is about 17 TWh. The improvement in the electricity balance is slightly higher in the winter period than in the summer, about 17 TWh in the winter and about 12 in the summer.

Table 20 Hydro production and demand in the Nordic region in 2020 for 3 scenarios [31]

		Hydro (TWh/y)		Demand (TWh)		Difference (TWh/y)		
Scenario	Region	Winter	Summer	Winter	Summer	Winter	Summer	Total
Reference	Norway	70	52	82	62	-12	-10	-23
	Sweden	38	29	84	62	-46	-33	-79
	Denmark	0	0	20	18	-20	-18	-39
	Finland	7	7	56	49	-49	-42	-91
	NordPool	114	88	242	191	**-128**	**-103**	**-231**
Echam	Norway	77	58	81	60	-4	-3	-6
	Sweden	40	33	82	61	-42	-28	-70
	Denmark	0	0	20	18	-20	-18	-39
	Finland	7	8	54	48	-47	-40	-87
	NordPool	125	98	237	188	**-112**	**-90**	**-202**
Hadam	Norway	78	56	80	60	-2	-4	-6
	Sweden	40	33	81	61	-41	-28	-70
	Denmark	0	0	20	18	-20	-18	-39
	Finland	7	7	54	48	-46	-41	-87
	NordPool	125	96	235	187	**-110**	**-92**	**-201**

Considering both the potential for increase of the hydro power production and the decrease of the demand about 10-15 % more hydro power will be available in the climate scenarios for either covering more of the demand in the Nordic region (phase out of the thermal production) or for export to other countries.

Considering the flexibility of the hydropower system in a shorter time perspective than year/time of the year, the difference between the hydro generation capacity (MW) and the load is important. Even though the inflow will increase in the climate scenarios, the physical capacity of the production system will not increase. But because the demand is to some degree decreased, the difference between the production capacity and the instant demand will increase slightly. But since the demand reductions are very limited, the impacts of the changes can be neglected.

The efficiency of a power plant is dependent of the levels in the reservoirs. In the climate scenarios there will be less variation of the reservoirs levels over the year. According to [31] the reservoir levels increase for all countries in the late winter and early spring in the climate scenarios compared to the reference case. The levels in the late summer/early winter remain relatively similar to the reference situation

To summarize: Climate changes will impact the hydro power flexibility in the Nordic countries and the changes will probably not have any negative influence on the flexibility. The ability to export electricity may increase with about 30 TWh/y. The short time flexibility (within the week, day, hour) seem to be influenced very little.

5 BARRIERS FOR INCREASED HYDRO FLEXIBILITY

5.1 PHYSICAL LIMITATIONS

The flexibility of the Nordic hydropower system is influenced by the geographical dispersion of hydropower resources and distances to the main load centres, the types of hydropower generation that can be developed (run-of- river power plants and storage and pumping power plants with reservoirs) and the annual water inflow allowing hydro generation (see also section 4.4 Consequences of climate change).

Regulation reservoirs are generally situated in sparsely populated areas, and usually at high altitudes in the mountains in order to make the fullest possible use of the head of water. Run-of-river power plants provide mainly unregulated power into the system, with seasonal variations.

Norway's hydropower potential, e.g. the amount of energy in its river systems that is technically and financially available to generate electricity, was estimated (at 1 January 2008) to be 205 TWh per year. Of this, 121.8 TWh is already developed and used in the existing power plants, and 45.5 TWh per year is protected from hydropower development (see section **Error! Reference source not found.** Regulatory barriers). The remaining potential that can be developed, is thus of about 37.7 TWh per year.

Most of the studies estimating the future increase of Norwegian hydropower capacity do not consider that major reservoir and generation capacities will be built, see for example [12].This is due to both economic and environmental protection considerations. Instead, the system's capacity will increase mainly through the development of small scale (run-of-river) hydropower units, upgrading the existing hydropower plants and building new pumping units between existing reservoirs.

In Sweden and Finland the increase of hydropower generation does not include in the national plans for the achievement of RES targets [34].

5.2 CHALLENGES RELATED TO GRID EXPANSION AND VOLTAGE UPGRADE

Limited transmission grid capacities both within each country and between the Nordic region and the ENTSO-E continental European region are a major barrier for the exchange of balancing services.

This issue will be is studied in detail in Task 16.2.3 and the results will be available in deliverable D16.3.

5.3 MARKET BARRIERS

The current electricity market rules can act as a barrier against the full usage of the 'technical' flexibility potential in the Nordic hydropower system.

An important barrier to present and future increase of cross border energy exchange and trade of balancing power within Europe is that there are differences in the balancing markets mechanisms in the European countries. There are differences in the timing of the different services with regard to when they start and end i.e. in the interactions between the balancing markets and the intraday markets [35].

The balancing market consists of three main pillars: balance responsibility, balancing service provision, and imbalance settlement [36]. Within this market there are three main actors involved: the Transmission System Operator (TSO), the Balance Responsible Party (BRP), and the balancing Service Provider, (BSP).

If we look at the Nordic electricity market, the Nordic TSOs, Statnett, Svenska Kraftnät, Fingrid and Energinet.dk, have the role as “Settlement Responsible” as well as “System Operator” in Norway, Sweden, Finland and Denmark respectively [37].

The interaction of balancing (which is the responsibility of the TSOs) and other markets in the Nordic system, operated by the Power exchange (PX) Nord Pool can be described as in Figure 21 below [35]:

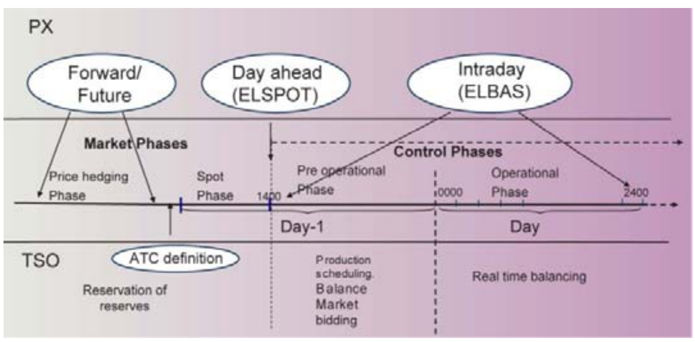


Figure 21 Transition from market to physical operation in the Nordic region [35]

The market phases start with bilateral contracting and financial trading and end with the spot market settlements every day at noon. The available transmission capacity (ATC) for the different intersections is defined by the TSO before the opening of the Elspot market. In the pre operational phase, the production schedule is carried out by each producer that submit bids for the real time balancing market, which are used in the operational phase. The intraday trading takes place also in the pre operational phase, up to one hour before operation. Procurement of balancing resources in advance (or reservation of reserves) is done in the market phases.

For reservation of reserves in Norway, the TSO uses a kind of medium term ancillary service market (Power Reserves Acquirement – with a time resolution of one week) where both producers and consumers are allowed to bid reserves and are paid for their availability (the regulation offers selected in the bidding process receive an option payment [NOK/MW period]). The selection of offers is based on the bid prices within predetermined bidding areas and the market clearing price is determined by the last offer accepted.

Denmark has adopted a similar Option Market as in Norway while in Sweden and Finland reserves are procured in advance through bilateral contracts.

The common Nordic balancing market function in described in the following [35]: The BRP's submit bids for regulating power to their respective TSO who transfer the bids to the common TSO information system, for the common balancing market for the whole balancing region plus Denmark. For each hour, the balancing price is determined in all Elspot areas as the marginal price of the activated bids in the joint list, if there are no bottlenecks in the system.
Activation of bids for the management of bottlenecks within the operational hour (both up and downward regulation) is done after Elspot clearing and is considered a 'special' type of regulation. When choosing a bid, attention must be paid to both the price and effectiveness of the activation of the regulating object behind the bid.

The balancing reserves that can be available for sale to the continent depend on what the Nordic market actors announce in the reserves market (because often not all the 'technically' available balancing reserves are announced) and on the uncertainty in demand estimation.

Moreover, there are only quite few retailers that operate in more than one of the Nordic countries, and only very few that operate in all these countries. Due to differences in the national end user markets, a Pan-Nordic retailer has to have parallel supply functions through most of the value chain. Balance settlement and reconciliation settlement are significant parts in this value chain and different rules and routines in this area represent barriers for entry.

To achieve a common balance and reconciliation settlement in Sweden, Norway, Denmark and Finland, a Balance Responsible Party (BRP) should have one interface (the settlement responsible unit) and one set of rules when settling its' imbalances in the Nordic Countries. The Nordic Council of Ministers has for several years supported a development of a common Nordic end user market for electricity. A recent proposal for a common Nordic balance and reconciliation settlement should allow, for example [37]:

- Lower entry barriers for new actors through equal rules in all countries
- Harmonization of laws, regulations, balance settlement agreement and rules to reduce the administrative cost for market participants and ease the operation for market players operating on a Nordic scale.
- Efficient operation across national borders by reducing the cost of administrative systems as well as IT systems.
- Cost effective solutions for the settlement and invoicing of reconciled energy

5.4 REGULATORY, ENVIRONMENTAL AND SOCIAL BARRIERS

In Scandinavia, the use of the hydropower potential is limited by various restrictions.
When watercourses are used for hydropower development, conflicts often arise between a number of user groups and environmental interests.

In Norway for example, an extensive legislation relating to hydropower provides requirements for obtaining licenses for various purposes. The most important elements in the framework for hydropower development are the protection plans for water resources, the Master Plan for Water Resources, the Industrial Licensing Act, the Watercourse Regulation Act and the Water Resources Act (see also section 3.2.5).

River system protection was codified in the 2000 Water Resources Act, which defines what is meant by protected watercourses and also lays down provisions for their protection from types of development other than hydropower projects.

Moreover there are strict limitations on hydropower generation. For example, the difference between the highest and lowest permitted water levels in a reservoir is stipulated in each power plant license and takes into account factors as topography and environmental considerations.

In the future, more strict rules are likely to be imposed, due to local environmental and social (recreation, aesthetics, fishing etc.) concerns. This will have a substantial effect on how much of the remaining hydropower potential in Norway can be used.

The same applies for Sweden and Finland (where the increase of hydropower generation does not seem to be included in the national plans for the achievement of RES targets.

5.5 ECONOMIC CONSIDERATIONS

Economic issues will play a very important role in the future development of hydropower in the northern Europe. This concerns both the cost of new hydropower and grid technology (*to be developed*) as well as actor's willingness to invest.

The economic barriers may resume to the simple fact that balancing capacity can be developed if there is a European 'customer' to 'buy it'. For investors in balancing power it is important that long-term political and economic agreements (through TSO's) are made and that markets will be re-organized in order to allow for large scale trading of balancing services. Support instruments (e.g. long term contracts, feed-in tariffs) as well as financial barriers which have to be overcome, regardless the specific type of support instrument in place (lack of trust among banks or investors, low predictability of capital subsidies and cash flows) will be extremely important for investment decisions.

For TSOs the most important is the timing for the construction of the export cables due to the new North Sea transmission sea cables seem to be only 'marginally' profitable [38].

5.5.1 POLITICAL BARRIERS

The future development of hydropower systems in Northern Europe to significantly increase the flexibility and balancing possibilities cannot be realized without political and social support, at national and international levels. For this, 'the right' political decisions should be made and accepted by the energy industry partners and citizens in the Nordic and EU countries. Inter-governmental agreements and an even benefit sharing among countries and across the 'value chain': generation, transmission and end-users, are essential.

The policies and measures currently implemented on the European renewable energy market have so far been mainly directed towards the promotion of renewable electricity.

The EU energy policy decisions are fully dependent on national implementation [39]. On the other hand, the EU has no influence vis-à-vis deciding the composition of the energy mix nationally, but has some influence, indirectly by setting targets e.g. for renewable energy. The choice of instruments has not been prescribed or harmonised in Europe, and therefore each country has adopted its own unique set of promotion instruments based on the national goals specified in relation to renewable energy. These include achieving environmental goals, security of supply, and creating employment support for (developing) national renewable energy industries.

For example, the implementation of the EU's water and RES directives is likely to bring new regulation rules for Nordic hydro power (rivers, reservoirs). This may actually act both as a barrier for more exchange of balancing power (high development of domestic wind power as a result of the RES directive) or as a driver (Norway makes commitments to contribute with balancing power) [40].

The main long-term driver behind the development of the power system will always be to maximize the value of electricity consumption to society. Society involvement will be a crucial parameter in any political decision (on short and long-term) that will enable full scale use of renewable energy resources. Low social acceptance poses difficulties for building new hydro power plants and transmission grids in Norway and other countries.

5.6 BARRIERS RELATED TO ENERGY BALANCE

Due to the Nordic countries commitment to contribute to EU's RES objectives and reducing CO_2 emissions it is expected that in the future (towards 2020) the Nordic area will have substantial power surplus due to increased investments in renewable energy generation which likely not be compensated by a corresponding increase in demand [38].

Most of the increase in RES developments in the Nordic countries will likely be in the form of unregulated energy sources based on wind and solar power with hydropower contributing marginally to this (mostly in Norway in form of small scale run of river power plants and capacity increase in the existing plants) [34].

These developments will increase the need for reserves and balancing services provided by regulated hydropower, thus limiting the possibilities for export outside the Nordic region.

5.7 ADMINISTRATIVE/ORGANIZATIONAL BARRIERS

A major barrier can also be the large number of actors/authorities whose active and coordinated involvement and cooperation is crucial for the future development of the Nordic hydropower system and its flexibility.

First there are the investors in new hydropower generation and pumping capacities, and TSOs (as responsible for national transmission networks and international connections investment). To invest, these actors need incentives of both economic and regulatory/political manner. Long lead times to obtain necessary building permits (in different countries) for both power plants and transmission pose a first major barrier. Crucial are also: attractive market prices, long term trading agreements for balancing between countries (assumed to be needed in case of 'large' scale balancing) and non-discriminatory market settlements and rules.

6 DISCUSSION/CONCLUSIONS

Hydro generation has ideal characteristics for providing real-time balancing energy in comparison to thermal generation. This is because of its high regulation speed and low operating cost. Therefore, hydro generation can add a good flexibility to the power system production in order to compensate the uncertainty introduced by the growing renewable power penetration. The below is a first discussion of the existing and future flexibility in the Nordic system. The flexibility will be further analysed in the following subtasks 16.2.3 and 16.2.4.

When studying the flexibility of the power system in each country the report covers: the available generation capacity, energy storage and pumping capacities, geographical distribution of hydropower stations, historical use of hydro storage (inflow pattern, reservoir levels vs. consumption, etc.), limitations on min. production and grid capacity.

Further analyses should focus on a more specifically defined 'system flexibility', and should for example include more detailed short term analysis of the system within the hour, between hours or both. Further analyses should also distinguish between the flexibility within the Nordic system and the 'flexibility' for exchange of power between the Nordic system and the rest of the Northern Europe.

The Nordic synchronous system has since 2002 been operated as one control area. Thus, the information presented in this report focuses on the Nordic region. However, there are substantial differences between the systems in the different countries, and therefore the three Nordic countries with hydro power production (Norway, Sweden and Finland) are described in more detail.

The report builds up on official power system data as well as on results from various studies available. It is important to mention that there are limited work/results available so far on this subject, for the whole Nordic system. Official reports and research studies (on different aspects within this subject) are available and significant research work is currently carried out on the subject in Norway[41]. Less information is available for Sweden and Finland.

<u>The existing flexibility of the Nordic system</u>

The existing flexibility in the Nordic system is based on import from adjacent countries in periods with low prices and export in periods with high prices such that the total energy exchange over a period is approximately zero. Since there is hardly any pumping capacity in the Nordic system, the import to the region must be balanced with reduction of the hydro production. The flexibility will vary a lot from winter to summer, from working-day to weekend and from peak hours to off-peak hours. Due to such uncertainties, the 'flexibility' of a system is rather difficult to quantify, but some frames are possible to calculate. The maximum theoretical flexibility in the Nordic system based on hydro power is about 35 000 MW. The number is based on 25 000 MW capacity in Norway and about 10 000 MW (16200 MW installed capacity – 5825 MW run-of-river) in Sweden. Finnish hydro power is not included because it is mainly run-of-river. Thus, in periods with low prices in other countries, up to 35 000 MW hydro power production, in theory, could be reduced and *stored* and electricity corresponding to the real demand can imported to the Nordic region.

This theoretical potential is limited by the maximum available production capacity and the consumption, at given times and during the system's peak hours.

The total expected available capacity in the Nordic system in 2012 is **78 000** MW, excluding the allocated reserves in the system. These reserves are of about 5850 MW plus an additional 800 MW which Norway reserves for forecast errors.

The expected peak load on an average winter day is **68 150** MW. This is 1700 MW lower than the sum of the peak values for all the Nordic countries because of the so-called coincidence factor.
Thus, in an average peak hour in the winter it may be possible to export electricity from about 10 000 MW production from the Nordic region to adjacent countries. The number will off course be lower in very cold periods when the peak consumption is higher than in average winters.

These estimations do not consider bottlenecks in the transmission system within the Nordic region or between the Nordic region and other countries or other limitations like requirements for minimum production etc.

The future flexibility

In the future, the flexibility of the Nordic system can change as a result of various factors:

- Changes in the hydro power system like increase of production capacity or installation of pumping.
- Changes in capacity for other sources than hydro power. Substantial increase in wind power production in the Nordic region will require more short term flexibility (within the hour and in a few hours perspective), but will increase the available energy in the system.
- Increase in transmission capacity both within each Nordic countries and between the Nordic region and other European countries.
- Major changes in the Nordic electricity demand, e.g. increase due to the large-scale electrification of transport or decrease because of large-scale deployment of heat pumps in regions where electricity is used for heating.
- Changes in demand or production because of climate changes

As described in Figure 19 Norway has about 30-35 TWh of hydro power potential which is not already developed or not protected. About 16.5 TWh are categorized as small power stations with probably limited ability for regulation. Thus about 11-18 TWh could be developed and contribute to increase of the flexibility. As an example 14 TWh with a use of 4000 hours per year requires a capacity of 3500 MW. As described in the sections **Error! Reference source not found.** and **Error! Reference source not found.** it is not likely that a substantial increase of the hydro power capacity in the Swedish and the Finnish systems will be possible in the next years.

The existing production could be upgraded with increase of production capacity. As described in chapter **Error! Reference source not found.** the Norwegian regulator has done a rough calculation for the potential and estimated it to be about 16 500 MW in Norway where about 11 500 MW is located in the south and east parts of Norway. In the potential for upgrading described in Figure 2 and Figure 19 there is also 6.5 TWh partly resulting from upgrade of existing hydro power production. These capacities may be (partly) overlapping with the estimates from NVE.

There is very limited documentation of the potential for installation of pumping capacities. As described in chapter **Error! Reference source not found.**, Statkraft has estimated it to be about 10 – 25 000 MW in the south of Norway. The only estimate found from Sweden is the possibility of pumping between Vänern and Vättern and the installation of 50 000 MW capacity. It is a huge volume, but since it is not found included in any political document from Sweden it must be considered to be discussions or ideas at the moment.

At the completion of this report, a recent study appeared [42] where the potential of increased hydro capacity in Norway is further refined based on some of the above restrictions. It is found that an increase of 18.2 GW is feasible through a combination of pumping and expansion upgrades in 13 existing plants.

7 SCENARIO ANALYSIS OF HYDRO POWER POTENTIAL

As has been discussed above, the potentially available hydro production within the Nordic system can add more flexibility to the production portfolio in the Continental European system. It is anticipated that the need for production flexibility will increase because of increased production uncertainty due to rapid expansion of renewable energy resources such as wind energy. Future increase of large wind power production, especially from offshore wind in the North Sea, will require more production flexibility in the countries across the North Sea. Production flexibility can guarantee the real-time balance and hence, reliable and secure operation of the transmission grid in the power systems. However, use of Nordic hydro power to balance wind power variations requires available transmission capacity on the corridors between the Nordic system and the other Power systems system across the North Sea.

In task 16.2.3 and 16.2.4 incremental scenarios of the potential increased hydro production in the Nordic system will be defined. The effects on the grid utilisation and economic impact will be investigated. Table 21 and Table 22 show the hydro potential input to tasks 16.2.3 and 16.2.4 scenarios. Table 21 represent the incremental hydro potential scenaros in 2020, while Table 22 shows the potentials in the year 2030. Scenarios presented in report D6.2 in reference [43] will be used as the reference scenarios for the mentioned incremental scenarios.

The incremental scenarios in Table 21 and Table 22 are based on expected hydro production development, and they are divided into two categories – "most likely" and "optimistic" following the division of offshore wind scenarios developed in task 16.2.1, where wind scenarios are divided into two categories: "most likely" and "optimistic".

Production dispatch will be limited by assumed production capacity and transmission capacity for each scenario investigated. The simulation work in tasks 16.2.3-16.2.4 will investigate the optimal output power of generators, the flow on transmission lines within and between the countries, utilisation of the grid, operating cost of power production and economic impact for the different scenarios considered.

Table 21 Incremental Hydro Potential Scenarios in 2020

Countries	Maximum increased hydro potential (GW)	Scenario 1		Scenario 2	
		Most likely	Optimistic	Most likely	Optimistic
Norway	10	5	10	5	10
Sweden	10	0	0	5	10
Finland	0	0	0	0	0

Table 22 Incremental Hydro Potential Scenarios in 2030

Countries	Maximum increased hydro potential (GW)	Scenario 1		Scenario 2	
		Most likely	Optimistic	Most likely	Optimistic
Norway	20	10	20	10	20
Sweden	20	0	0	10	20
Finland	0	0	0	0	0

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EC-GA nº 249812
Project full title: Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions

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