ETH ZURICH

# The Green Battery of Europe

## Balancing renewable energy with Norwegian hydro power

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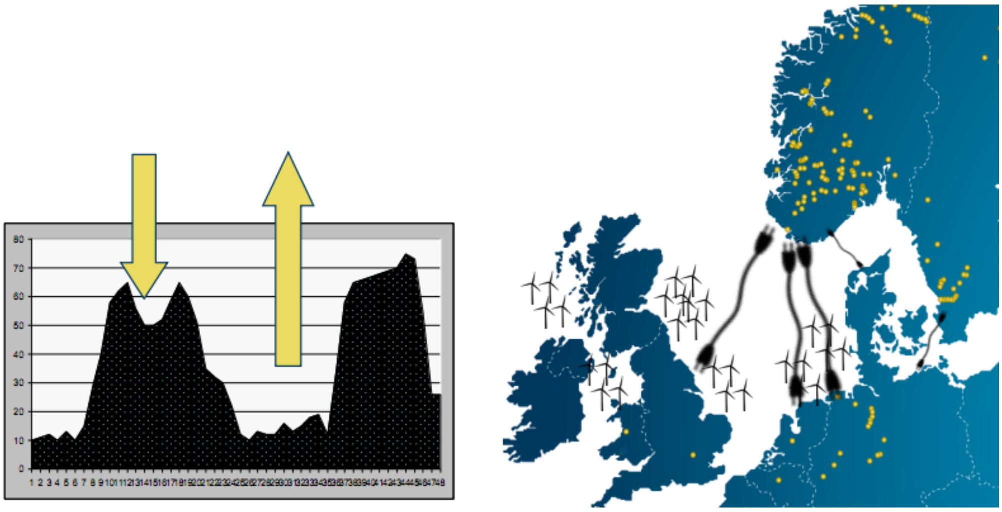
This paper investigates Norway's potential for becoming the Green Battery for Europe with both the benefits and constrains this result in. It takes a closer look at wind power production in Germany to assess certain aspects of pumped hydro storage. Finally, it concludes on whether or not Norway should become the Green Battery of Europe.

# Contents

# Introduction

Making the world's longest subsea transmission cable and beating their previous Guinness world record. The Norwegian grid owner and operator Statnett have big plans for the future. They want to expand the connection between Norway's hydro power and Europe with 6,100,000 kW. Several issues must be untangled: how will this affect power prices and security in supply? Will the grid projects be profitable? Why should Norway be chosen as a Green Battery? What do the politicians say? Is the hydro capacity in Norway big enough?

Many challenges arise when Europe is increasing their share of renewable energy. One important aspect is how to balance power supply with demand. As Norway is identified as the best hydro battery in Europe, this report investigates the benefits and challenges that arise in order to realize the idea of Norway – "The Green Battery of Europe".



## Rationale for renewable energy: EU's 20-20-20 targets

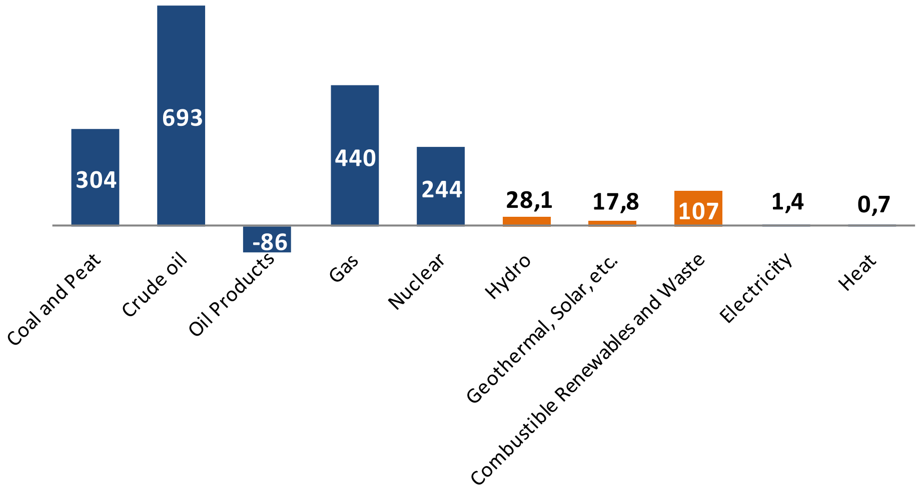
Renewable energy is a hot topic since the world is facing serious challenges in concerning climate change and emissions. In November 2010 the EU Heads of State set a series of demanding targets for energy and climate that is to be met by 2020, also known as the "20-20-20" targets (ec.europa.eu):

- The greenhouse gas emissions should be reduced by 20 % compared to 1990 levels
- 20 % of EU's energy consumption should come from renewable sources
- A 20 % reduction in primary energy use by increasing the energy efficiency

This is good news for the environment, but also challenging to realize in practice. Currently EU's total primary energy supply of renewable energy is only 8.8 %, whereas 5.5 % is from wind power.[1]

[1] TPES used as comparison since TFC is after conversion to electricity, and does not identify the renewable energy sources.

**Figure 1: Total Primary Energy Supply in EU in 2008; Mtoe (IEA)**

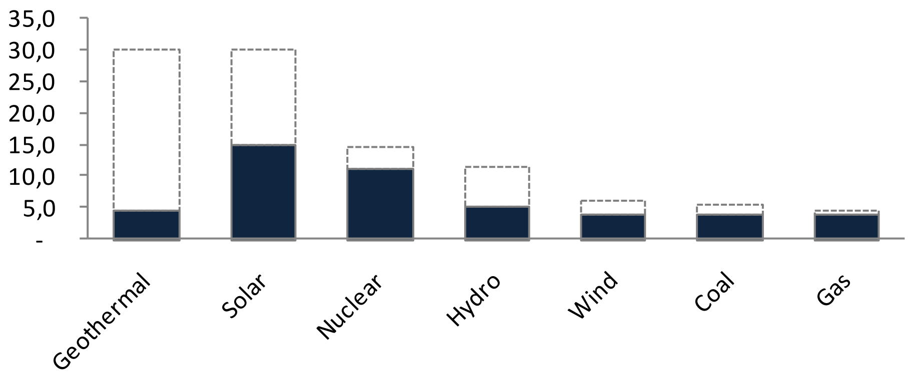



Several countries have developed renewable energies for years in effort to cut their emissions. Between 1995 and 2010 EU's investment in renewable energy has grown by ~17 % per year (vindkraft.no). Although renewable energy can help solving the climate challenge, there are several complications to the future development.

## Complications with renewable energies

Renewable energy is more expensive than the traditional power from fossil fuels. As the production, installation and operation of renewable energy technologies are becoming more efficient, their prices are increasingly more competitive.

**Figure 2: Cost for different energy sources; upper and lower range; cents/kWh (coldenergy.com)**



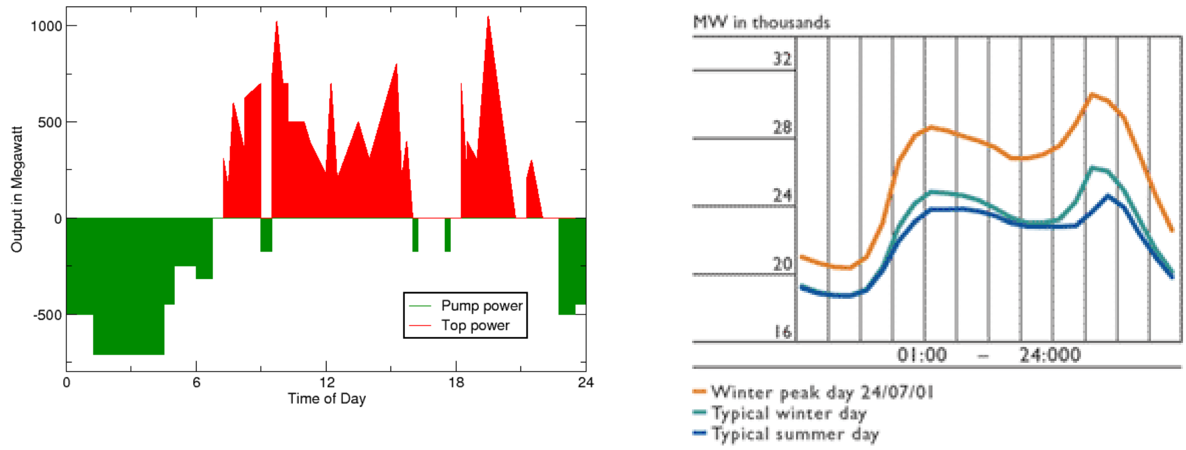

Price is not the only concern. Renewable energy sources have a stochastic element tied to them. It is hard to predict when the wind will blow and with what speed, and when the sun will shine and give us solar power. To make things even more difficult the demand for power also varies with time of day and time of year. The net effect is an unpredictable supply and a variable demand. In order to secure supply, especially in peak demand, we need to access other power sources quickly. Gas power plants are frequently used because they have a fast response time and a quick start and stop. Hydro power possesses the same properties, and in contrast to gas power plants it is also environmental friendly.

Since power is fed directly into the grid, overproduction of renewable energy is another concern. The ideal solution would be to store this energy. Pumping water back to the hydro reservoir could function as a battery, and power could be accessed at a later point by releasing water. Hydro reservoirs as a storage solution have gained trust and recognition the last years in light of increasing renewable energy production. This idea leads to the idea of Norway as Europe's Green Battery because of their large hydro storage potential.

## EXPLANATION OF THE GREEN BATTERY CONCEPT

The Green Battery concept is simple: excess electricity production is transported to a hydro power station that pumps water back to the reservoir. When demand exceeds supply, the reservoir lets water flow into the turbine which generates power and sends this back to the market. The variable elements in renewable energy production *and* in energy consumption are netted out. The idea of a green battery is illustrated in figures 3 (coal2nuclear.com, eskom.co.za).

**Figure 3: Output from a hydro power plant (left); typical demand curve for electricity (right)**



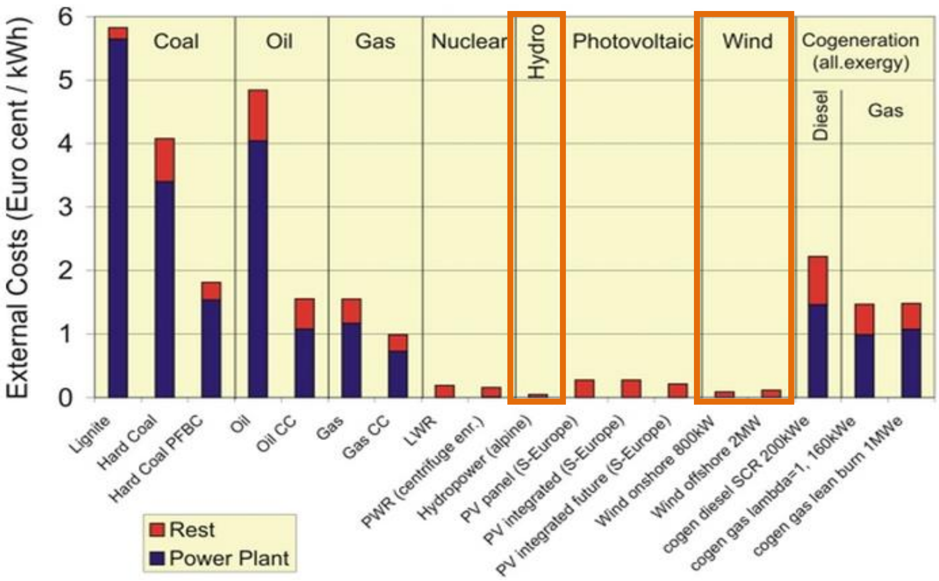

These figures have similarities in the sense that the hydro output mimics the demand curve. The real beauty behind this concept is that the mixture of renewable energy together with hydro storage not only secures supply; it is also 100 % green. "Wind and hydro makes one of the most perfect renewable electricity generating systems ever devised". (coal2nuclear.com)

# NORWAY AS EUROPE'S GREEN BATTERY – POTENTIAL AND LIMITATIONS

## HYDRO POWER

Hydro power is the most common of all renewable energy sources covering ~14 % of the global electricity demand. Advantages of hydro power is that is has no cost of fuel and virtually no CO2 emissions. There are some emissions during manufacturing and construction, but these are a fraction compared to the fossil fuel electricity generation. A study conducted at the Paul Scherrer Institut and the University of Stuttgart compared all energy sources in terms of greenhouse gas emissions and externalities. This showed that hydro electricity generation was the best alternative, followed by wind (Project ExternE-Pol, Paul Scherrer Institut [2005]).

**Figure 4: External costs from different energy sources**

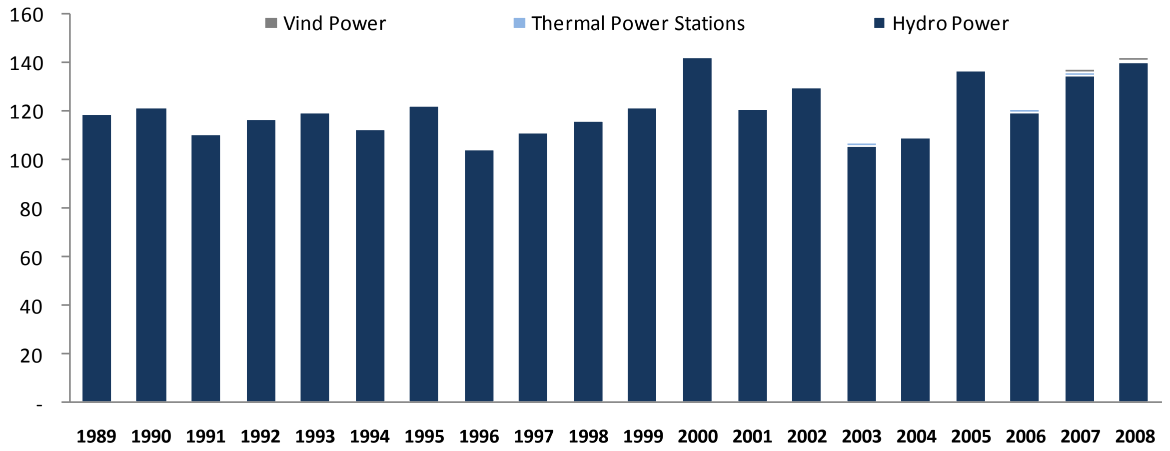



Hydro plants have a long economic lifetime and some plants are still in service after 50-100 years. Normal operation requires few workers, and operating costs are low. The obvious constraint to further development is demography, and in most parts of the world the hydro power potential is already exploited. Disadvantages with hydro power are that the large reservoirs required for operation can damage the ecosystem, and that the investment costs can be substantial. Periods of low inflow of water can lead to a power shortage in areas that are highly dependent on hydro power.

## HYDRO IN NORWAY: CAPACITY AND CONSTRAINTS

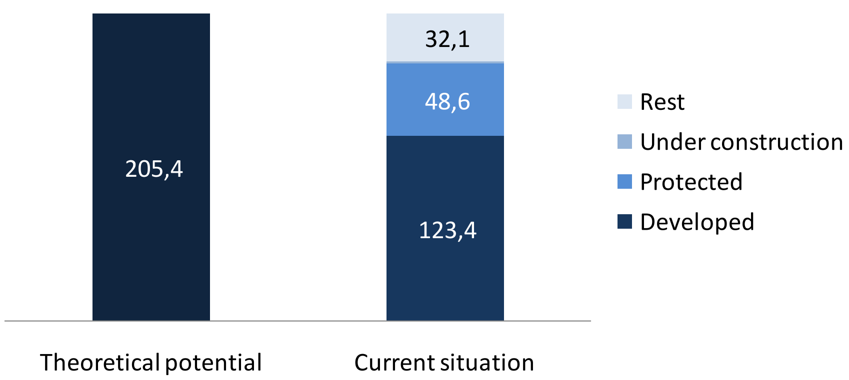
Norway is the sixth largest hydro power producer in the world, and the largest in Europe. Almost 50% of Europe's reservoir capacity is located in Norway (newton.no). In 2008 hydro power accounted for 98.5% of Norway's production of electricity.

**Figure 5: Production of electrical power in Norway; 1989-2008; TWh (Statistisk Sentralbyrå)**




While the total potential for hydro power in Norway is large, there are several constraints for the future development. Most large reservoirs are already in use, and the smaller hydro power plants have a low profitability. Certain reservoirs are also protected by NVE[2]. Current status allows only for smaller hydro power plants.

**Figure 6: Hydro power potential in Norway in 2010; TWh (Statistisk Sentralbyrå)**




Currently 123.4 TWh of hydro power have been developed. Maximal available effect from hydro power in the winter is about 25,000 MW, which is lower than the installed effect due to variation in inflow of water to the reservoirs, maintenance and other factors (NVE).

[2] The Norwegian Water Resources and Energy Directorate

Statkraft, the Norwegian state-owned energy company, quantified the potential for pumped storage capacity in southern Norway in a recent study (cedren.no).[3] Pumped storage means that the energy companies must manipulate the reservoir levels and the time that water is stored in the reservoir. The potential calculated by Statkraft depends on how soon energy companies are allowed to do this. Their estimations show a 30 GW potential if the reservoir levels can be manipulated up to 50 cm/hour and with discharge over five days. If the regulations are stricter, and changes in reservoir levels are limited to 1 cm/hour, the capacity is reduced substantially to 3.2 GW. These estimations are in disregard of future reservoir developments.

## GRID SITUATION NORWAY-EUROPE: CURRENT AND FUTURE

In September 2010 Statnett opened a new EU office in Brussels. Their aim is to be closer to the developments in EU's energy policies and to promote Statnett's expertise. In addition they aim to promote Norway as the Green Battery for Europe. Statnett will play a key role in EU's energy policy by linking the Norwegian electricity grid to Europe. This will allow for trade of clean hydro power to Europe and renewable power from wind and solar to the Norwegian hydro batteries. New infrastructure and market improvements are essential to achieve this (Statnett.no). Statnett have announced ~40 BNOK in investments on the Norwegian national grid up to 2020 (Dagens Næringsliv [2011]).

**Figure 7: Statnett's current and planned cable developments (Statnett.no)**

| Existing and approved cables | | | | Panned cables | | | |
|---|---|---|---|---|---|---|---|
| ***Name*** | ***Capacity*** | | ***Operational*** | ***Name*** | ***Capacity*** | | ***Operational*** |
| Skagerrak 1, 2 & 3 | 1 000 | MW | Yes | NORD.LINK/NorGer | 1 400 | MW | 2016-2018 |
| NorNed | 700 | MW | Yes | Tyskland 2 | 1 400 | MW | n/a |
| Skagerrak 4 | 700 | MW | 2014 | NorNed 2 | 700 | MW | 2016-2018 |
| Sum | 2 400 | MW | | NSN to UK | 1 400 | MW | 2017-2020 |
| | | | | Sydvestre Linken | 1 200 | MW | 2016-2017 |
| | | | | Sum | 6 100 | MW | |

Figure 7 show that Statnett not only had expansive plans earlier, but that their plans for the future are quite remarkable.

## EUROPEAN RENEWABLE ENERGY RELATED TO NORWAY

Due to the 20-20-20 targets, Europe is rapidly stepping away from the reliance of fossil fuels towards energy from renewable sources, wind and solar in particular. When looking at Norway's Green Battery potential, not all renewable energy production in Europe is relevant. This is because the transport costs and energy losses increases the further away from Norway we get. Sweden, Denmark, England, Scotland, Netherlands and Germany are the most relevant sources for renewable energy storage. Germany was the first country to develop scenarios for how Norwegian reservoirs could balance the renewable energy production. England and Scotland are also planning on constructing numerous large-scale offshore wind farms, which means that they are in critical need of balancing power through storage. In fact, a recent study from the UK identifies Norway as the preferred solution to this problem (cedren.no).

[3] Centre for Environmental Design of Renewable Energy

## Norway's Green Battery Potential

Tom Nysted, CEO of Agder Energi, claims that more transmission lines abroad is needed because Norway will have 25-30 TWh in excess power in few years (Agder Energi; ae.no magazine [Dec. 2009]). This is due to a declining Norwegian consumer demand, that the industry has reduced their consumption considerably and that the weather is expected to become even wetter. A scenario from Thema Consulting backs this statement, and states that the Nordic region would have a power surplus of 45 TWh per year in the near future because of renewable energy developments. Without new cables, 25 TWh can be lost in a wet year. Let's assume that Nysted is correct and see where this leads us.

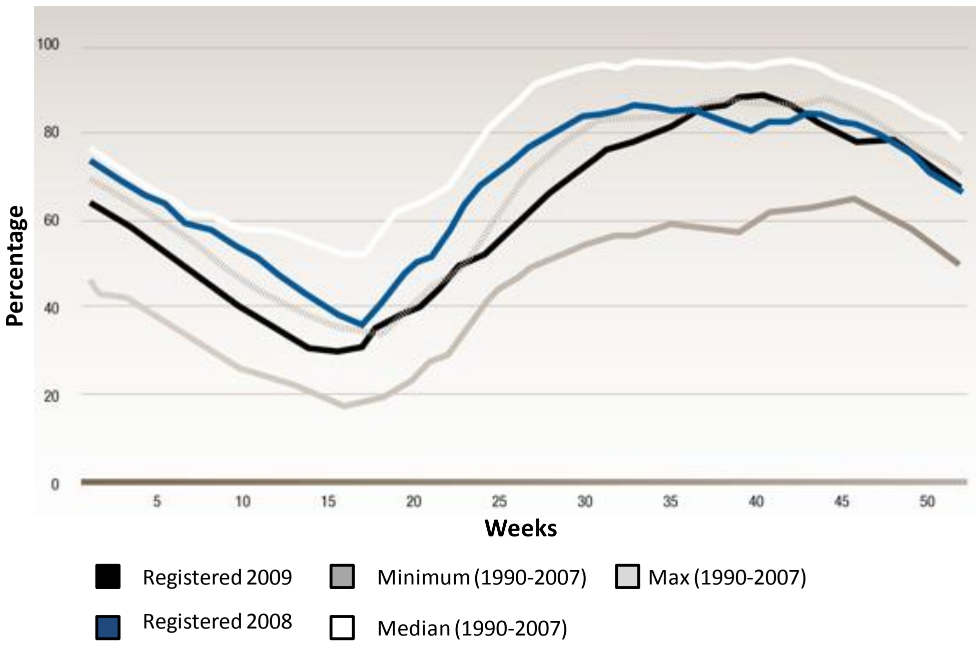
With 123.4 TWh of developed hydro power and 25,000 MW in maximal effect we get a utilization of 4,936 hours per year. Most hydro power plants in Norway have an average usage of 3,500-5,000 hours per year, and since maximal effect cannot be utilized the whole year we assume 4,380 hours of usage per year (50 % of the year).

**Figure 8: Excess production scenarios**

| | Low | High |
|---|---|---|
| Excess power (TWh) | 25 | 30 |
| Utilization (hours) | 4 380 | 4 380 |
| Capacity (GW) | 5,71 | 6,85 |

This case does not include importing cheap wind and solar power. With the accumulated grid capacity to Europe of ~8.5 GW in 2020 there is still room for importing and exporting more power. In order to assess this, we need to investigate the constraint in hydro storage. Norway has Europe's largest hydro storage potential of 84 TWh, but the water magazines are not fully utilized the whole year.

**Figure 9: Filling of reservoirs in Norway per year as percentage of full capacity (NVE)**



Keep in mind that the storage potential has seasonal variations. The peaks in water levels would likely normalize to a certain extent when power is exchanged to Europe. From figure 9 we see that the current situation allows for an increase in net imports to store in the reservoirs.

The total storage potential of 84 TWh is the maximum amount that can be stored in the reservoirs. With an increase in trade the reservoir level could be regulated up and down, and we could fill the reservoirs several times. With today's 123.4 TWh in production and 84 TWh in maximum reservoir capacity the reservoirs are filled 1.47 times per year. Let's assume that this can be doubled by regulating the reservoir levels with trade. This implies that discharge and inflow of water to the reservoir must be doubled as well. The utilization must still be ~50% because the water pipes must be used for pumping at night, which excludes production. The remaining 50 % of the year is therefore assumed to be dedicated to pumping. The result is a doubled production of 246.8 TWh, or approximately 50 GW. However, not all of this is suitable for storage for other countries as Norway will need much of the capacity themselves.

This is a high case where the water levels in the reservoirs are severely manipulated. The current maximal effect of 25 GW is restricted by laws that regulate the discharge and inflow of water from the reservoir in order to protect the ecosystem. If these regulations are less strict in the future and power producers can manipulate the filling of reservoirs up to 50 cm/hour, the hydro storage potential would be 30 GW[4] (Statkraft.no). In addition NVE has additional 10 TWh of hydro power planned (Teknisk Ukeblad [2011]).

CEDREN states that the first 10 GW of transmission capacity does not require any expansion of pumped storage power in Norway. This means that the current pumped storage potential for countries outside Norway to store power in Norway is around 10 GW.

In order for Germany to achieve their 2050 targets they need to store 25 GW. They already have 6.4 GW with the potential to add 2.5 GW, which means that they need 16.1 GW (circleofblue.org). Today's wind resources in Europe amount to 80 GW and are expected to increase rapidly up to2020 (EWEA).

We have observed that an overproduction is likely to occur in Norway the coming years. In addition, the grids in 2020 can handle more transport of power in excess of this overproduction. The current situation for reservoirs also allows for a net import of power to the hydro reservoirs. The hydro storage in Norway for countries besides Norway is assumed to be around 10 GW by CEDREN. When power is traded we could manipulate the hydro reservoir levels to a certain extent and obtain a hydro storage potential of 30 GW. This allows for Germany to store their need for balance power in 2050.

On a long term basis it will still be necessary to increase the installed effect to meet the demand from other European countries as well. We should keep in mind that hydro storage capacity can also be gathered from neighboring countries in the Nordic region. Still, further investment in grids and pumped storage facilities in Norway would be required, and the regulations in manipulating water levels in reservoirs must become less strict.

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[4] Applies only for the south of Norway as this is the most relevant area for hydro storage

# NORWAY AS GREEN BATTERY – THE CASE OF GERMAN WIND POWER

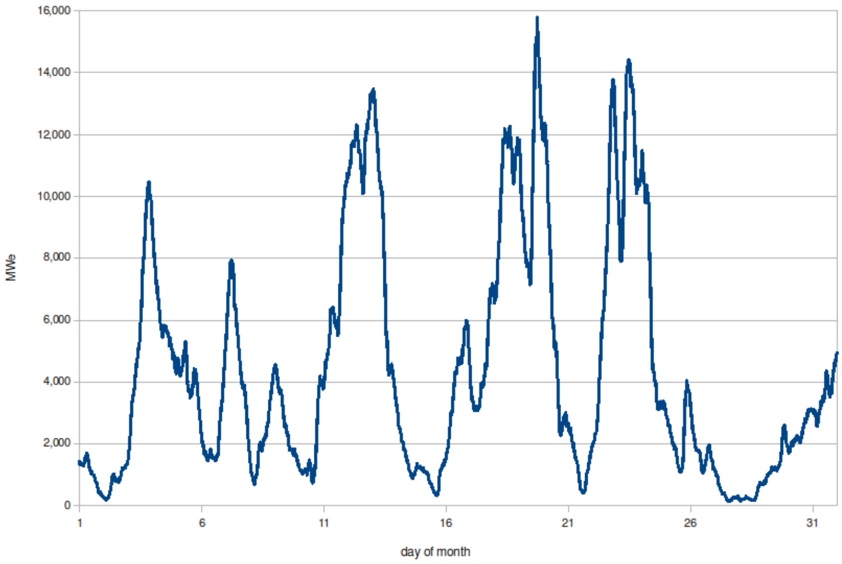
To better understand certain aspects of the Green Battery concept we will here closer look at Germany. Their wind power production is fairly close to the Norwegian south coast, and Norway is rich in hydro power with the best hydro storage potential in Europe.

## GERMAN WIND PRODUCTION AND CONSUMPTION

In 2009 Germany had an installed wind capacity of ~26 GW, and they plan on further developing their base of renewable energy sources to ~55 GW in 2020 (wind-energie.de). A recent report by the German Advisory Council on the Environment discusses the possibility for Germany to have 100% renewable electricity in 2050. Today electricity stands for ~40% of Germany's total emission of CO2, and they plan to increase their base of renewable energy in wind and solar power to meet their goal (SRU: Climate-friendly, reliable, affordable: 100 % renewable electricity supply by 2050 [2010]).

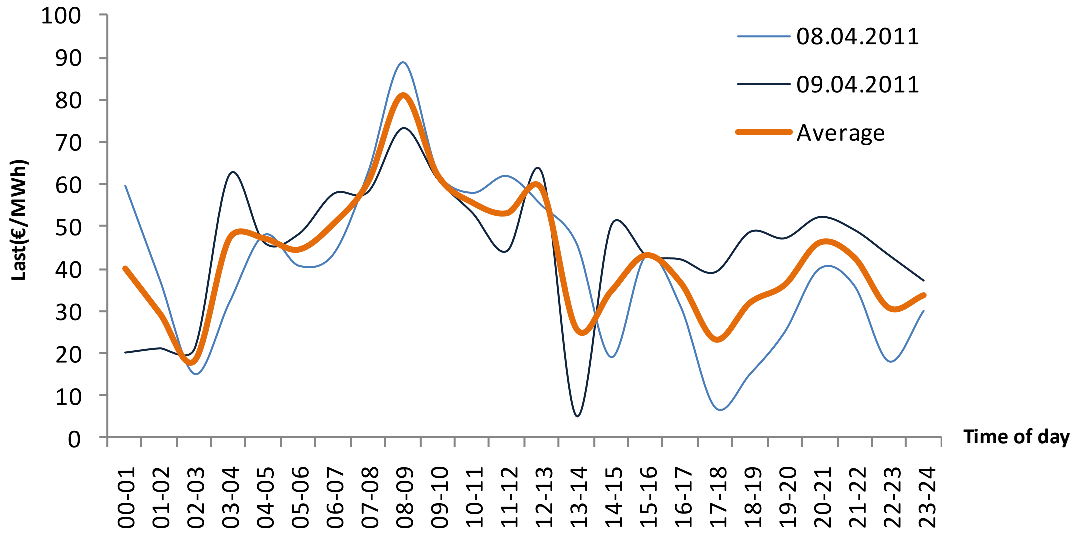
Since the wind power generation in Germany is unpredictable the report states that the main challenge is to balance load in order to achieve a reliable, low cost supply of electricity.

**Figure 10: Wind power production in Germany, January 2010; MWe (coal2nuclear.com)**




The German demand for electricity also varies a lot during the day and in different times of the year.

**Figure 11: Demand for electricity; selected interval for Germany in 2011 (eex.com)**




The variation in demand together with the unpredictability in wind power generation makes it difficult for Germany to reach their goal of 100% renewable electricity by 2050 without power storage. Even today there are difficulties with balancing the generation to meet demand. In order to achieve their goals they need more grid connections to the Denmark-Norway energy network, which will give them access to the Scandinavian pumped storage system. Norway would be used as a Green Battery to store wind and solar power which would be fed back to them during peak demand periods to ensure stability.

## Why Norway?

The report from SRU presents several scenarios. The solution with grid connections to Norway and Denmark is preferred because it is a proven low-cost system with low energy losses.[5] They conclude that other solutions would have much higher costs than the pumped storage solution, even after the competing technologies become commercially available.

Other locations for hydro energy storage were considered, such as Austria and Switzerland, but Norway was the most feasible location since the wind parks are located in the North of Germany. In addition Norway has about 50% of Europe's total hydro reservoirs (newton.no), and there are numerous water systems in Norway that are available for conversion into pumped storage systems. This could be done at relatively low cost and with low ecological impacts. Norway has a storage potential of 84 TWh which is huge compared to the German storage potential of 40 GWh – only 0.05 % of Norway's potential (cedren.no).

[5] The pumped storage system has a net energy loss of 20-30 %, but is still more efficient than available alternatives (circleofblue.org).

## Competing hydro batteries technologies

The SRU report also looked at other storage alternatives. On second place after hydro storage in the Nordic region they identified compressed air energy storage (CAES). This technology compresses air to underground salt caverns to store energy, and such salt caverns are quite common in places where wind power is produced. However, with the best performance the minimum costs of this technology are ~EUR 1,000 per kW – about the same as for pumped storage power. In addition this technology will not be commercialized until 5-10 years and the cavern walls will be in danger of collapsing due to the high air pressure.

Producing hydrogen with the excess power generated is another technical solution. Hydrogen can later be used to generate power, but this method is more costly with low energy efficiency. Further grid developments in Europe can also be used to balance power. This implicates a liberalized electricity market, which the European Commission is currently working on. Thermal power can also be used to adjust the supply-demand differences (cedren.no).

## Norway's grid developments towards Germany

A recent study by Thema Consulting and Econ Pöyry indicates that laying more cables between Norway and Germany would be profitable, but only up to 8 GW of capacity. This differs substantially from SRU's estimate of 42 GW (cedren.no).

Statnett has planned three new cables to Germany: Nord.Link, NorGer and Tyskland 2, all with 1,400 MW capacities. Nord.Link and NorGer are both owned by Statnett with a share of 100% and 50%, respectively. It is still unsure if both of these cables will be built. Both are applying for licensing in Germany, but Nord.Link has recently entered the second stage of the German licensing process while NorGer is only in the first. OED[6] manifests that there are only room for one of these projects on a short-term basis until 2020, and this statement is shared by Statnett. Lyse Energi and Agder Energi each own a 16.6 % share in NorGer, and are both energy producers. Therefore both OED and former Norwegian Energy Minister Terje Riis-Johansen prefer Nord.Link over NorGer since a commercially cable such as NorGer will primarily make profits to the owners of the cable. It is not preferred that energy producers also have stakes in transmission grids (Teknisk Ukeblad). Nord.Link on the other hand will be a regulated cable where profits will be returned to consumers through reduced tariffs.

Currently the NorNed cable to the Netherlands puts Statnett in Guinness Book of Records for the longest subsea transmission line in the world with a total length of 577.5 km (Statnett.no). Both NorGer and Nord.Link would beat this record with their length of 600 km. To analyze the profitability for Norway in these kinds of projects we will take a closer look at the Nord.Link project, since this seems most likely to be finalized.

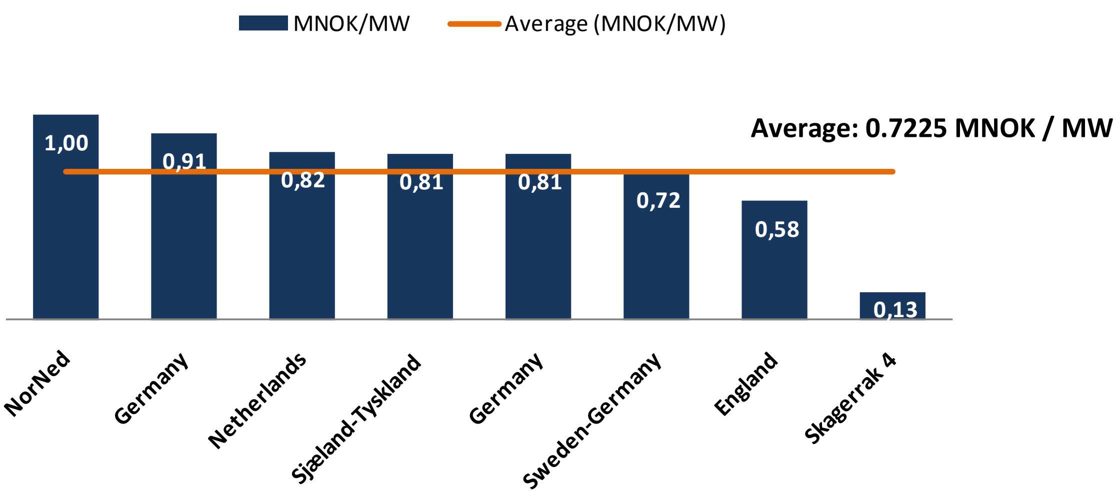
[6] Olje –og Energidepartementet (Department of Energy and Oil)

## WILL NORD.LINK BE A PROFITABLE PROJECT FOR NORWAY?

The high voltage DC transmission cable Nord.Link has a planned transmission capacity of 1,400 MW and length of ~600 km. This corresponds to the capacity of almost four offshore wind parks. Currently there are four such parks being planned for construction on the coast of Schleswig-Holstein in Germany, each with a capacity of 400 MW. Nord.Link is scheduled for completion in 2016-2018 with a projected cost of ~NOK 12 billion (Statnett.no).

Profits on the cable will return to the consumers through reduced tariffs; however it is still interesting to see how profitable such a project would be. The earnings of this project are the price difference for every hour multiplied with the exchanged volume between Germany and Norway. This is difficult to predict, and in this model we therefore use the simplification of comparing revenues with previous cable projects to Europe (Statnett.no: NorNed [2004]).

**Figure 12: Yearly trading income per MW installed capacity; $NOK_{2004}$**



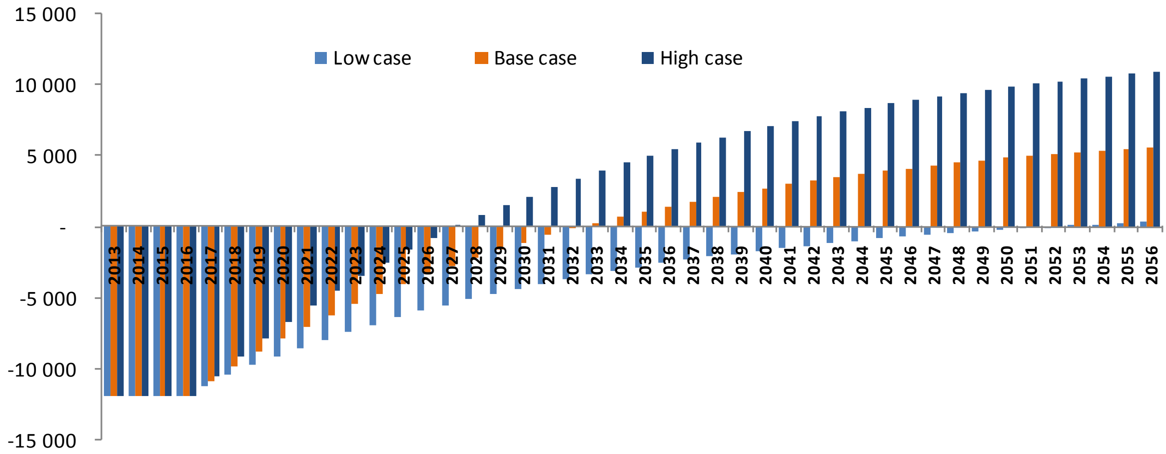

In the model we assume that the project will start construction in 2013, and that the stated construction costs of 12 BNOK are the present value of the total construction costs occurring in 2013. Statnett states that the cable will be operational in 2016-2018, so it is assumed that transmission starts in 2017. If we adjust the average yearly trading income per MW up to 2017 with a 2.5 % inflation rate (norges-bank.no), this makes a yearly average of 0.9959 $NOK_{2017}$/MW in trading income. Considering the Nord.Link capacity of 1,400 MW, this gives a yearly trading income of 1,394 MNOK. Future spot prices are very uncertain, and to account for this variability there is a low-, base- and high case scenario in this model, with trading income varying with ± 30 %. Furthermore, we assume that Statnett's discount rate is 6 %, which is the recommended risk adjusted discount rate for investments in network investments proposed by NVE (Statnett.no: NorNed [2004]). The cable is assumed to be operational for 40 years – the same as expected in NorNed (Statnett: Kabler til utlandet – muligheter og utfordringer [2010]). Hence will the calculations reach from 2013-2056 since construction is expected to take four years and 2013 is year zero. The detailed calculations can be found in the appendix, and the general results are shown in the table below.

**Figure 13: Profitability for Nord.Link with different scenarios**

| | Results | | |
|---|---|---|---|
| ***MNOK*** | ***Low case*** | ***Base case*** | ***High case*** |
| Investment costs | 12 000 | 12 000 | 12 000 |
| PV incomes | 12 331 | 17 615 | 22 900 |
| NPV 2013 | 331 | 5 615 | 10 900 |
| IRR | 6,18 % | 8,72 % | 10,90 % |
| Payback time (years) | 39,2 | 19,4 | 14,0 |

These results only include trading income and investment costs, and do not include the total social economic benefits or maintenance and repair costs. However, these numbers still tells us that such a project would be quite feasible.

**Figure 14: Payback time for the different scenarios; MNOK**




There are several uncertainties in projects like this, and calculating the economical benefits is not straight forward. Nonetheless, even the low case of -30% in revenues makes this project worthwhile. Another interesting aspect is that the average yearly trading income per MW derived from the previous projects has a clear outlier, namely "Skagerrak 4" (figure 12). By removing this, the base case NPV equals ~7.7 BNOK with an internal rate of return of 9.61 %.[7]

In order to verify if these results are plausible, we can compare them with NorNed. This project had an internal rate of return of 16 % (Statnett: Kabler til utlandet – muligheter og utfordringer [2010]), but did also have the largest yearly trading incomes per MW in figure 12**.** If we use 1 $MNOK_{2004}$/MW in Nord.Link as well, we get an IRR of 11.5 %. Considering that the total social economical benefits are not included in our model, the results seem plausible.

Another rough test tells us that NorNed had 600 MW installed capacity[8] with a total NPV of ~2 BNOK, which leads to a surplus of 3.3 MNOK/MW installed. Nord.Link has 1,400 MW in capacity and a NPV of ~5.6 BNOK, which gives us 4.0 MNOK/MW installed. Again, there are some costs and benefits not

[7] Yearly trading income in 2004 equals ~0.81 MNOK/MW with this adjustment
[8] Note: capacity for the transmission lines varies from different sources. This source tells that NorNed has 600 MW in capacity while other sources state that the capacity is 700 MW.

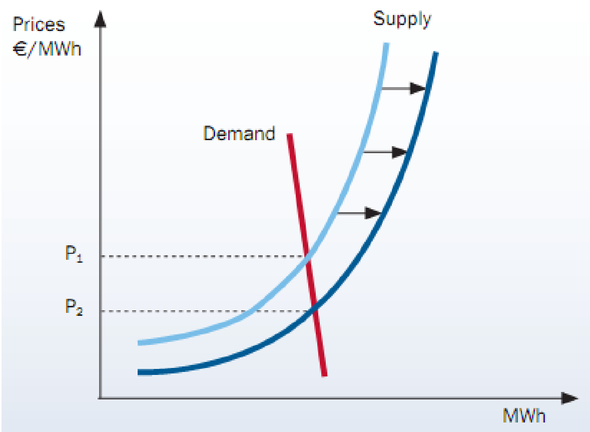
included in our model, so the cases are not fully comparable. But this rough test tells us that our results are in a probable range.

One of the benefits and intentions with this project is that price differences between Norway and Germany should decrease over time, and that the prices will be more stable for both countries. This means that the yearly trading income will be reduced over time as well. In this model this effect is not accounted for. But since this effect will come many years after the cable is operational, the present value effects of this decline is expected to have a small effect on the NPV. The low case scenario will probably take the full effect of this decline into account.

## Social economical benefits for Norway and Germany

Analyzes performed by Statnett shows that the social economical benefit from this project will be very satisfactory. With a surplus on the project, they expect that the Norwegian central net could be upgraded. The increase in renewable energy production will give an increase in supply. Looking at this problem from a micro economical point of view, electricity prices are expected to decrease as an effect of this since demand is quite inelastic.

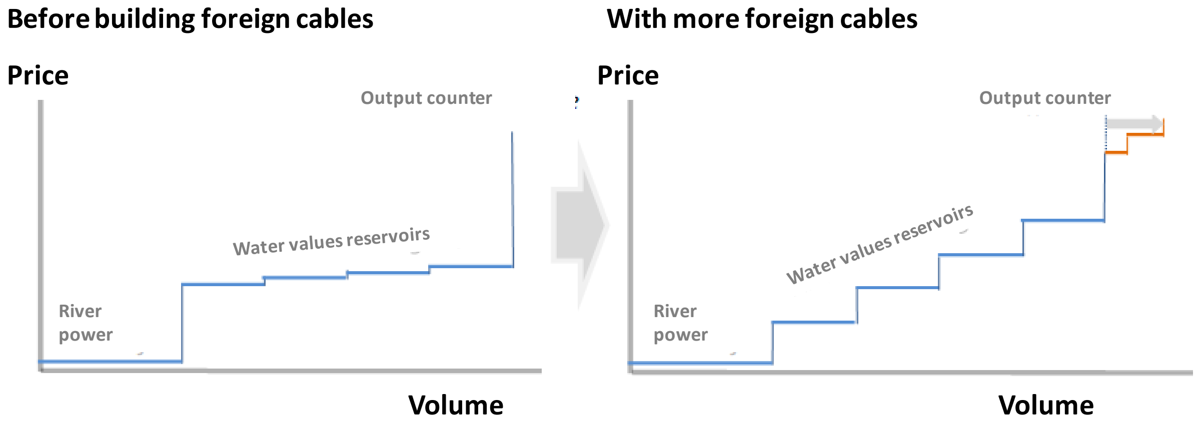
**Figure 15: Typical supply and demand curves in wind energy capacity increase (EWEA)**




Export during the day will give higher prices in Norway, and import during the night will give lower prices in Norway. Statnett's analysis shows that the effect on average prices for Norwegian consumers will be quite limited, and that a likely increase in Nordic power prices will be below 1 øre/kWh[9]. The main reason that prices do not decrease as depicted in figure 16 is that exports will be substantial. Statnett also impose that Nord.Link will give an improved supply of power, and opportunities to balance the Norwegian and German power markets. Currently the prices in both Germany and Norway are quite volatile; Germany because of uncertainty in wind power generation and Norway because of uncertainty in inflow of water to the reservoirs. Over time projects like this will lead to more stable prices, and the safety of supply will be enhanced (Statnett.no).

[9] ~0.125 cent/kWh in Euros

**Figure 16: Foreign cables will stabilize electricity prices in Norway as the supply curve evens out**




Through this project Germany could further develop their efforts in renewable energy, both for wind and solar, and their chances of reaching their 100 % renewable electrical power by 2050 is enhanced. This seems to be a win-win situation for Norway and Germany. But it's more than that; rather a win-win-win situation as this solution is 100% green and the environment wins as well. These types of projects are expected to give value creation in both ends of the cable due to an increase in employment when the cable is under development and when the cable is installed (agderenergi.no).

## VIEWS ON NORWAY AS EUROPE'S GREEN BATTERY

In December 2010 representatives from CEDREN visited key German researchers and representatives to enhance knowledge of balancing power and the concept of the Green Battery. The conclusion from the workshop was crystal clear; Norwegian hydro power could play a vital role in Europe's path in becoming powered by renewable energy (cedren.no). The visit was motivated by the fact that many Norwegian energy companies already is playing with the thought of themselves as Green Batteries (politikkavisen.no).

Norway consists of many local communities which have been accustomed to the traditional hydro power generation, namely that hydro reservoirs are drained during the spring and then filled up during the winter. Pumped storage power is a completely new way of running the hydro power system in Norway, and involves variation in the reservoir levels at all times of the year. Studies indicate that pumped storage might give higher reservoir levels on the average, and that the reservoirs will be filled earlier in the spring because of a surplus of wind power in the winter and autumn. Changes in the current system may damage Norwegian ecosystems and will require political and public acceptance. Recently there have been heated debates concerning overhead lines across the beloved Hardangerfjorden in Norway. This shows that changes in the ecosystem are a sore subject to the Norwegian public.

The Green Battery will have several positive aspects for Norway. Power supply is expected to stabilize and power prices are expected to stay the same. As seen in the case of Nord.Link, the economical benefits are likely to be substantial and gain the consumers in terms of lower tariffs. Although grids, especially in the south of Norway, needs to be upgraded, this will be beneficial for the public and can be financed by the surplus from foreign grid developments. The surplus could also be used to keep the energy prices from rising by subsidies. The cable projects will give a higher employment both during and after construction. In addition Norway would be supporting the renewable energy developments in Europe. If the public can overcome the negative aspects associated with the possible damages to the ecosystem, they could harvest many benefits.

It seems that the Norwegian politicians are positive to the Green Battery concept. In January 2011 The Norwegian Prime Minister Jens Stoltenberg visited London, where the discussion of energy balancing was prioritized. His vision is a system where Norwegian hydro power is used as storage for European power. He also stated that in order to go for this concept it is important to assess in detail what consequences this will have (Trønderavisa [2011]). In addition, Stoltenberg said yes to the introduction of Green Certificates. This means that ~50 BNOK will be invested in wind power in Norway. Experts argue that this will lead to lower power prices, and increase the return to Norwegian hydro power producers. Hydro power could to a larger extent be exported, which support the Green Battery concept (Dagens Næringsliv [2011]). If the Green Battery concept is realized there are many parties in need of economical support: the municipalities, the energy companies and the grid suppliers to mention a few. How to fairly divide the economical benefits will be a challenge.

International grid projects are in some cases shared between the countries which mean that some of the benefits are shared as well. However, balancing supply and demand is the most essential aspect for the connecting countries. As seen previously in this report, several surrounding countries are in need of balancing power, and their view towards Norway as Green Battery is positive. For the future it is important that the EU, Germany and Norway come to agreements, and that they gain public acceptance for their plans. The debate has already started, and by the looks of the SRU report and Statnett's expansion plans towards 2020, the idea of Norway as a Green Battery is on its way.

# CONCLUSION

## POSITIVE ASPECTS EXCEEDS THE NEGATIVE ASPECTS

With a more secure and stabilized supply, small expected changes in the power prices, positive NPV of grid projects together with grid upgrades, lower tariffs and higher employment the Green Battery concept will be feasible for Norway. The connecting countries would get a stabilized and more secured supply and could further invest in renewable energies, increasing their chances of reaching EU's 20-20-20 targets. Hydro power together with wind has the lowest externalities and no CO2 emissions during operation. The damages on ecosystems in Norway would be compensated by the gains in renewable energy developments in Europe. Still, this is a sensitive area for the Norwegian public that requires further investigation.

## NORWAY SHOULD ACT FAST

The report from SRU recommends that the politicians in both Norway and Germany launch negotiations as soon as possible. Dr. Hohmeyer, professor at the University of Flensburg, believe that the German government will support the development of infrastructure for renewable energy in the short term.

If Norway waits, the risk associated to the grid projects could be lowered. Waiting gives the North Sea countries and the EU time to create multinational agreements that can lead to a more secure and larger investment market than the current one. If Norway waits too long competing technologies might catch up. The energy companies and Norwegian authorities can secure a competitive advantage by moving quickly. This means signing bilateral agreements with the European countries in need of storage capacities.

One problem that may arise is if Norway has enough pumped storage capacity to meet demand. But as seen earlier, CEDREN states that the first 10 GW of transmission capacity does not require any expansion of pumped storage power in Norway. With the planned grid development of 6.1 GW on top of the current 2.4 GW there is no reasons for why Norway should delay the process of connecting their battery capacity towards Europe.

The conclusion is that Norway is well positioned to become Europe's Green Battery in the short term up to 2020. In the long term an increase in installed effect will be needed in addition to new grid developments. This also requires less strict regulations in manipulating water levels in reservoirs.

# APPENDIX

**Figure 17: Detailed NPV calculations for Nord.Link (MNOK)**

| NORD.LINK | | | Incomes in trading | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Year* | *#* | *Annuity* | *Low case* | | *Base case* | | *High case* | |
| | | | PV | Accum. | PV | Accum. | PV | Accum. |
| 2013 | 0 | 1,0000 | - | - | - | - | - | - |
| 2014 | 1 | 0,9434 | - | - | - | - | - | - |
| 2015 | 2 | 0,8900 | - | - | - | - | - | - |
| 2016 | 3 | 0,8396 | - | - | - | - | - | - |
| 2017 | 4 | 0,7921 | 773,13 | 773,13 | 1 104,47 | 1 104,47 | 1 435,81 | 1 435,81 |
| 2018 | 5 | 0,7473 | 729,36 | 1 502,49 | 1 041,95 | 2 146,42 | 1 354,53 | 2 790,34 |
| 2019 | 6 | 0,7050 | 688,08 | 2 190,57 | 982,97 | 3 129,39 | 1 277,86 | 4 068,20 |
| 2020 | 7 | 0,6651 | 649,13 | 2 839,70 | 927,33 | 4 056,72 | 1 205,53 | 5 273,74 |
| 2021 | 8 | 0,6274 | 612,39 | 3 452,09 | 874,84 | 4 931,56 | 1 137,29 | 6 411,03 |
| 2022 | 9 | 0,5919 | 577,73 | 4 029,82 | 825,32 | 5 756,88 | 1 072,92 | 7 483,95 |
| 2023 | 10 | 0,5584 | 545,02 | 4 574,84 | 778,61 | 6 535,49 | 1 012,19 | 8 496,13 |
| 2024 | 11 | 0,5268 | 514,17 | 5 089,02 | 734,53 | 7 270,02 | 954,89 | 9 451,03 |
| 2025 | 12 | 0,4970 | 485,07 | 5 574,08 | 692,96 | 7 962,98 | 900,84 | 10 351,87 |
| 2026 | 13 | 0,4688 | 457,61 | 6 031,70 | 653,73 | 8 616,71 | 849,85 | 11 201,72 |
| 2027 | 14 | 0,4423 | 431,71 | 6 463,41 | 616,73 | 9 233,44 | 801,75 | 12 003,47 |
| 2028 | 15 | 0,4173 | 407,27 | 6 870,68 | 581,82 | 9 815,26 | 756,37 | 12 759,84 |
| 2029 | 16 | 0,3936 | 384,22 | 7 254,90 | 548,89 | 10 364,14 | 713,55 | 13 473,39 |
| 2030 | 17 | 0,3714 | 362,47 | 7 617,37 | 517,82 | 10 881,96 | 673,16 | 14 146,55 |
| 2031 | 18 | 0,3503 | 341,95 | 7 959,33 | 488,51 | 11 370,47 | 635,06 | 14 781,61 |
| 2032 | 19 | 0,3305 | 322,60 | 8 281,93 | 460,86 | 11 831,32 | 599,11 | 15 380,72 |
| 2033 | 20 | 0,3118 | 304,34 | 8 586,27 | 434,77 | 12 266,09 | 565,20 | 15 945,92 |
| 2034 | 21 | 0,2942 | 287,11 | 8 873,38 | 410,16 | 12 676,25 | 533,21 | 16 479,13 |
| 2035 | 22 | 0,2775 | 270,86 | 9 144,24 | 386,94 | 13 063,20 | 503,03 | 16 982,15 |
| 2036 | 23 | 0,2618 | 255,53 | 9 399,77 | 365,04 | 13 428,24 | 474,55 | 17 456,71 |
| 2037 | 24 | 0,2470 | 241,06 | 9 640,83 | 344,38 | 13 772,61 | 447,69 | 17 904,40 |
| 2038 | 25 | 0,2330 | 227,42 | 9 868,25 | 324,88 | 14 097,50 | 422,35 | 18 326,75 |
| 2039 | 26 | 0,2198 | 214,55 | 10 082,80 | 306,50 | 14 403,99 | 398,44 | 18 725,19 |
| 2040 | 27 | 0,2074 | 202,40 | 10 285,20 | 289,15 | 14 693,14 | 375,89 | 19 101,08 |
| 2041 | 28 | 0,1956 | 190,95 | 10 476,14 | 272,78 | 14 965,92 | 354,61 | 19 455,70 |
| 2042 | 29 | 0,1846 | 180,14 | 10 656,28 | 257,34 | 15 223,26 | 334,54 | 19 790,24 |
| 2043 | 30 | 0,1741 | 169,94 | 10 826,22 | 242,77 | 15 466,03 | 315,60 | 20 105,84 |
| 2044 | 31 | 0,1643 | 160,32 | 10 986,54 | 229,03 | 15 695,06 | 297,74 | 20 403,58 |
| 2045 | 32 | 0,1550 | 151,25 | 11 137,79 | 216,07 | 15 911,13 | 280,89 | 20 684,47 |
| 2046 | 33 | 0,1462 | 142,69 | 11 280,48 | 203,84 | 16 114,97 | 264,99 | 20 949,46 |
| 2047 | 34 | 0,1379 | 134,61 | 11 415,09 | 192,30 | 16 307,27 | 249,99 | 21 199,45 |
| 2048 | 35 | 0,1301 | 126,99 | 11 542,08 | 181,41 | 16 488,68 | 235,84 | 21 435,28 |
| 2049 | 36 | 0,1227 | 119,80 | 11 661,88 | 171,15 | 16 659,83 | 222,49 | 21 657,77 |
| 2050 | 37 | 0,1158 | 113,02 | 11 774,90 | 161,46 | 16 821,28 | 209,90 | 21 867,67 |
| 2051 | 38 | 0,1092 | 106,62 | 11 881,52 | 152,32 | 16 973,60 | 198,01 | 22 065,68 |
| 2052 | 39 | 0,1031 | 100,59 | 11 982,11 | 143,70 | 17 117,30 | 186,81 | 22 252,49 |
| 2053 | 40 | 0,0972 | 94,89 | 12 077,00 | 135,56 | 17 252,86 | 176,23 | 22 428,72 |
| 2054 | 41 | 0,0917 | 89,52 | 12 166,53 | 127,89 | 17 380,75 | 166,26 | 22 594,98 |
| 2055 | 42 | 0,0865 | 84,46 | 12 250,98 | 120,65 | 17 501,40 | 156,85 | 22 751,82 |
| 2056 | 43 | 0,0816 | 79,67 | 12 330,66 | 113,82 | 17 615,22 | 147,97 | 22 899,79 |

**Figure 18: New installed capacity per year in EU (MW)**

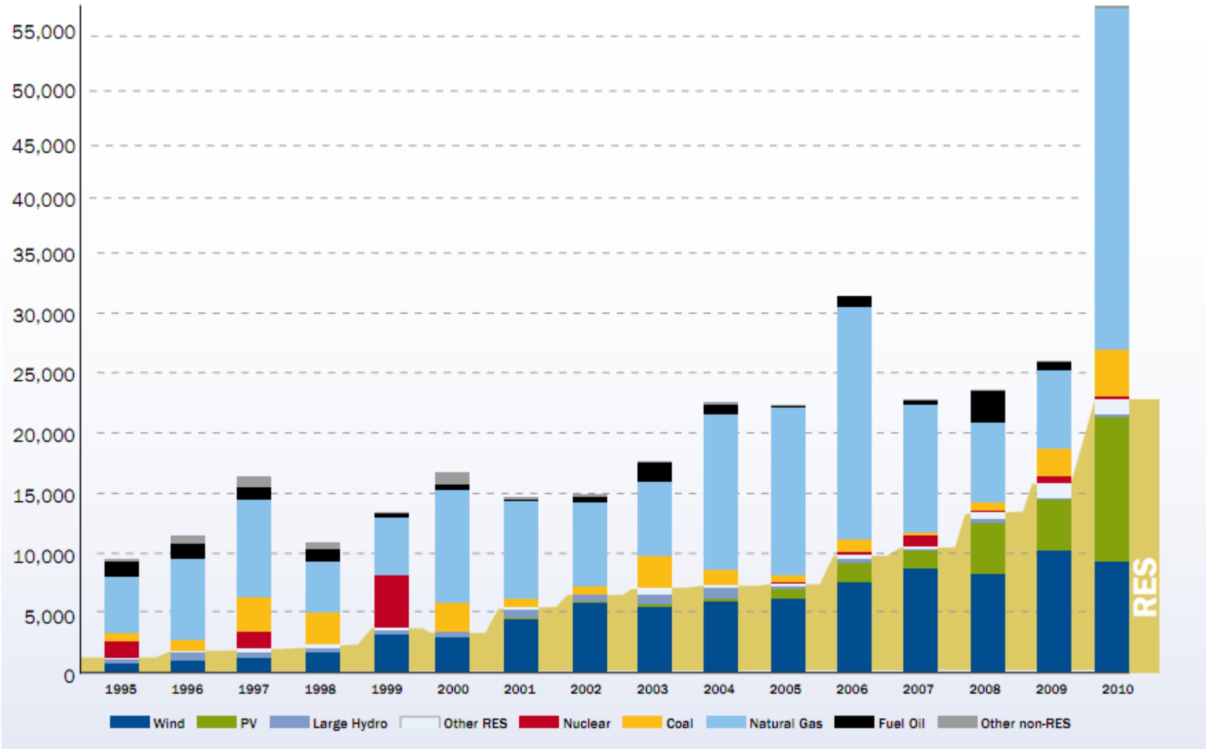
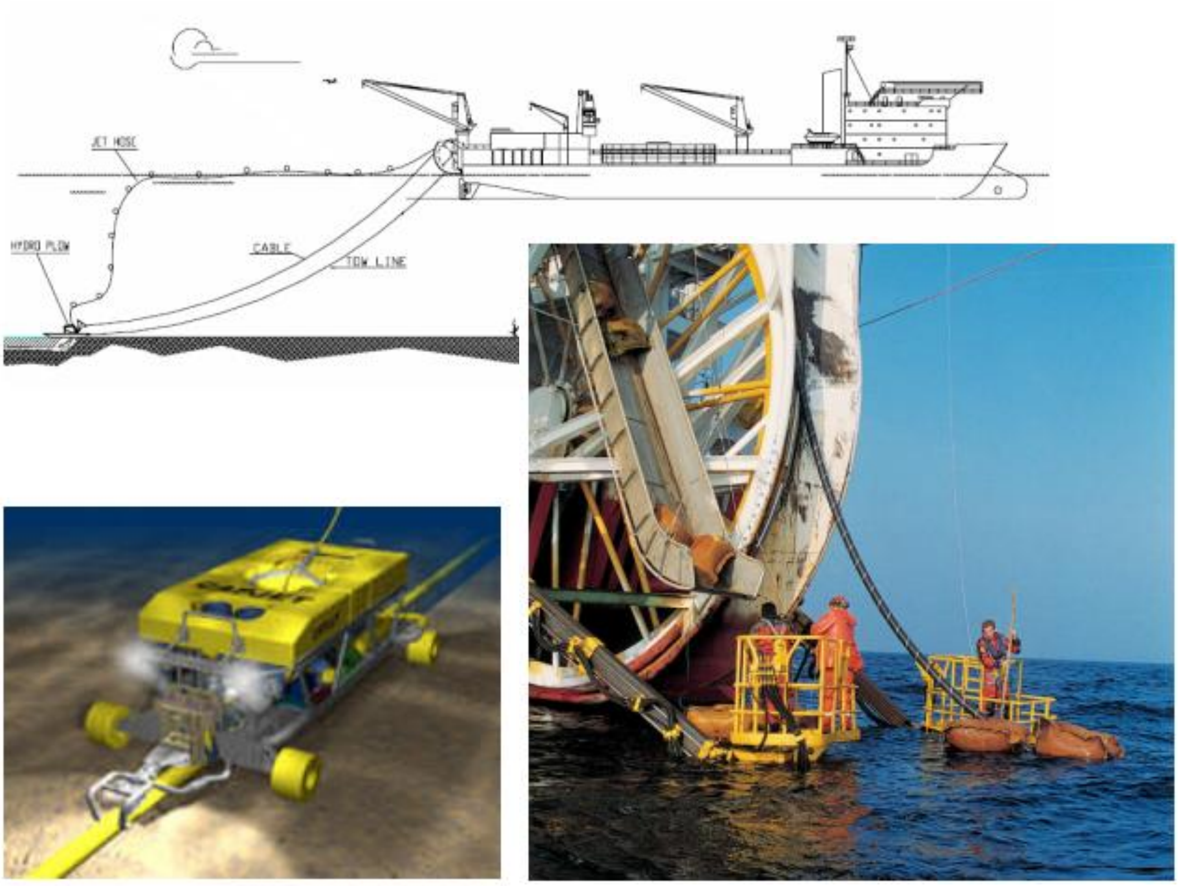



**Figure 19: Technical configuration for deployment of subsea transmission lines**



# OVERVIEW OVER FIGURES

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