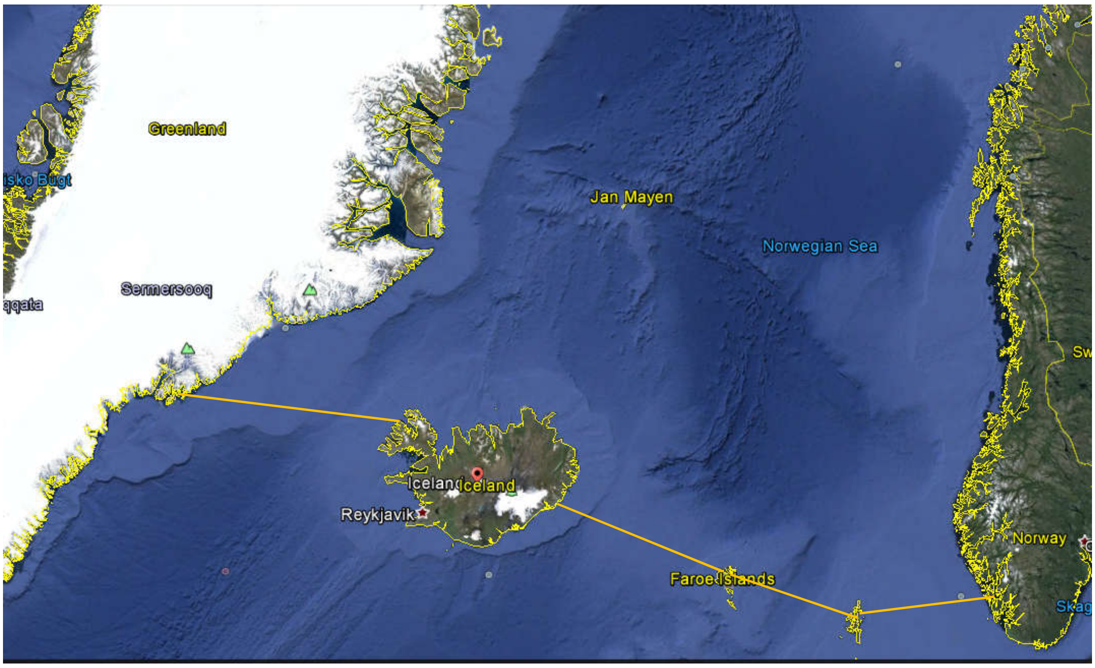
North Atlantic Energy Network

January 2016



Orkustofnun (OS) - National Energy Authority of Iceland

Norges Arktiske Universitet (UiT) - The Arctic University of Norway

Energy Styrelsen - Danish Energy Agency

Jarðfeingi - Faroese Earth and Energy Directorate

Shetland Islands Council - Economic Development Service

Greenland Innovation Centre

EXECUTIVE SUMMARY

The aim of the North Atlantic Energy Network project was to investigate how isolated energy systems in the North Atlantic can be connected to Norway and Greenland to form an electrical grid in the North Atlantic. Representatives of Greenland, Iceland, Faroe Islands, Shetland and Norway met in Copenhagen in the end of February 2015 to formulate how to tackle this question. Each country documented its status regarding energy production and potentials in the fields of renewable energy and the technological aspects were investigated.

Greenland has a big hydropower and solar energy potential, which is not known in detail. Further work is needed to map the potentials. Due to lack of infrastructure and experience a cable connection between Greenland and the neighbouring countries is not realistic in the nearest future.

It is technically possible to connect all of the neighbouring countries around Iceland with subsea cables. Iceland now produces about 18 TWh of electricity per year and could have the potential to double the production from geothermal and hydropower alone. There are many unclear aspects that need to be investigated further to draw a full picture of the pros and cons of interconnectors from Iceland. The legal and regulatory framework must be in place before a project of this kind can be realized and extensive grid reinforcements are needed to support export through a cable at a single connection point in Iceland.

A 100 MW cable between Iceland and Faroe Islands is possible but might not be economically competitive. Faroe Islands and Shetland have offshore wind conditions on land and large windfarms in Faroe Islands need powerful interconnectors. A large cable from Iceland to Scotland could be laid via the Faroes and Shetland and could possibly transmit energy from Iceland, Shetland and Faroe Islands to Scotland and Europe. A probable synergy effect could be to transmit hydropower from Iceland in summer and windpower from Faroes and Shetland in winter.

The submission of Scottish Hydro Electric Transmission's (SHE-T) needs case for developing a 600 MW transmission cable between Shetland and the UK national grid, is expected to be submitted to the UK electricity regulator Ofgem in 2016. The Shetland to UK interconnector project has been in process for over a decade and is the main focus for harnessing Shetland's exceptional wind resource. The North Atlantic Energy Network has highlighted the potential for Iceland and Faroe Islands to export renewable energy to electricity markets in the UK, Norway and connect to the wider European grid. Cable routes from Iceland to the UK are currently being investigated and Faroe Islands also have an interest in securing a supply of renewable energy from Iceland.

Although the NAEN project has the potential for localized introduction of electricity from renewable resources for both Shetland and oil platforms along the cable route, the economic benefit seems reduced with respect to Norwegian interest. This especially so with the new HVDC subsea interconnector to Great Britain to be finished in 2021.

The North Atlantic Energy Network has explored the potential of connecting some of the best renewable energy sources in the Arctic, Nordic and northern European regions to the large energy markets of the UK and European continent. The project has allowed informative exchange of knowledge between the participating regions and organisations.

Access and utilization of renewable energy is a key element in fighting global warming. The countries behind the NAEN project could benefit from integrated future cooperation regarding exporting energy and knowledge in this field in the widest sense. A platform to develop this cooperation and mapping the possibilities for future development in this area could be beneficial for all of Europe.

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Introduction

The North Atlantic Energy Network Project aims to investigate how small isolated energy systems can be connected to an electrical network grid and onwards to the European market. The Project focuses on Greenland, Iceland, the Faroe Islands, Shetland, Norway and offshore companies in the area.

The purpose of the Project is to examine whether it is possible to connect these communities via undersea electric cables. Greenland, Iceland and Norway have a high potential for hydro power and all of the countries have potential for other types of renewable energy. Faroe Islands and Shetland are today heavily dependent on oil for their energy supplies. Greenland is today also dependent on oil, despite its possibilities as this large islands is scarcely populated and lacking the necessary infrastructure to harvest all of its abundant renewable energy potential.

An electric cable connection, in addition to reducing overall oil dependency, will open up the opportunity for exploitation of the wind potential that is available in the Faroe Islands and Shetland and other potential renewable energy sources, such as tidal energy.

Norway, Greenland and Iceland have a large, hydropower capacity, that can become a kind of battery to regulate production from wind and the tides, which are very fluctuating energy sources. The interconnection of the electricity supply systems between the Faroe Islands, Iceland and Shetland also creates the opportunity to operate the oil platforms in the area with renewable energy, and the creation of offshore wind farms in one of the world's best areas for wind power generation.

The principle focus of the Project is to identify the interests and opportunities that the different parties see in such a network, and to examine the technical and economical aspects.

Conclusion

The European energy market is very complicated and the greatest risk involved in connecting to this market are energy politics. The European Union creates and develop regulations regarding interconnectors and each country also influences their energy market with country specific emphasis.

The installed generating capacity of wind power is showing rapid growth in Europe and when there is a lot of wind, prices go down. More flexibility and storage is needed and hydro power reservoirs offer flexibility and storage possibilities.

For the past five years energy prices have been going down and a lot of power plants can't survive the current prices that are close to 3 Eurocents pr. kWh. What the future may hold in terms of prices and politics is hard to predict.

Norway has led the way in interconnectors and finished a new connection to Denmark in 2014. Interconnector's are seen as an important and integrated part of the power system in Norway and Denmark. Two additional interconnectors are planned in the near future; one to Germany to be up and running in 2019 and another to the United Kingdom to be finished in 2021.

A connector between Iceland and the Faroese Isands has been up for discussion for decades but has not been seen as financially feasible for just that purpose. In correlation with the NAEN project a cooperation between a cable project between Iceland and the UK (IceLink) and a Faroe Islands connection was discussed. The IceLink connection would probably have to pass Faroe Island waters and it was discussed as a possibility that the cable could be taken ashore in the islands. This might be an advantage for both Faroe Islands and the cable owner as Faroe Islands could import and export energy from both UK and Iceland and cable faults could be easier to locate.

During the process of this cooperation between all of the countries involved in the NAEN project representative of Shetland reported that there will possibly be a new 600 MW cable connection between Shetland and UK in the near future. The plan is to export windpower from Shetland to the UK grid from the Viking Energy wind farm project. The Viking Energy wind farm has planning consent and would be built if the Shetland to UK grid connection is approved. (http://www.vikingenergy.co.uk/the-project). The Viking Energy project originally got planning consent from the Scottish energy minister Fergus Ewing in April 2012 and was reaffirmed in February 2015.

Most of the studies regarding estimates of hydro power potential in Greenland have focused on Western Greenland. These studies indicate possibilities of 14 TWh/year. A theoretical maximum potential taking into account all natural water from the locality where it is formed and via turbines resulted in an estimation of 470 TWh/year potential. This theoretical estimation was conducted in 1994 and might reveal a higher potential if it were recalculated today as the ice in Greenland is melting much faster today. This theoretical value would never be the end result but it depicts the abundant resources that are available.

The necessary infrastructure to harvest Greenland's abundant power sources has not yet been developed. Greenland will not be using subsea interconnectors to other parts of the world in the near future. This does not prevent them from exporting their power in some other form. Iceland has been exporting power in the form of aluminum for half a century and Norway started its export the same way before Iceland did. Possibly Greenland could build up infrastructure and knowledge the same way as Iceland and Norway have done in the past by attractking industry that needs a lot of power.

Access and utilization of renewable energy is a key element in fighting global warming. The countries behind the NAEN project could benefit from integrated future cooperation regarding exporting energy and knowledge in this field in the widest sense. A platform to develop this cooperation and mapping the possibilies for future development in this area could be beneficial for all of Europe.

Energy markets in Europe

To decide upon the financial feasibility of a network of this kind and its connection to Europe through Norway is a very complicated task.

Energy markets in Europe are integrating and through this integration prices are expected to be levelized in an ideal market. The European energy market has not reached this state as there are bottlenecks in the system and therefore huge price differences. Prices to different areas of the market like home and industry also differ between countries. The market is complicated and therefore it is difficult to determine the prerequisites for detailed calculations.

Interconnection of power markets is supposed to lead to more economic distribution of energy than without the interconnectors. Interconnectors can contribute to security of supply; less need for investment in production and reserve power, better utilisation of electricity and less cost involved in balancing the systems.

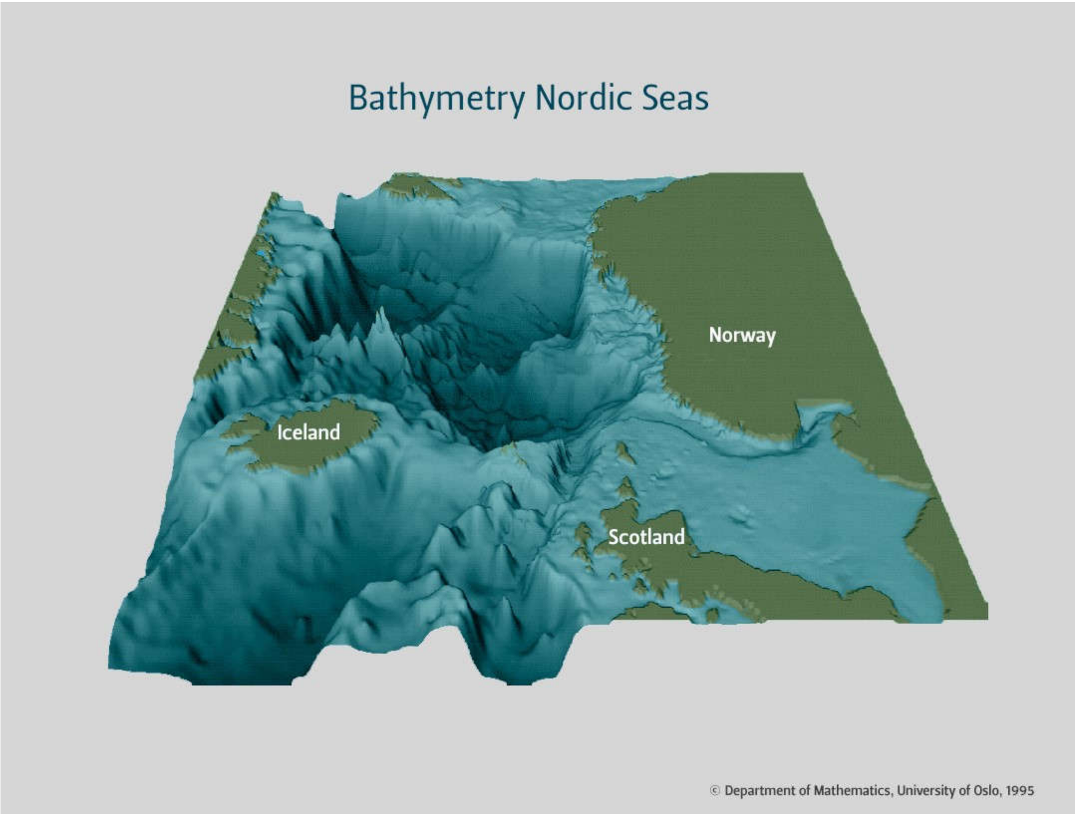
Interconnection cables for island systems are expensive and will have lasting effects both on production of electricity and prices. Technologically it is possible to lay sea cables to create a North Atlantic Energy Network (NAEN) but there are many risk factors that need to be considered. The economic risks involved in the installation and operational cost of the interconnectors and market prices for electricity.

The North Atlantic Energy network

Likely connection points for the countries involved in the NAEN project have not been decided for a possible network. Each interconnector would need a thorough survey of the seabed as well as indepth analysis of various aspects of each project before connection points can be decided.

Approximate length of each cable as depicted on the front page give an idea of the distances in question. These are just shortest routes estimated through Google earth or large scale maps and the depths are assumptions that should be reviewed as such.

Link	Approximate length [km]	Approximate depth [m]
Eastern Iceland – Faroes	450	500
Faroes – Shetland	350	1100 - 1200
Faroese – Scotland	400	1100 - 1200
Faroese – Norway	650	1500
Shetland – Norway	300	350
Iceland – Greenland	470	800
Iceland – Scotland	900	1100 - 1200
Iceland – UK	1200	1200
Shetland - Scotland	250	100



Bathymetry Nordic Seas - Borrowed from Landsvirkjun webside – ORIGINALLY FROM MATHEMATICS, UNIVERSITY OF OSLO 1995.

Rated power of the interconnectors in question were not established, but indications are that for long distances losses rule out the benefits of cables with low capacity.

Financing cables

Initiating subsea projects involves deciding which type of contract the operating entity should follow. In submarine cable projects three types of structure are common:

1. Private ownership
2. Consortium
3. Public Private Partnership

It is rather common that cable projects adopt more sophisticated structures mixing some of the above mentioned structure types in order to optimize the projects.

Different cable projects, in the planning phase or operating, illustrate this. One of the cables between the UK and Norway is owned by Statnett (NO) and National Grid (UK) with investment costs for Statnett of 1.5-2 billion euro. Another example is one of the cables between Norway and Germany- the NORDLINK with a different owner structure. 50% is owned by Statnett and 50% by TenneT and KfW in Germany. The investment costs for Statnett equals the investments for the cable between the UK and Norway. Both these projects are in the construction phase. An increase in capacity for the countries involved to exchange electrical energy will probably give a more stable reliability of electric supply, contribute to added labour and a future of climate friendly energy systems. Another aspect of this is the financing model within each nation in the study. In a project like the North Atlantic Energy Network, there has to be enough power delivered from renewable sources and willingness to invest in electricity grids.

The costs of financing cables will most likely be implemented as a model where the different nations involved will divide the costs between them. If we look at two other similar projects, with a Norwegian starting point, with only two countries involved there are at least two different models of dividing the costs. The cable between the UK and Norway is owned by Statnett (NO) and National Grid (UK) with investment costs for Statnett of 1.5-2 million euroThe cost for investing for Statnett equals the investments for the cable between UK and Norway.

Installation cost

Bipolar v.s. Monopol

It is possible to use just one cable instead of two (bipolar) and let the current flow in the earth and/or sea between two specially designed earth electrodes. This arrangement is a type of single wire earth return system and is often called monopol.

According to ABB specialists Mr. Ola Hanson and Darren Fennel they would not recommend a monopolar connection as a solution, as there is a great opposition regarding environmental effects of electrode stations. The seabed will be disturbed where you place the electrodes and small amount of chlorine is developed. Chlorine is toxic and can be leathal to some organisms (2014. IGRC. Balsle). Laying a bundled bipolar costs about the same as laying a monopole so the savings of starting off with a monopole are only what you save by delaying the cost of one cable. The extra cost of the electrodes which will be obsolete once the second cable has been laid and the laying of the second cable later on, cost so much that it outweighs the benefits of starting out with a monopol. If the plan is to lay a bipolar they would recommend laying a bundled bipolar in one go as it would be cheaper and more acceptable environmentally.

Cable size

For long cable stretches the loss in the cable is considerable and for a 200 MW cable you can have 30 MW of losses or about 15%. Larger the cables and higher the voltages give relatively less transmission losses. For long cables you should go for high capacity. Cable prices are related to cable weight and the price depends mostly on price of aluminium and copper. If you go up by 20% in power you have about 10% heavier cable so you go 10% up in price. All indications are that when laying a cable it is most cost effective to lay as large a cable as possible with current technology.

Other things that need to be considered is that losses are less in a copper conducter but copper is very expensive so for long stretches a cable would probably be aluminium. Installation is mainly decided by the nature of the route and the cost of laying a 200 MW cable is about 70% of the cost of laying of a 1000 MW cable. There are more losses in extruded cables but they are less expensive. It must be studied what is optimal for each solution.

Depths

In deep waters cables won't get damaged by anchors, trolls or floating icebergs so the cables don't need to be buried and that saves some money. Close to shore you need to bury or cover the cables to protect them. Taking cables ashore can be expensive if you have to drill cable routes through bedrock.

Cables have been installed at great depths and cable tunnels have been created as long as 1600m. It saves a lot of money if they can be avoided so cable routes and landfalls should be chosen with great care.

It may be necessary to survey the seabed after cables have been laid to make sure they are sitting where they are supposed to be and that material has not moved from under them.

A 525 kV cable has not yet been qualified for a 1000 m depth, but it might be before IceLink or some parts of the NAEN project will be realized. A cable with aluminium conductor is likely to have an advantage when laying at greater depths due to the lower cable weight compared to a cable with copper conductor

It is no problem to leave a cable in deep waters between cable stretches, it's no problem to pick it up again for splicing when you come again with the next stretch

Prices

A price of 2000 DKK/m for a monopole cable was mentioned but that is only for the cable itself and not the laying of the cable or the converter stations at each end. This means 4 M DKK /km for a cable pair.

To answer how much it will cost to lay the cable depends on the nature of the cable route which must be researched properly so it can be estimated how much it will cost.

Price of metal is the deciding factor in cable prices.

Recently there was an article (Ing.dk. 2015) regarding a 740 km long submarine cable from Denmark to UK. The cable should be able to transport 1400 MW and the cost estimate is for 15.000 million DKK or 20 million DKK pr km which is almost exactly 2 million pounds pr. km.

At a meeting with National Grid in Faroe Islands in June 2015 a similar price was also mentioned.

Ships

A cableship can lay 500 to 600 m/h on seabed but it can only handle 200 m/h if you need to trench the cable through soft bed rock or sand. Clay and hard bedrocks can add to difficulties and hence the cost.

Necessary research for thorough preparation only costs about 1% of the total cost of laying a cable. Extra ships are needed both to guide the way, make sure that other traffic is not in the way and a ship is needed to clean the route of junk and obstacles that could harm the trenching equipment or the cable.

Timescale

The capacity of cable factories will be a bottleneck, since the demand is high and growing.The ABB factory f.ex. is today booked for 3 years. It is realistic to extimate that itmay take 4 to 7 years from bidding until commissioning.

It is possible to lay 2 bundled cables at a time in 85 km stretches in 30 to 35 days. This is the overall time for loading cable onto ship, sailing, laying and going back for more cable.

This means that 4*85 = 340 km of cable can be laid in one summer or each year. It would therefore take two summers to lay a cable to the Faroe Islands from Iceland.. However, production capacity is also important. No manufacturer will allow any project to virtually block for other orders for the time it will take to manufacture e.g. the IceLink cables.

To set up connector stations would take 3 to 4 years.

Alternating Current (AC) technology

For long distances Direct current (DC) cables are the only technical solution but AC cables can be used for shorter distances. ABB has provided an AC cable to Goliat oil field 100 km off shore.

Transformers, Converter stations

It takes at least 6 months to get a new transformer if there is a breakdown. Therefore it is sensible to use three single line transformer for each end and have one spare transformer at each end to shorten the outage because of transformers. One reserve transformer costs about 8% of a converter station.

Surveys

Extensive surveys are needed to find the most appropriate route for a submarine cable. It is necessary to do a comprehensive Marine Survey and Landing Site study to map the geology and physical geography in the area.

Hazardous environmental phenomena need to be investigated. Among other things it is essential that the cable is not layed in sediments with high thermal resistivity as it decrease the capacity of the cable. Seabed conditions must be investigated for conditions that might lead to requirements for heavy armouring of cables, movemetnts of sediment, earthquakes, fishing, shipping, floating icebergs, wrecks etc.

Manufacturers of cables have specified what type of surveys are necessary and money is well spent on thorough preparations. Surveys cost a fragment of the total cost and it is very expensive to find the obstacles during installation.

Operation cost

Possibilities for shutdown for new installations can hardly be estimated. However, based on experience and statistics, there will be a probability for a breakdown one or more times during the life span. This can either be as a breakage of the cable itself, or in converter structures. If the repairing has to take place in deep water, this will be a highly expensive operation. In addition, normal maintenance for the different systems has to be performed. Experience from operational costs estimate this to approximately 5% of investment costs.

Operational cost includes costs for operation and maintenance of the subsea cable and converter stations, as well as onshore costs due to losses and increased cost for running and managing the onshore grid. There will be electrical losses depending on the total length and number of converter stations. As basis for further work, electrical losses can be estimated to about 1% per 100 km, and 1 % per converter station.

Finally the repair cost for subsea cables should be taken into account, due to a risk evaluation. Estimated cost for one cable repair is 2-5 million Euro. In addition the value of downtime (estimated to 30-100 days per subsea repair) should be calculated.

Lifetime

The submarine cable technology is well established, and has been used for energy transmission in more than 100 years. The principles with paper tape insulated cables today are more or less the same as those used for decades, and the service experience is extremely good.

Generally, high voltage power cables have a proven life span of more than 70 years, and a large number of the cables in services today are more than 50 years old.

Due to the route length, the transmission must be by utilizing high voltage direct current (HVDC). Submarine cables made for HVDC transmission have somewhat shorter history, and literature estimate the life span of a submarine HVDC cables to be approximately 30 – 40 years. Equipment for plant control is most likely to be changed after 20 years due to development of technology.

A HVDC system will consist of two main sub-systems, the submarine cable, and the converter system. All this is passive, robust and well-proven equipment, and consist of simple structures.

Technologies

Submarine cable faults

A Cigré report from 2009 is interesting regarding shedding light on submarine cable faults.

Total number of submarine faults reported 1990 to 2005

According to Cigré report from 2009, 49 failures in submarine cables were reported during that period: "

Failures 1990 to 2005 - overview and main classification						
	AC			DC		
	XLPE	SCOF	HPOF	MI	SCOF	Grand Total
Internal					4	4
External	2	7	2	11		22
Other	1	10		5		16
Unknown	1	4		2		7
Total	4	21	2	18	4	49

- The faults reported are mainly external faults, with immediate breakdown or an unplanned outage of the cable system.

- Six answers, classified as unknown, failed to specify whether the failure was instantaneous or not. These failures are reported to have been caused by anchor and trawling and as consequence are considered to be instantaneous. Therefore 40 cases may be classified as instantaneous failures and 9 cases may be classified as occurrence requiring unplanned outage.

- Eight of the nine cases requiring unplanned outage were reported on SCOF type cable. The remaining case was termination related (hydraulic system) on MI cable. Six of these failures were reported to be on terminations, joints and other components. Oil leaks are expected to be the main reason in these cases.

- Owing to the fact that few replies were received from utilities and that manufacturers may not be aware of all failures, the number of faults reported may be slightly understated. If so, this is most likely to be the case for the lowest voltage levels of XLPE and EPR cables installed in short lengths in shallow water.

- Repair joints for armoured submarine cables are not available off the shelf from accessory suppliers. Such accessories are designed and type tested by the submarine cable suppliers. Therefore it is rather unlikely that the submarine cable suppliers would not be informed about damage and repairs requiring joints. Installation of cable in long lengths and / or in deep water will require assistance from the supplier. Therefore, the reported number of failures, repairs and joints are assumed to be fairly accurate (information from the suppliers has been used to compensate for unsatisfactory response from utilities in parts of the world).

- In total 49 faults were reported, 55% on AC cable systems and 45% on DC cable.

- 7 cases (14%) are reported to have an unknown cause of failure.

- 16 faults (33%) are reported to have been caused by "other" reasons. This is rather higher than expected. "Other" was defined as physical external parameters excluding anchors, trawling or excavation and could include for example subsidence, increased burial depth resulting in overheating or an abnormal external system (e.g. lightning)

- The origin of the undefined faults (reported as "Other" or "Unknown" has been investigated to try to clarify the type of fault, internal or external."

49 cases over a fifteen year period or just over three cases a year does not give a very reliable statistics to estimate failure in the future. Predicting the likelihood for failure of a cable is therefore a rather uncertain.

Analysing failures categorized as "Other" is according to the same Cigré report as follows:"

Evaluation of cause of failure defined as Other			
Type of Cable	Number of cases	Protection at fault location	
All types	3	Landfall troughs	19%
	7	Unprotected	44%
	2	Direct burial	13%
	3	Other protection	19%
	1	No Information	6%
Grand Total	16		100%

- Failures reported as being caused by incidents other than trawling, anchoring and excavation may have not been specified.
- 63 % of these failures are reported on AC-SCOF cable and 31% on DC – MI cable.

- 19% of these failures have occurred in landfall troughs where wave induced movement and thermal effects may cause lead sheath fatigue and failure of paper insulated cables with lead sheath.
- 44 % of these failures are reported to have occurred at locations with unprotected cable.
- It is assumed that a significant part of this group is related corrosion, mechanical impact from wave action, unplanned thermal exposure etc in landfall area during time in operation.
- The major part of these failures occurred after nearly 10 years and more in operation.
- Supporting information regarding potential lightning and switching over voltages has not been given."

In the report a comparison is made with older Cigré reports on cable failures. It states that the number of reported faults are significantly lower today than in 1950-1980. It is stated that the reason is probably because of improved methods for surveying and finding optimal routing, laying and protecting the cables.

The report goes through many statistical aspects of submarine faults and outage times at different voltage levels. The outage times are half the time, less than 2 months, but over 20% last more than 6 months.

Repair can be difficult if not impossible in the winter time in the North Atlantic, so failures could cause long outage times if they happen in the worst of times.

Windfarms

In the two following chapters there will be some information on landbased and offshore windfarms, mostly in connection with production of energy to interconnectors in the North Atlantic.

This means, that focus will be on the special challenges in the north Atlantic region with its very good wind conditions.

Land-based windfarms

Windfarms in the north Atlantic region have only been in production for the last ten years, and only the last three years have given some experience and results from windturbines specially designed for high wind speeds and rough wind conditions.

In the table below you can see the capacity factor for windturbines in Shetland, Faroe Islands and Iceland.

Site	Capacity factor
Shetland Burradale	52%
Faroe Islands Neshagi	42% (*)
Iceland	44%

(*) This figure is an underestimate, since the simultanous production from hydro, heavy fuel and wind in some periods of low demand implies a downregulating of the production from the windtubines.

Small electricity systems such as in the Faroe Islands and Shetland set very high demands to the quality of the energy from the windturbines to the grid.

Also the very high windspeeds that are in the area are a challenge to the windturbines.

These conditions are not very common in most parts of the world, and therefore the range of suitable turbines is not high.

In particular turbines from one company have been choosen in all three countries mentioned.

These are the relatively small turbines E-44 from the German company Enercon, V47 and V52 turbines from Danish company, Vestas. Recently a 3MW, E82 E4 Enercon wind turbine has been erected in Shetland.

It can be a good lesson to describe in some details the features of these turbines that make them usable in the mentioned small and vulnerable grids in these countries with very challenging weatherconditions.

Windturbines of different wind classes

Some sites are windier than others. A lowland site in the middle of southern England might have an average wind speed of 6 m/s, whereas an exposed site in the North Atlantic might have an average wind speed of more than 10 m/s.

Because the 'power in the wind' is proportional to the cube of the velocity, this means that the wind turbine on the 10 m/s site would on average be exposed to well over three-times the loads compared to the 6 m/s site.

There is also a second dimension that affects wind class which is 'turbulence intensity'or wind shear, which is basically a measure of how turbulent the wind is at a site. This is important because complex topography can cause turbulence, and turbulence can cause varying loads on wind turbines which causes them to wear down more quickly. In extreme cases, if a site is just too turbulent the wind turbine manufacturer will refuse to supply a wind turbine because they will know that the turbine will not operate reliably for the full design life at such a site.

Basically, for wind class 2 and wind class 1 sites on-site wind monitoring is essential to determine the exact annual average wind speed and the turbulence intensity, so that the optimum turbine can be specified to ensure long term, reliable operation.

Wind Class 1 turbines are designed to cope with the tough operating conditions experienced at sites with average wind speeds above 8.5 m/s. Typically these turbines have smaller rotors (i.e. shorter blades) and are on shorter towers to minimise structural loads. They are also heavier-duty in design, which makes them more expensive.

The table here shows the International Electrotechnical Commission (IEC) Wind Classes and the wind speeds that the turbine must be designed to withstand.

	IEC Wind Class		
	1 (High Wind)	2 (Med. Wind)	3 (Low Wind)

Reference Wind Speed	50 m/s	42.5 m/s	7.5 m/s
Annual Average Wind Speed (Max)	10 m/s	8.5 m/s	7.5 m/s
50-year Return Gust	70 m/s	59.5 m/s	52.5 m/s
1-year Return Gust	52.5 m/s	44.6 m/s	39.4 m/s

With regard to 1-year Return Gust it can be mentioned, that the turbines situated in Faroe Islands already after two years in operation have been exposed to windspeeds above 80 m/s.

There is an extension for windclass 1, namely an S, which stands for “site specific”. The new turbines on Faroe Islands have this extension. They have therefore been specially designed after the turbine company has made a thorough examination from one year quality wind measurements at the specific site.

Optimal grid integration

The share of wind energy in the electricity generation is on the rise in many countries electricity systems. That is why the technical requirements of local grid operators regarding the electrical performance of wind energy converters (WECs) and wind farms (WFs) are also getting more extensive and challenging.

Wind energy converters (WEC technology)

In Enercon turbines the rotor is directly connected, that means without intermediate gearbox, to the multi-pole, electrically excited annular generator. The electrical power produced by the generator is fed via a full-scale power converter into the electric network. The converter system itself consists of a rectifier, a DC link and several inverters.

In electrical terms the annular generator is completely decoupled from the grid. This enables a high level of rotor speed variability and, in turn allows for a more mechanically robust design with fewer moving parts. In addition to this the electrical properties of the WEC’s are solely determined by the inverters used and the corresponding FACTS- (Flexible AC Transmission System) controller.

Advances in relation to the electrical grid

- Contributes to maintaining grid voltage and frequency
- Optimum power quality through an adapted control system and operating mode in accordance with IEC standards and FGW (Federation of German Windpower) regulations
- The idea behind the grid management system is to control and regulate power feed without power peaks
- FACTS properties enable the turbines to provide system services similar to those provided by conventional power plants or beyond

Annular generator

The annular generator - comprising rotor and stator - forms the key component of the wind energy converter design. Combined with the hub, it provides optimal energy flow. The sophisticated wind energy converter technology means maximum running smoothness, low sound emissions and a long service life. One special feature is that, thanks to the externally excited annular generator, there is no need for the use of permanent magnets that are manufactured from highly controversial neodymium (rare earths). The magnetic fields required for power generation are created electrically.

SCADA System

The Supervisory Control and Data Acquisition (SCADA) system comprises all components for data acquisition, remote monitoring and control of a wind farm. The adaptability of the standard topology consisting of the WEC- and SCADA System allows complying with the most demanding grid codes and additionally providing a multitude of system services. Provision of such system services allows wind farm operators in many markets to generate additional income, and ensure optimal operation.

Closed-loop control of the wind farm at the point of connection

A wind farm controller can be used to accurately control the active and reactive power of a wind farm at the point of connection (PoC). In conjunction with the wide reactive power range of the WECs, a wind farm controller can be used for rapid control of the voltage at the network connection point. With these wind farm regulation, the setpoints for control can not only be programmed specifically into the relevant device but also be received dynamically from the grid operator via a communication interface. This enables optimal integration of the wind farm into existing grids.

At last in this chapter we will descibe in some details the capability of these mentioned WEC's to cooperate with and stabilize the receiving grid, which as mentioned above has limited size and strenght.

- Reactive power capability
- Power-frequency control
- Inertia Emulation
- Fault Ride Through
- Storm control
- De-Icing

Reactive power capability

Reactive power is needed in order to keep the grid's voltage within the required limits and compensate for electrical equipment connected to the grid. Due to the full-scale converter concept, the WECs can provide reactive power flexibly.

The Q+ option extends the reactive power range i.e. the maximum reactive power available from an ENERCON WEC.

The STATCOM option enables an ENERCON WEC to provide the full reactive power range regardless of the active power production. Even when idle, the full reactive power of the WEC will be available.

The Q+ option and the STATCOM option can be configured project specifically onto meet the requirements of certain grid codes. Both options are installed in the WEC eliminating the need for external STATCOMs, capacitor banks or choke coils.

Power-frequency control

For any electric power system, generation and consumption of power have to be balanced at all times. If this balance is disturbed, the grid's frequency will deviate from its nominal value. In case a grid fault leads to temporary over frequency, the WECs will reduce their power infeed according to certain set parameters. In addition, reserve power can be retained during normal operation in order to compensate for an event of under frequency.

Inertia Emulation

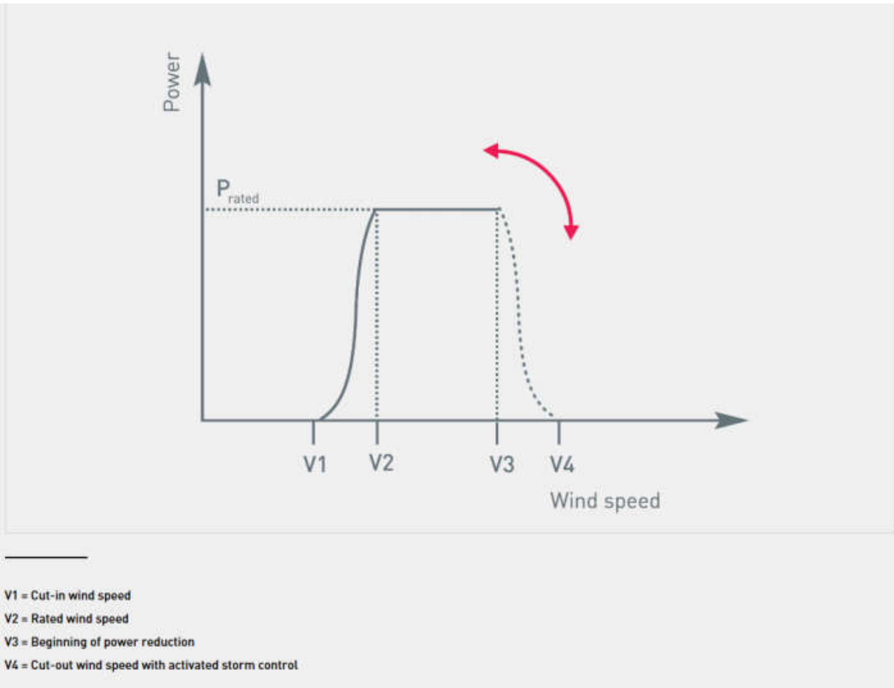
The WECs equipped with the Inertia Emulation option can increase their active power output in the event of frequency drops without setting aside reserve power. For a certain period of time, a power greater than that contained in the wind is fed into the grid.

Fault Ride Through

TheWECs are capable of remaining in fully operational and connected to the grid for 5s in case of overvoltages or undervoltages caused by grid faults. Furthermore the Fault Ride Through (FRT) option enables an adjustable current to be fed in during the fault in order to dynamically support the grid voltage.

Storm control

The wind energy converters run with a special storm control feature. This slows the wind turbine down so that it can continue to operate even at high wind speeds. Numerous shutdowns which lead to considerable losses in power output can thus be avoided. When storm control is activated, the rated speed is linearly reduced starting at a predetermined wind speed for each turbine type. When wind speeds surpass 32 m/s the Storm Control System does not shut down the turbine abruptly, but rather reduces the power by continuously pitching the rotor blades. The output is only reduced to zero at wind speeds of approx. 40 m/s. This strategy improves electrical behaviour in the grid at the same time increases output.



Rotor blade de-icing system

The de-icing system shortens thawing time. A fan heater installed in the blade root is activated and starts heating the air inside the rotor blade using air recirculation. The temperature of the blade surface warms up to above 0°C and the ice build-up melts off.

The rotor blade de-icing system can be operated at sites with low icing potential even when the WEC is in operation. Thin layers of ice are thawed off at an early stage thus maximising energy yield and reducing downtime.

Offshore Wind Turbines

Worldwide offshore wind is accepted as the central focus to increase energy production from renewable sources over the next decade. But there are still major challenges ahead, since the industry is not yet mature in either technology or supply chain. It is still a young technology facing considerable challenges and political and economic support is needed to live up to the strategy and to ensure that it can meet its potential.

The move to sites further offshore will give access to improved wind resources.

Offshore wind is a strong asset in European maritime economy and is one of the fastest growing maritime sectors. It is a promising industry with great potential to transform and decarbonise the electricity system. The global installed capacity at the beginning of 2014 was 6.5 GW and in 2020 it is expected, that 4% of the European electricity demand (40GW) could come from offshore wind. By 2030, offshore wind capacity could total 150GW and meeting 14% of the EU consumption.

The bottom fixed foundations used today are limited to depths less than 40-50 m due to today´s technical and economic restrictions. And as the sector is growing, the areas with suitable conditions become increasingly limited and the engineers are looking for solutions, where floating wind power turbines could be installed. This technology could play a vital role towards a greener power generation. Floating wind power technology is derived from deep water offshore oil & gas structures used in this sector for a long time. And there is an opportunity to use the synergy and the expertise from this area to establish an industry around this segment.

Floating wind turbines in deep water environment

Offshore floating wind turbines may hold the key to large-scale offshore wind energy. They can operate in deep waters, far from shore where visual impacts are negated and where the wind resource is generally strong and consistent. However, floating turbines have significant challenges as well, in particular the increased loading on the blades and tower due to the higher inertial and gravitational forces caused by the motion of the floating platform.

If we take Faroe Islands as an example, we can say, that although there still is plenty of areas onshore Faroe Island where wind parks can be installed, the big potential and hence the future may lie in the water surrounding the islands.

Floating wind represents a new and significant renewable energy source that will complement an existing and expanding array of alternative energy projects in North Atlantic.

In 2013, the global installed capacity for offshore wind was around 6.5 GW, almost all of this built on bottom fixed foundations. Many coastal areas of the world the waters are too deep for this technology. Floating wind turbine technology offers a new opportunity to provide clean energy to countries and coastal regions with deep water coastlines. Floating wind turbines can be deployed in deep to ultra-deep waters, in the 1,000 metres range and beyond.

Hywind, a new demonstration project in Scotland, consists of a wind turbine placed on top of a ballasted steel cylinder. This pilot project is expected to demonstrate the feasibility of multiple floating wind turbines in a region that has optimal wind conditions, a strong supply chain within oil and gas and supportive public policies such as enhanced support for floating offshore wind pilot parks under the Renewables Obligation (Scotland).

Statoil's Hywind concept combines known technologies in a completely new setting and opens up the possibility for capturing wind energy in deep-water environments. Based on Statoil's background in design, installation and operation of floating offshore oil and gas platforms, Hywind has been designed as a slender cylinder structure, chosen as the most feasible and economical concept for a floating wind turbine.

The floating turbine technology was first conceptualized in 2001, a scale-model was used to test the concept in 2005 and the world's first floating full-scale wind turbine Hywind Demo was installed in 2009. Hywind is turbine independent and, in principle, any offshore wind turbine generator can be used as long as the combined weight of the nacelle and rotor is within the requirements for marine stability.

Statoil's proprietary Hywind-specific pitch motion controller is integrated with the turbine's control system and mitigates excessive motions of the structure. This also eliminates the loss of energy due to aerodynamic or hydrodynamic movements and maximizes the power output from the turbine. The structure is ballast-stabilized and anchored to the seabed. The mooring system consists of three mooring lines attached to anchors suited to the seabed conditions on site.

The water depth around the coastline of the Faroe Island, Iceland, Greenland and Norway is much deeper than it is in the central North Sea, where until now the majority of offshore wind farms are installed. And the conditions regarding wind, waves and current are much harsher and more challenging. Hence the countries lack extensive areas of shallow water suitable for conventional offshore wind farms. Norway is in a similar situation and is concentrating on solutions based on floating offshore wind. The first test turbine Hywind was installed outside the Norwegian coast in 2009. But today the activity regarding offshore wind in Norway is very low due to lack of economic incentives. There is an oversupply of almost CO_2 free hydro production and the motivation is limited.

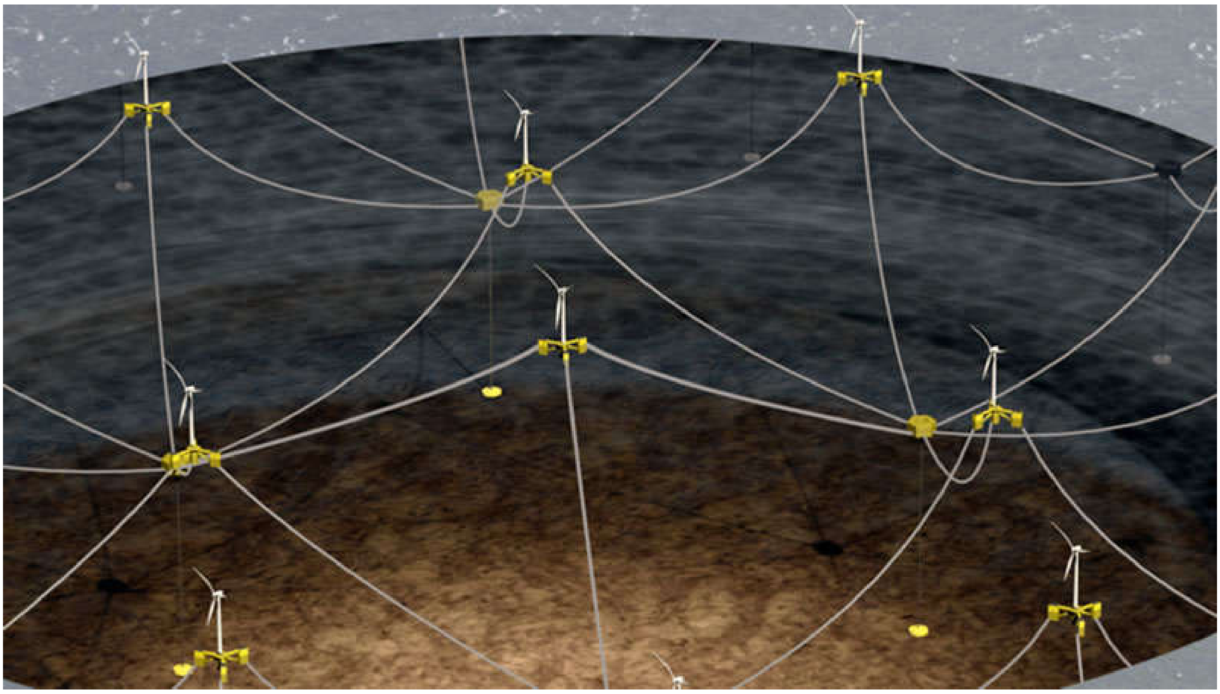
But Norway, as well as Great Britain, has an extensive offshore expertise from the oil & gas industry. And with the low activity at the moment due to low oil prices, these two countries are in a situation where companies could benefit from this and becoming a world leader within offshore renewable and at the same time diversify the economy by export of the offshore wind supply chain. But this could only be implemented with a strong subsidy and a clear long-term national plan in order to reduce the financial risk and attract investors.

Due to these circumstances, it is very unlikely, that we will see any Offshore Wind Projects outside the central North Sea in the nearest future. It is possible to install Wind Turbines on land for a fracture of the cost for offshore turbines. Turbines which could produce the same amount of power as offshore turbines

Substructures, station keeping and anchoring

The number of developers and substructure concepts is constantly growing. Even though alternative designs are suggested, the industry is currently dominated by the three key design philosophies: SPAR, Semi-Submersibles and Tension Leg Platforms (TLPs), all well-known from the offshore oil & gas industry.

Future systems will be correlated to developments in turbine design, the introduction of new materials like polyester, graphene and carbon fibre for mooring lines and tendon systems. Going towards increasingly deeper waters and larger arrays is likely to lead to new innovative mooring and anchoring solutions.

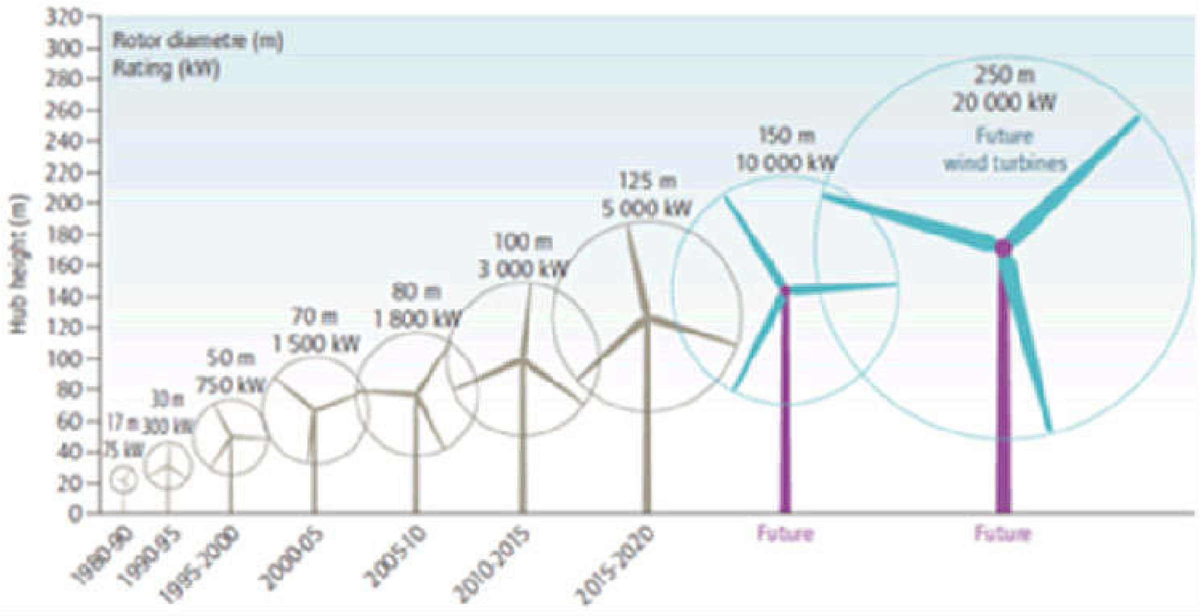


Graphic from DNV - GL showing connections (mooring lines) between floating offshore turbines (2015. DNV- GL)

Rated power and rotor size

The trend is towards increases in turbine rated power and rotor size, leading to higher energy yield and improvement in LCOE. Turbines installed offshore in 2013 had an average size of 4 MW and demonstration projects for floating wind turbine systems currently under development are applying turbine sizes of 6-7 MW.

Most likely the turbine size is bound to increase in the coming decades. Some developers beleive that 10 MW offshore turbines, with a hub height of 130 metres and a rotor diameter of 200 meters, will be commercially available in the early 2020s. For 2030-2050, the average size could grow to sizes of 10-15 MW and up to 20 MW for new installations in the later part of the period.



Growth in size of wind turbines since 1980 and future prospects according to EWEA (2015. DNV- GL)

After the Fukushima nuclear disaster in Japan, causing a meltdown of three reactors, many of the country´s nuclear power plants have been shut down and alternative energy supply is needed. One of the focus areas is wind power, and since Japan is a crowded and mountainous country, the main option is floating turbines in deep water off the rugged coastline.

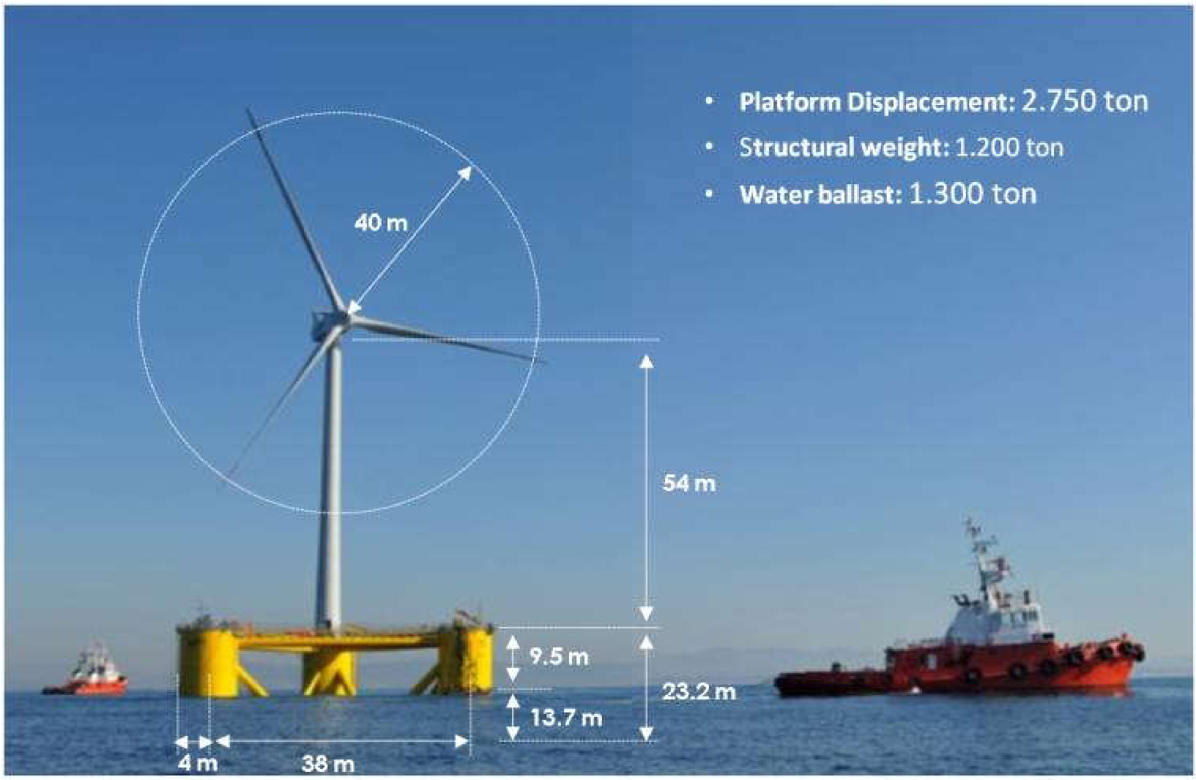
Fukushima Forward is a trial project for offshore wind power plant conducted by the Japanese Ministry of Economy, Trade and Industry. In the first phase a floating 2 MW turbine was installed.

The second phase is ongoing and include installation of two 7 MW turbines. A Swedish company is selected to provide the distributed buoyancy modules, dynamic stiffeners and connectors, cable protectors etc. (2015. Trelleborg.)

Windfloat Portugal

In October, 2011, Principle Power deployed a full-scale prototype WindFloat 5km off the coast of Aguçadoura, Portugal. To date the system has produced in excess of 9 GWh of electricity delivered by sub-sea cable to the local grid. The structure was completely assembled and commissioned onshore before being towed some 400km along the Portuguese coast (from it's assembly facility near Setubal, Portugal). Additionally, certification (or class) was an area of focus in the prototype design as it will be a future requirement for commercial projects. Principle Power continues to operate the prototype system gaining priceless operational data and experience for use in future WindFloat systems world-wide (2015. Principle)

WindFloat of the Portuguece coast (2015. Cleantechnica)



Fukushima (Japan) Floating Offshore Wind Farm (2015. Fukushima forward)

More information about cable ship (laying & repair) can be found:

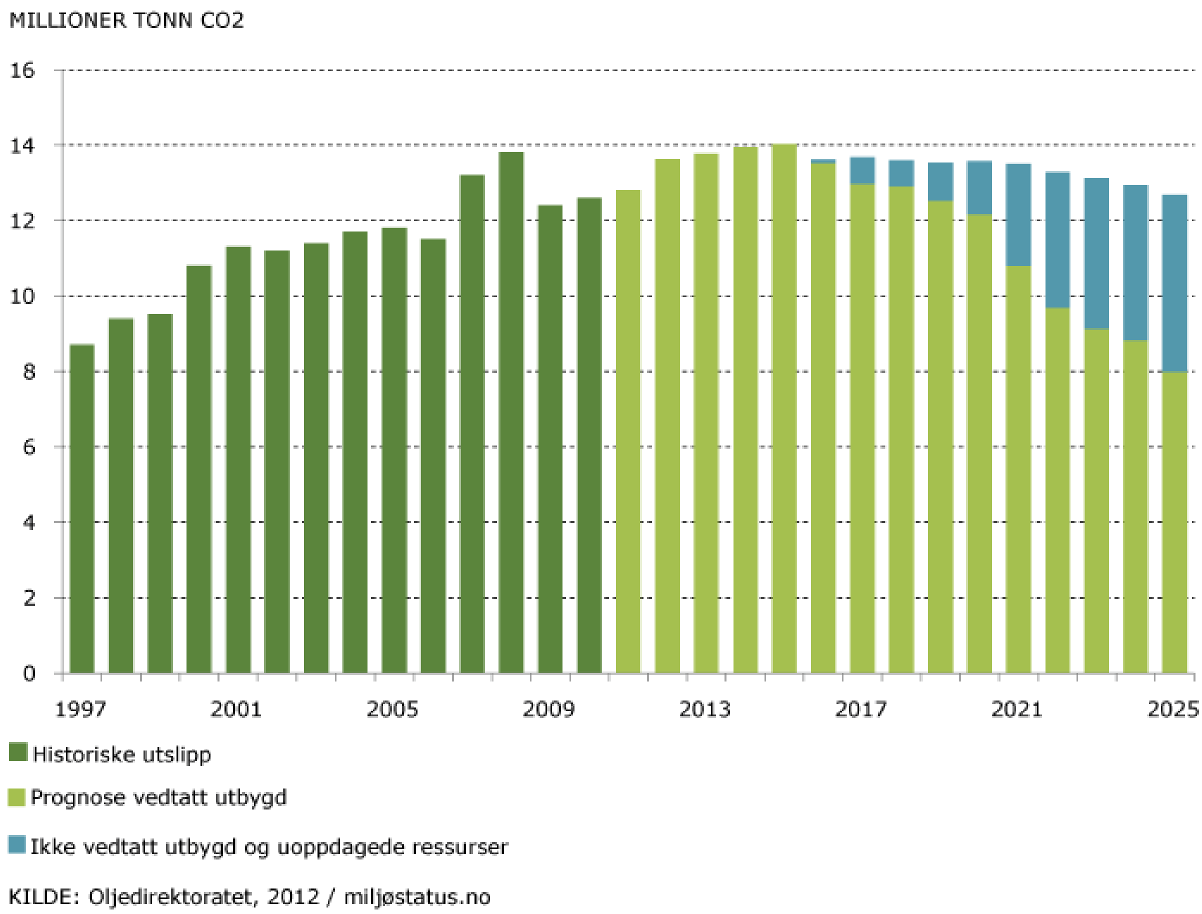
https://www.iscpc.org/ The International Cable Protection Committee (ICPC) is dedicated to the sharing of information for the common interest of all seabed users. ICPC represents all who operate, maintain and work in every aspect of both the telecommunication and power cable industry. All areas of this site are available for public viewing except for the Members area which is reserved for administration of the ICPC.

Electricity usage on oil platforms

The areas of the North Sea and the Norwegian Sea has a high density of oil fields – both on the Norwegian-, Danish- and the UK shelf we find installations potentially to be included in an electric subsea grid . At present only two fields on the Norwegian shelf are fully electrified, including British Petroleum's (BP) Valhall field. The discussion of electrification of fields on the Norwegian shelf started itwenty years ago. After three reports and impact assessments Norway has still not decided fully on electrification. This only shows some of the obstacles in the electrification debate.

Ellen Hambro, the director in the Norwegian Environmental Authorities said in a statement "that Norway's climate goals will not be possible to achieve unless we will see large cuts in discharges from the Norwegian shelf" implying that all new projects in the North Sea will have to be electrified. New fields are planned and developed in several of the countries in this study, and oil and gas possibilities will be in focus in the years to come. The North Sea and the Norwegian Sea will possibly be important regions for oil and gas production for many years, even with the oil prices we have seen in 2015. "Utsira høgden" is a large area with some of the largest findings of oil and gas in Norway's history. One of the fields on Utsira, the Johan Sverdrup field will be fully electrified as it is set in production in 2019. In the whole of the North Sea Area there are about 61 fields in production (www.norskpetroleum.no).

The decision of electrification of Utsira came in 2014 and other fields on the Norwegian shelf, as the Goliat field in the Barents Sea will be supplied with electrical power from land, which will reduce Goliat's CO_2 emissions by half (www.eninorge.com).

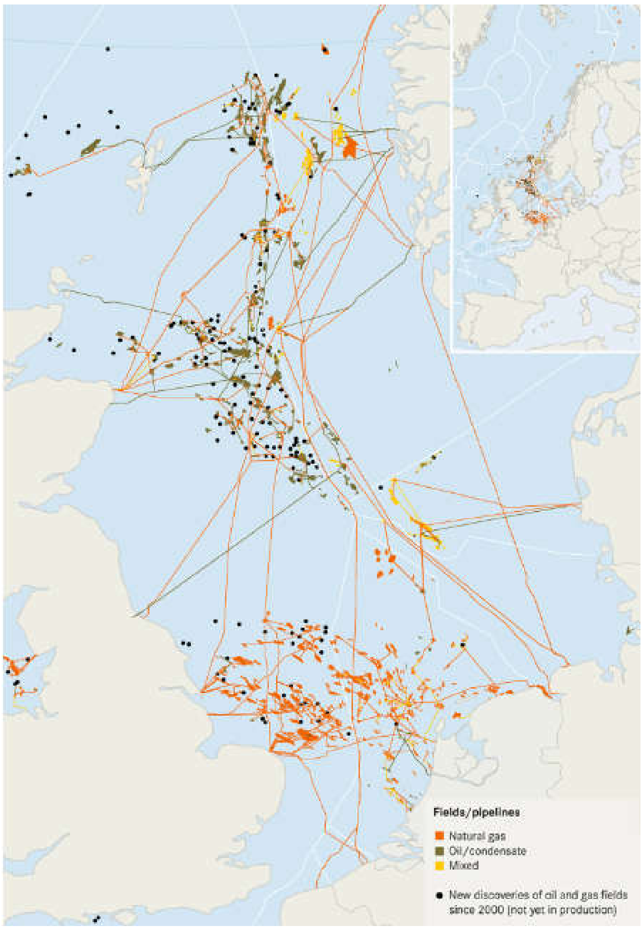


CO_2 emissions from the oil and gas industry in the period 1997-2010 and prognoses to 2025.

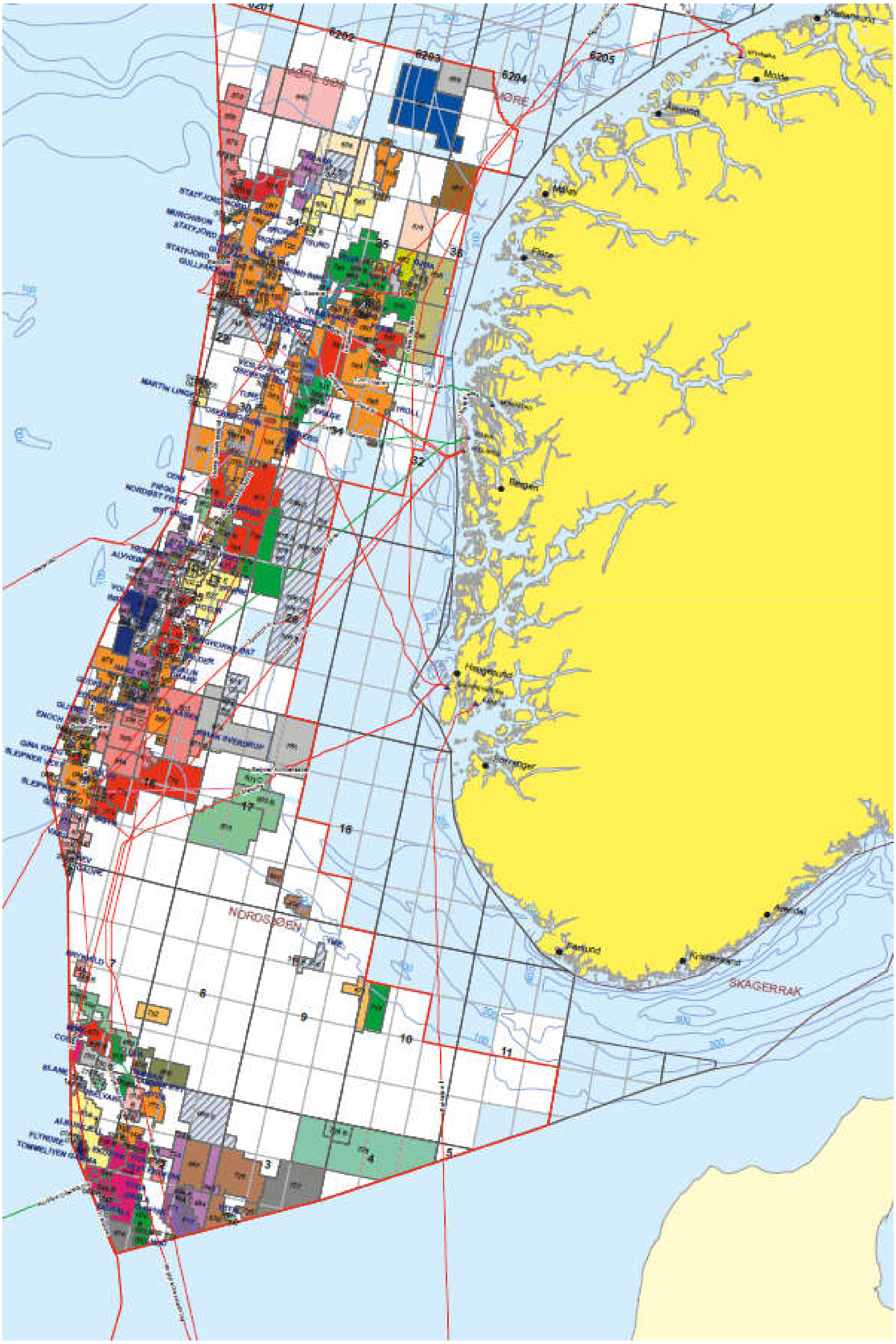
The electrification of oil and gas fields is still a hot topic in Norwegian politics. Trond Lien, the Norwegian minister of Petroleum and Energy has in the last year made several statements linked to energy politics: "Stating that the world needs more energy and more sustainable energy, renewable energy and a power grid developed to meet future challenges is a part of this picture. The use of electricity will increase in the future for example through electrification of the shelf and increased industrial production". (2014. Miljødirektoratet)

Connecting oil platforms to the network

At present only two fields on the Norwegian shelf are fully electrified. Norway's climate goals will not be possible to achieve unless large cuts in discharges from the Norwegian shelf. The Norwegian shelf is divided into regions and region I and II in the southern parts of Norway are most relevant to this study. In both these regions there are several large oil fields in productions today, new fields are planned and this will be an important region for oil and gas production for many years to come yet. "Utsira høgden" is a large area with some of the largest findings of oil and gas in Norway's history. One of the fields on Utsira, the Johan Sverdrup field will be fully electrified as it is set in production in 2019. In the whole of the North Sea Area there are about 61 fields in production (www.norskpetroleum.no). The decision of electrification of Utsira came in 2014 and other fields on the Norwegian shelf will be supplied with electrical power from land, which will reduce Goliat's CO_2 emissions by half (www.eninorge.com). The two figures below give an impression of the amount of oilfields in the project area. There is a heavy density of oil and gas fields in particular on the Norwegian shelf.



Map of the North Atlantic Oil and Gas production



Map of the North Sea area of the Norwegian Continental Shelf (www.npd.no)

Benefits

Figure 2 and 3 give an impression of the Oil and Gas production fields in the study area. In addition both the Faroe Islands and Iceland are developing the potential for an Oil and Gas industry. Given this and the already existing fields in the study area, there should be a substantial potential for electrification of some of the fields. Commitments with respect to CO_2 emissions for the countries in this study could have a positive overall effect from such a project. The possible elictrification of new Oil and Gas installations, can imply huge benefits for the CO_2 account within each country.

Cost

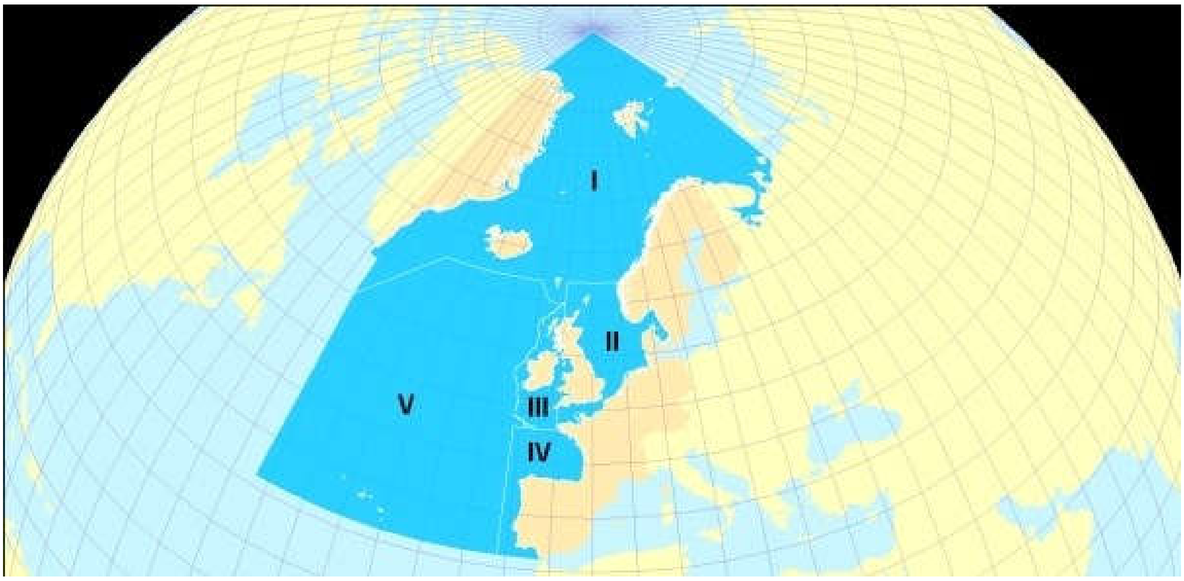
Cost estimates concerning electrification of the oil and gas fields vary a lot and are at least in Norway the centre of attention in the electrification debate. British Petroleum's (BP) Valhall field is one of the fully electrified fields on the shelf. Cost estimates from BP show that the costs to electrify this field were around 1.8 billion NOK. According to BP the electrification has been a success. The operation- and maintenance costs are heavily reduced, and the emissions are reduced by 250 tons of NOx and 300.000 tons of CO_2 a year. This can be compared to the yearly emissions from 100.000 cars. These are numbers from the oil producers – however there are several discussions at present related to the real costs of electrifying oilfields.

CO_2 emission

Reports handling the issues of electrification of oil and gas installations on the Norwegian shelf give a hint of the benefits related to CO_2 emissions. One of the largest oil production areas in Norway at present is the Utsirahøgden. These areas consist of four different oil fields, and the total emissions are approximately 800.000 tons of CO_2 pr. year. According to the Central Bureau of Statistics in Norway, the emissions from some fields are larger than the total emissions of CO_2 from the larger Norwegian cities (2015. Statistisk sentralbyrå)

Impact Assessment

Environment, natural and societal impact assessments is as a general rule applied to any project that will have possible impacts on the natural or societal resources. The European Union Environmental Impact Assessment (EU EIA) Directive applies to almost all countries in this study and gives a guidance of the issues that needs focus. In addition, each country in the study has laws and regulations derived from the EU directive that apply to environmental and social issues on a national level. The OSPAR (see Acronyms) convention (agreement from 1992) applies to any operation affecting the environment in the marine environment in the North-East Atlantic. OSPAR is the current legislative instrument regulating international cooperation in these areas, including submarine cables and oil and gas activities.



The North-East Atlantic and range of application of the OSPAR Convention (Norwegian Environmental Agency).

The environmental and societal review in larger studies should start with a screening phase where the present situation including available data and an overview of studies and reports from the study area is documented. The Environmental and Societal impact assessment program (ESIAP), and hearings of these, make the basis for the focus areas during the Environmental and Societal Impact Assessment (ESIA). The purpose of the assessment is to ensure that decision makers are conscious of the environmental and societal impacts when deciding whether or not to proceed, or form, a project. The ESIA has to include both the development- and the operational phase of the project. A proposal of a surveillance program should also be outlined for the project. (2015 EU Environmental Impact Directive and 2015. OSPAR)

What can we learn from other projects

It will be interesting to follow up on developments of similar projects, like the IceLink Project on a 1000 MW interconnector between UK and Iceland as this concerns a cable going through the same waters as an Interconnector between Iceland and Faroe Island which is a part of the NAEN project concept. The Isles project is looking at a meshed offshore network and coordination of various interconnections like the NAEN project. It has been ongoing for a number of years and may lead the way for future development in this area.

The IceLink Projcet

The IceLink project is a project designed to deliver renewable, flexible generation to Great Britain from 2024. The project aims to deliver more than 5 TWh of flexible renewable electricity per annum.

The interconnector will be approximately 1000 km long, 1000 MW HVDC transmission link, connecting east Iceland to northern GB, and offering bi-directional flows.

The entire Icelandic hydro system will provide flexibility to GB after a number of hydro repowering upgrades are completed along with the new assets.

The project is not economically viable without the support of UK Contract for Difference (CfD) and getting a UK CfD will require political support from both countries and the CfD itself will need to be adapted to the unique nature of the project.

An interconnector between Norway and Holland was established in 2008. The link has capcity of 700 MW and was at that time the longest in the world or 580 Km.

The cable between Shetland and UK is most likely to be realised in the near future. There is a lot of indication that the Icelink cable might be realised and it is technically possible to take it ashore in the Faroe Islands. All of the connections discussed for this project are most likely to happen one at a time if all of the connection require more indepth analysis and as for Greenland the necessary infrastructure is not in place for a subsea cable to be realistic in the near future.

The Isles project

According to the latest documentation regarding the Isles project (2015 www.islesproject.eu) there is a significant opportunity to take a coordinated approach to delivery of electricity generation and transmission in the Irish Sea and around the western coastal waters of Scotland – the ISLES zone.

The study demonstrates that coordinated development of harnessing renewable resources in the ISLES zone can benefit consumers in Ireland and Great Britain. The ISLES vision is a meshed offshore network to harness the wind, wave and tidal resources in the area.

The benefits are seen to be reduction in cost of Governments and consumers, project developers, system operators. Policy barriers, regulatory barriers and commercial and technological barriers could stop a project of this kind.

A number of important challenges regarding this project remain to be resolved, including operation of energy markets and promotion of innovation and investment, to facilitate major coordinated development.

"The main recommendations of ISLES have key implications for governments, regulators and industry at national and EU level. The ISLES partners consider that the study will contribute to understanding at jurisdictional and EU levels of the challenges and opportunities for enhanced cross-border cooperation on renewables and grid development."

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Acronyms

Acronym	Explanation
A	Ampere unit of current (I)
AC	Alternating current
DC	Direct Current
HVDC	High Voltage Direct Current
V	Voltage (V)
Watt (W)	Unit of power named after James Watt
kW	1000 Watt
MW	1000.000 Watt or 1000 kW
GW	1000.000.000 Watt or 1000 MW
TW	1000.000.000.000 Watt or 1000 GW
Wh	Unit of energy = power * time, 1 Wh is the energy produced by 1 W over a period of one hour. In a year there 1 kW of power produces 8760 kWh
kWh	1000 Wh
MWh	1000.000 Wh or 1000 kWh
GWh	1000.000.0000 Wh or 1000 MWh
TWh	1000.000.0000.0000 Wh or 1000 GWh
SCOF	Self Contained Oil-Filled (cable type)
XLPE	Cross-linked polyethylene (cable type)
EPR	Ethylene propylene rubber (cable type)
MI	Mineral insulated
IEC	International Electrotechnical Commission
CfD	Contract for Difference CO
OSPAR	OSPAR is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic.
EU EIA	European Union Environmental Impact Assessment

Appendix A
North Atlantic Energy Network
Faroe Islands

Introduction

The project North Atlantic Energy Network is not the first investigation of the possibilities of connecting countries in the North Atlantic with subsea electricity cables. The tema has been an issue in Faroes for the last forty years. In 2007 an Icelandic/Faroes report "Indledende vurderinger af muligheden for at lægge elkabel fra Island til Færøerne"[1] concluded, that a connecting cable was technically and legally possible, and that the economy could be interesting, if the amount of electricity transmitted was of a certain amount.
In 2012 the Icelandic and Faroese governments signed a Memorandum of Understanding on cooperation in the energy sector, where they expressed their willingness to continue to explore the possibility of developing an electricity interconnection between Iceland and the Faroe Islands.
The faroese interest in an undersea cable running between the Faroe Islands and Iceland or between the Faroe Islands and Scotland is to establish a possibility to transmit electric power between the countries.
Even if both Faroe Islands and Denmark are part of the main project, this part of the project deals only with Faroese matters. The danish contributions are in form of input to technical matters in the main report.

Electrical Energy production

Electricity demand in the Faroe Islands is met via power plants driven by oil, hydro and wind.
In 2012, total electricity consumption, including grid loss, was 292 GWh, with 181 GWh from oil, 100 GWh from hydro and 11 GWh from wind. In 2014, production from wind was 35 GWh and will in all probability in 2015 grow to 56 GWh annually. Generally, there is a period in the summer in the Faroes when rainfall is limited, coupled with periods when there is little or no wind. Ultimately, this means that the Faroes must rely on oil-fired power plants to produce electricity with water and wind playing a role in reducing the consumption of heavy oil. The Figure below shows electricity consumption subdivided into oil, hydro and wind. It shows that in the summer months the contribution from water and wind is very little and thus a greater portion of demand has to be met by production utilizing heavy oil.

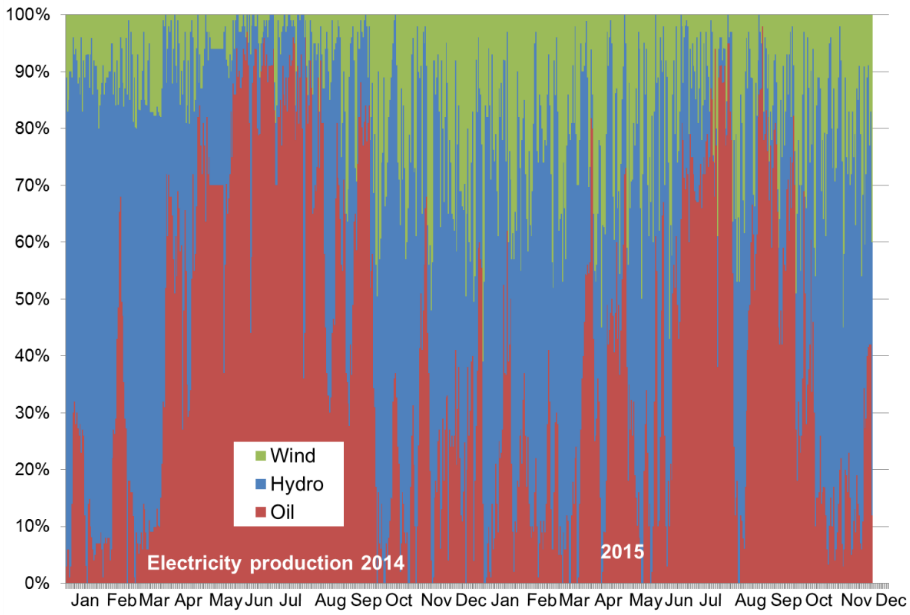

Figure 1. Distribution of electricity production between wind, hydro and oil in Faroe Islands in 2014 and 2015

[1] "Indledende vurderinger af muligheden for at lægge elkabel fra Island til Færøerne", Jarðfeingi 2007.

Production from wind

Wind turbines have been a part of the Faroese grid since 1993, but not until the five 900 kW wind turbines erected at Nes came online in November 2012 did wind energy make a meaningful impact on the net contribution between oil, water and wind.

When electric usage is low, e.g., at night, and wind is present, by year-end 2012 some 30% of production was derived from wind. With such a large portion of production coming from wind, several challenges arise, because wind energy is not stable.

These challenges grew even more complicated in 2014 when thirteen 900 kW wind turbines came online. Now some 20 MW of wind energy is available, which corresponds to 40-50% of total annual available power. When such a large portion of total power is derived from wind, this places new demands on the grid, especially the small and vulnerable grids found in the Faroes.

Links into the resilient international grid infrastructure enables Denmark, for example, to export electricity when its production is greater than its demand and to import electricity when production is less. Therefore, Denmark can maximize production from wind (ca. 50% by 2020). At the same time, such a well-integrated AC electric grid can provide the necessary stability across international boundaries.

When wind turbines initially only contribute to a limited extent to the stability of the grid, any subsequent increase in the input of the wind turbines into the grid necessitates an ever-increasing need for grid stability from other sources. Here synchronverters and/or large flywheels at the hydropower plants could contribute to maintaining the stability of the grid.

In connection with the erection of 13 new wind turbines in 2014, SEV determined that the first two years of operation would be trial years during which the electricity grid and procedures could be developed and refined so that an greater amount of wind energy could be integrated into the Faroese grid.

It is intended that a comprehensive evaluation be conducted regarding the future expansion of wind energy in the Faroe Islands.

Wind turbines have developed considerably over the last few years. With this in mind, it is recommended that possible locations for new windfarms be identified.

The resultant map shall be used to determine where the new windfarms should be located and to assist in planning how best to ensure that the grid can readily accept future wind production.

The government should assume the responsibility for arranging access to the designated areas, setting up the appropriate weather stations, carrying out environmental impact assessments and gaining the approvals necessary to implement a new option for wind energy potential.

The mapping of potential wind energy locations requires the participation of several government authorities. Close collaboration can help to ensure that any new windfarm projects can be quickly implemented.

Production from hydropower

The first hydroelectric plant was built at Botni in 1921. Since then, hydropower has become a good supplement to the heavy oil power plants.

All the water turbines in the Faroes are considered to be base-load units, and thus can operate more than 7,500 hours per year (85%), if sufficient water is available.

The water reservoirs scattered throughout the country are subdivided relative to the amount of water required for normal operation and for emergencies. Thus, 45% of the reservoirs are for normal operation, while 55% are set aside for emergency use. Water seldom runs out over the dams, thus there is no wastage.

All hydropower plants have, however, limited water storage capacity, and under normal operations in the Central Production Area the time required to drain the reservoir is between 7 hours (at Strond) and up to 413 hours ~ 17 days (at Vestmanna). The power plant at Eiði has a joint reservoir for three turbines with a drainage time under normal operations of 135 hours ~ 5.5 days.

Under normal operations, the drainage time in Suðuroy is between 77 hours ~ 3 days (turbine 2 at Botni) and 217 hours ~ 9 days (turbine 1 at Botni).

The water catchment areas in the Faroe Islands are different from those in Sweden and Norway where considerable amounts of water are contained in the snow accumulation, which melts in the spring. This “reservoir” of water provides sufficient water for several months of production.

Short drainage times and a relatively long period with little rainfall during the summer months means that hydropower in the Faroes cannot be considered a source of "secure" power, but only as a supplement to total electricity production. The various reservoirs and possible catchment areas can thus contribute to reducing the consumption of heavy oil, but cannot lessen the need for other power sources.
There is a potential for building larger reservoirs and thus making power from hydro more reliable also in summermonths.

Production from oil-fired power plants

Oil-fired power plants have a long history and have always been a part of Faroese electricity production. These types of power stations are considered to be reliable and secure sources of energy because they are not dependent upon the external vagaries of wind and rain. Of course, there will be periods when the power plants will stand idle during routine maintenance or repair, but otherwise these power plants can operate on "stand-by" or generate a little or a lot of power depending on the need.
Originally, the power plants were built as individual local plants, but over time they were linked into the 60 kV grid and today they provide excellent electricity production security for the Faroe Islands as a whole.
The oil-fired power plants can be subdivided into:
· Base-load units – more than 7,500 annual operational hours (85%)
· Peaking units – up to 1,000 annual hours (<12%)
· Emergency units (limited hours – only as needed)

Similar to the hydropower plants, oil-fired power plants have the capacity to ensure stability within the electricity grid and can provide 5-6 times the normal power in the event of a power failure. Because electricity production to date has been derived from hydropower and oil-fired power plants, historically there has been excellent correspondence between consumption and capacity within the Faroese electricity grid.
On Suðuroy, the new pelagic fish processing factory has resulted in the base-load engine (motor 3 at the Vági power plant) running many hours under a heavy load, which increases the wear and tear on the engine. Therefore, a quick solution to increased power production is necessary. There are two possibilities: 1) lay a cable to the Central Production Area, or 2) increase the current capacity at the Vági power plant. An AC cable connection has the advantage that the total electricity grid is rendered bigger and the power plants in both Suðuroy and the Central Production Area could collectively contribute to greater capacity and stability throughout the entire system. Thus, a cable connection between Suðuroy and the Central Production Area would result in a stronger grid overall.
Today, in the Central Production Area there are several base-load motors (e.g. motors 3 and 4 at the Sund power plant) that have run for many, many hours and therefore cannot be expected to remain fully operational as base-load motors much longer. In future, these particular motors should be used as peaking load units (i.e. during periods of momentary high consumption) or in special circumstances, e.g., breakdowns.
Therefore, greater production capacity must be arranged that could replace these particular power plant motors. SEV has taken the steps necessary to obtain the required approvals from the government authorities and it is planned that a new power plant at Sund will be operational in 2017. This new power plant will incorporate advanced leading-edge technology to ensure a viable, long-lived future that will also include options for a variety of different fuel types.
At the same time as the new Sund power plant is readied, it is recommended that a future long-term plan be drafted that addresses the inter-relationship between oil-fired electric power plants and wind and hydropower plants relative to current and future, accelerated electrification as well as the possibilities of storing power, e.g., in a Pumped Storage system. This study shall contribute to and serve as a foundation for a more comprehensive plan for the expansion of the entire energy system in the Faroe Islands, a plan that will ensure, as much as possible, the use of renewable energy resources in the future.

Production from tidal current power plants

There are several places with excellent conditions for tidal power generation, i.e. the tidal current is over 2.5 meters per second (5 nautical miles) and the depth is more than 40 m.

Moreover, peak tidal currents vary from place to place, meaning that the greatest potential for electricity production does not occur at the same time at the different locations. Two excellent locations are Skopun Fjord and Vestmanna Sound; the difference in peak tides is three hours.

Electricity production occurs in essentially the same manner as with wind turbines, except that the advantage of tidal current production is its predictability. Such a power plant can be viewed partly as back-up security and partly as a base-load unit.

The technology continues to be expensive to deploy, but its development should be closely followed. It is recommended that the technical specifications for such a power plant be compiled and the permitting requirements outlined so that it might be possible to launch several trials within the next few years.

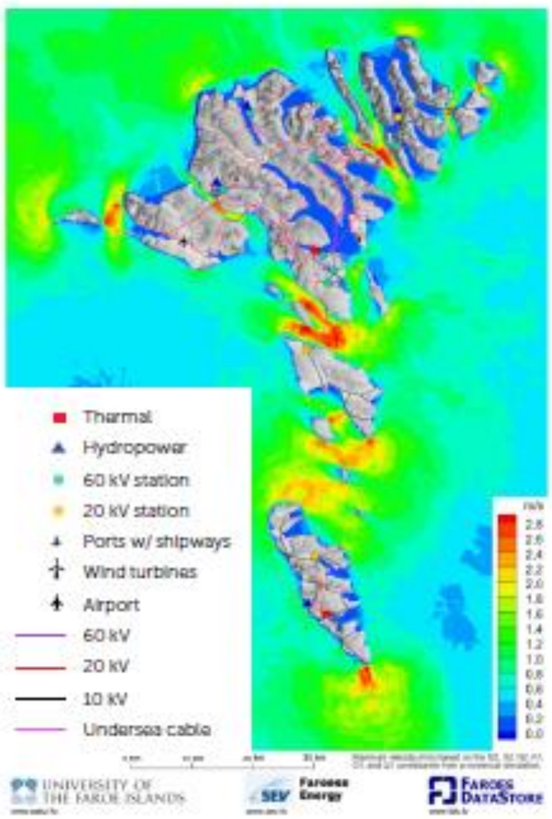

Figure 2
Tidal current tidalenergy potential in the Faroe Islands

Solar energy

Solar energy can be utilized via solar panels that heat water or solar cells that produce electricity. Both possibilities have been tried in small settings in the Faroe Islands, but, compared to the investment, little is gained, especially in winter. Considerable development has occurred in solar energy over the past few years and production per area has increased and the cost is less.

The future outlook for solar panels and solar cells built into the exterior facing of a building (climate screens) appears good. When hydro and wind production is lowest in the summertime, solar energy could serve as supplemental production during this particular time of the year.
Developments in this area should be closely followed.

Waste incineration

District heating was implemented in the Faroe Islands in 1988 when central heating pipes were laid from the Sandvíkarhjalla waste incinerator to a new housing development above Hoyvík. In 2008, this infrastructure was expanded by laying central heating pipes to the Sund power plant. Thus, the district heating network was connected to two heat sources that in turn supported each other and increased overall energy security.

More wind energy production results in less oil consumption at the Sund power plant, which in turn reduces the production of heat from this power plant. It is recommended that the possibility of burning waste be investigated to enhance the expansion of the district heating system in Tórshavn, and that heat production be supplemented by large heat pumps so that operations can remain flexible and of good quality.

Biogas power plants

There is considerable organic waste generated by the fishing industry and agriculture in the Faroe Islands. This waste pollutes the environment and is difficult to dispose of safely. The fishing industry has, however, discovered a clever way to handle a large portion of its “waste”. Another possibility is to use this organic waste as the basis for biogas production that could otherwise be linked into the district heating system.

It is recommended that the technical specifications for a biogas power plant be researched and compiled in order to explore and study the potential and the operational conditions of such a power plant.

The Grid and Electric System

The electric system and stability

The electricity system or infrastructure in the Faroes is, in the main, divided into two grids (see Figure 3), a small grid on Suðuroy and a somewhat larger grid in the Central Production Area of the Faroese electricity company SEV. In addition, there are some smaller islands that derive their electricity from small, oil-fired plants.

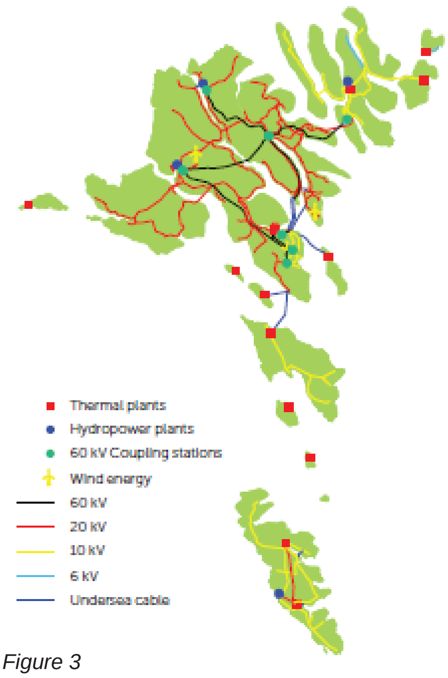

Figure 3
Faroese electric system

Certain prerequisites must be in place in order to adequately operate a national electric system. The system must have the requisite internal inertia that will ensure that everything operates as it should even in the event of a malfunction, such as a short circuit.
For the Faroese grid, it is the hydropower plants and the motors at Sund especially that ensure sufficient inertia within the system. The size of the flywheels on the water turbines are also of importance, because a large and thus heavier flywheel makes a considerable difference.
On the other hand, wind turbines to a much lesser degree are able to ensure sufficient inertia in the system, because they only supply a fifteenth of what the water turbines and the motors provide. This means that, if many wind turbines were linked into the grid, it would be necessary to ensure stability in another way, e.g., by having the motors and water turbines idling on standby or by linking synchronverters into the grid.
The Faroese electric system is small, tenuous and vulnerable because it is not linked to the grids of other countries. And this situation is compounded when even more wind turbines are linked into the system. Thus, it was considered that at most only 30 – 40% of total production could come from wind turbines. However, experience with the new wind turbines indicates that this percentage could be higher. Therefore, it is recommended that a detailed technical and economic analysis with recommendations be undertaken to ensure commercially reasonable investment when further wind turbine expansion takes place.

Grid development plan

There is a need for a plan relative to the development and expansion of the electric system in the coming years. A grid development plan would be a useful tool and it is recommended that a report be prepared analysing the various development options and the level of investment required.
Moreover, the plan should also address the transmission power line net, both the high and low tension lines, i.e. 60 kV, 20/10 kV and 230/240 V.

Technical Procedures

In the future, more and more different types of electrical equipment will connect to the grid. In many cases, this equipment will be owned by the customers themselves and therefore it will be necessary to stipulate specific conditions and technical requirements relative to the connection of this equipment into the grid to ensure equal treatment for all. It is recommended that a distinction be made between production entities and large consumers, e.g., immersion heaters, heat pumps and other equipment with varying electricity consumption. Approved regulations regarding connection to the grid should be drafted.

Electrification

Electrification, coupled with increased wind energy production capacity and possibly other sources of renewable energy, will enhance the potential use of electricity during periods of peak wind. Otherwise, the potential production will be lost.
At present it is not possible to store significant amounts of electricity, because, in the main, electric power must be consumed at the same moment it is produced. Thus, there must be a balance between production and consumption.
If it were possible to connect and disconnect large consumers of electricity, this would help minimize production loss. These consumers are, e.g., refrigeration compressors, immersion heaters and heat pumps. In addition, it is possible to use over production to pump water back up to a hydropower reservoir (Figure 4).
There should be an emphasis on how economic incentives could accelerate electrification efforts and how these could be advanced in a reasonable and effective manner.
SEV is underway to shift out all the electric meters. This work will be completed in 2015 and thus it will be possible to wirelessly measure all electricity usage. In this connection, it is recommended that a study be carried out to determine if it would be desirable to adjust the price of electricity so that it would vary throughout the day and would also be linked to annual usage and power consumption. Also it should be studied whether the price of electricity could vary based on what the electricity is used for, such that less would be charged for electricity for e.g.heat pumps.

Subsidy regimes and excise taxes

To hasten the shift to green energy resources, it is advisable to investigate various support initiatives relative to the purchase and installation of more green products or equipment. It should be possible to offer direct financial incentives, tax allowances, VAT-free or similar programmes to encourage the general public to invest in the latest and greenest technology.
Excise and similar taxes or surcharges could also be used as an effective tool to promote a more "greening" trend. For example, an excise tax could be levied on petrol for vehicles or on oil-burning furnaces. The VAT on heat pumps could be reduced and it is possible to offer tax allowances for renovations that reduce the heating demands of buildings and private homes. It is recommended that broad political agreement be forged in this area.
Such an initiative shall, however, be carried out consistent with a comprehensive evaluation of the economic impact and not just a desire to move from fossil fuel at any price.

Electrical market (prices)

The Faroese electricity marked is vertically organized as the electricity company SEV is a de facto monopoly owning almost 100% of the production, the transmission grid and all the distribution system. The company's activities are regulated in an electricity law administered by the Faroes energy authorities. The electricity prizes are the same for the same user groups throughout the country. The overall prize consists of an electricity prize and VAT.
The prizes are different for different user groups, and SEV is right now looking into differentiating the prizes day and night to cope with the intermittent production and the unequal usage of electricity in daytime and night-time. The differentiating will furthermore be an incitement for enhancing the electrification of energy usage.

Energy storage - Pumped Hydro

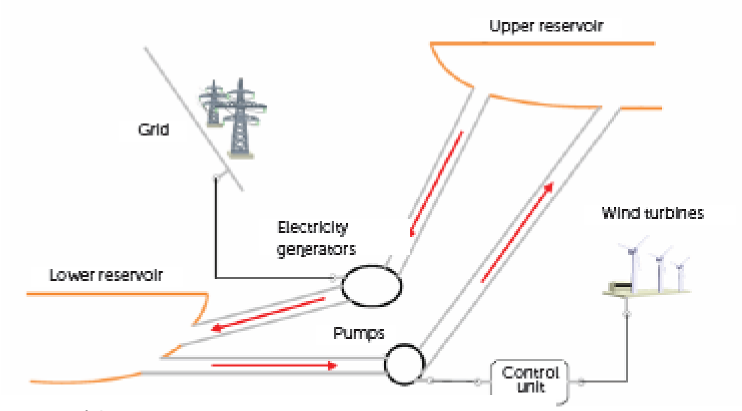

Figure 4 Pumped Storage
Demonstration of a wind/water energy storage system

Earlier studies have shown that there is good potential for the construction and operation of pumped storage power plants in the Faroe Islands. In 2013, the Nordic Council provided financial support for a preliminary study for such a facility in Suðuroy. The report[2] examines the technical issues and focus especially on the optimal size and related costs.

Based on the above-referenced report, a detailed analysis of the possibilities of constructing a pumped storage power plant is recommended. It will be a major challenge to discover exactly how pumped storage and wind power will work together and whether the pumps can quickly adjust to fluctuating wind. The report shall also discuss whether an independent, stand-alone power plant or one linked into the grid is the best option or whether it would be possible to use either. In addition, the report shall explore which locations in the Faroes are most appropriate. It is recommended that a Pumped Storage power plant be set up and evaluated in a special report.

[2] Wind power based pumped storage. Nordic Energy Research 2013

Cable possibilities involving Faroe Islands

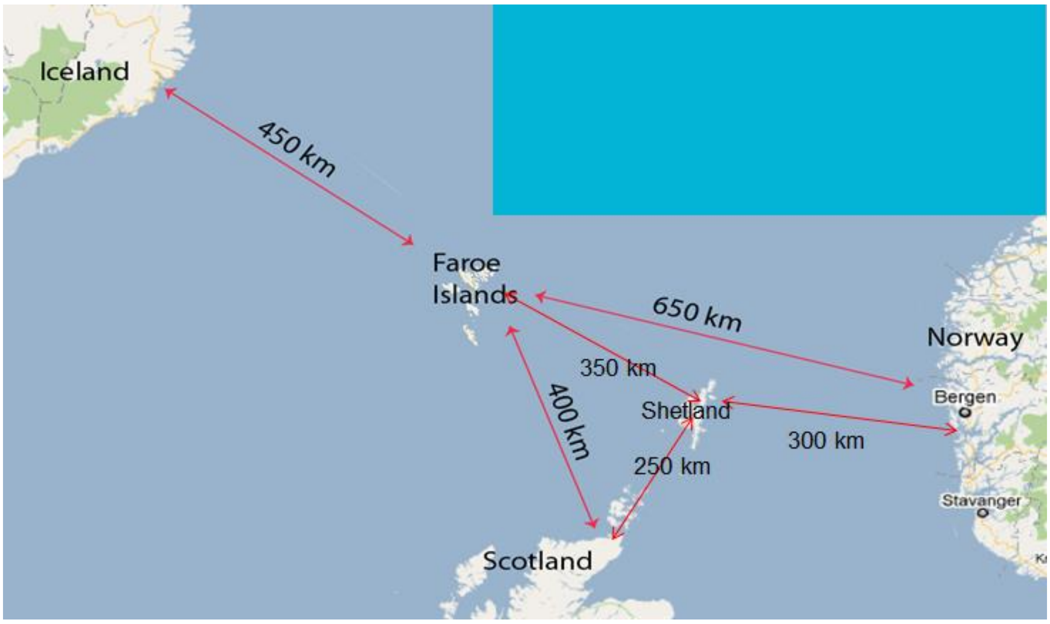

Figure 5. approximate length and depth of some possible cable routes involving Faroe Islands. (Google Maps)

Cable route	Approximate length (km)	Maximal depth (m)
Iceland - Faroes	450	500
Faroes - Shetland	350	1100
Faroes – Scotland	400	1100
Faroes – Norway	650	1500

Table 1

The picture and table above show approximate length and depth of some possible cable routes involving Faroe Islands.

It is interesting to note that given the fact, that there are good reasons for having cables as short as possible and as shallow as possible[3], that it could make good sense to connect the whole area with Faroe Islands and Shetland as interconnection nodes.

[3] Worzyk T. Submarine Power Cables: Design, installation, repair, environmental aspects. Berlin: Springer-Verlag Berlin Heidelberg; 2009

Connection point in the Faroes

Taking account of the size of converterstation at a connection point, it is likely that there will be only one such connection point. This has to be choosen with regard to

- the cable routes to and from the Faroes
- connections points to the high voltage transmission network
- connection points from power production units (windfarms etc)
- access to other infrastructure (construction and service)

In order to choose the best cable route, there are also several considerations to take

- fishing grounds
- anchors
- natural hazards landslides, earthquakes, ocean current
- places where it is possible to protect the cable

From Iceland most likely the cable would be laid from Reyðarfjørður on the south/east coast.
In The Faroes the connection point most likely will be on one of the two main islands, Streymoy or Eysturoy.

Cable sizes and cable prizes

The factors most influential on cable cost is of course length and size(transmission capacity) and also the environmental factors, where depth to the seabed is most important (see also the main report)
A very approximate estimate of the cost of a 500 km, 100 MW connection between Iceland and the Faroes was made in 2007[4] and updated in 2012 says a prize of 2,5 bio DKK (370 mio USD) included cable cost, converterstations on both sides and laying the cable. An estimate of a 600 MW, 1070 km cable between South-East Iceland and Peterhead in Scotland says 14 bio DKK (2,1 mio USD) also included cable cost, converterstations on both sides and laying the cable.[5]

[4] "Indledende vurderinger af muligheden for at lægge elkabel fra Island til Færøerne", Jarðfeingi 2007/2012

[5] IceScot Submarine Power Cable from Iceland to Scotland. Reykjavik Iceland 25th of March 2011
Annad veldi ehf.Skuli Johannsson

Cable for supplement of Faroese electricity production or cable for import or cable for both import and export

This is a crucial question regarding the economy of cable projects. For it is very clear, that it is the amount of transmitted electrical energy that shall finance the project.
This can be seen in figure 2, where a summary of the calculations in (6) are presented.
The cost of energy from the cable goes down from roughly 1 DKK/kWh with a transmission of 350 GWh/year to 0,6 DKK/kWh with an increased transmission to 700 GWh/year.

Rough estimates of the cost of production from subsea cable between Iceland and Faroe Islands*

JARÐFEINGI
FAROESE EARTH AND ENERGY DIRECTORATE

	Cost of production on Faroe Islands (DKK/kWh)
350 GWh/year through the cable*	1,0
500 GWh/year through the cable*	0,7
700 GWh/year through the cable*	0,6
Windenergy in Faroe Islands**	0,35
Heavy fuel based el in Faroe Islands**	> 1

*: Cost of production 2007 estimated to 2012 level
**: Estimated cost of production in Faroes in 2012

Some presumptions:

100 MW cable connection.

Lifetime 30 years, O&M 1% , interest rate 5%. Cost of electricity from Iceland: 0,22 DKK/kWh.

Overall powerloss15%, included cable, converterstations, the faroese tranmission and distribution grid.

680 mio. DKK for reinfocment of grid and backup kapacity in Faroe Islands.

* Jarðfeingi / Orkustofnun 2007- revised 2012

Figure 6. Estimates of cost of production from subsea cable between Iceland and Faroe Islands[6]

It is therefore important to have a good indication of the future development of the Faroese electrical energy production and consumption. There has in 2015 been published an official report [7]on these issues, as you can read some parts of in the upper part of this report.

6 “Indledende vurderinger af muligheden for at lægge elkabel fra Island til Færøerne”, Jarðfeingi 2007.
7ACTION PLAN. Report and Recommendations on the future electric energy system of the Faroe Islands.
Faroese Ministry of Trade and Industry January 2015

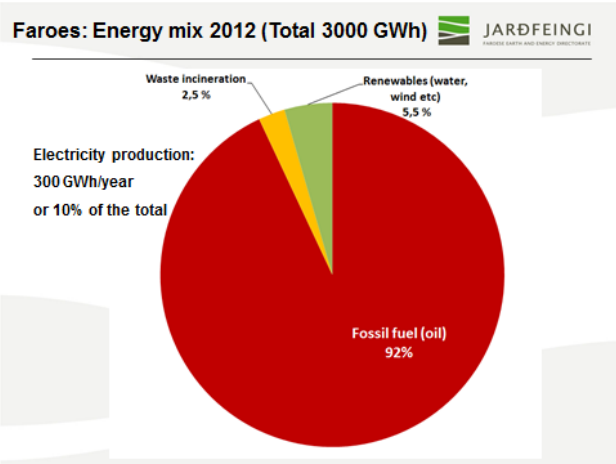

Figure 7. 2012 energy mix Faroe Islands.

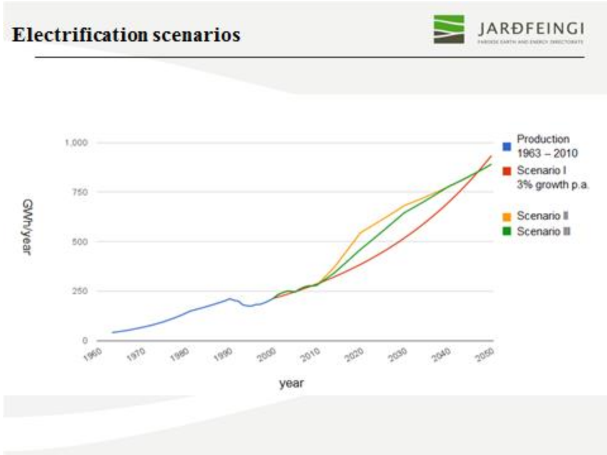

Figure 8. Electrification scenarios

It is an important fact to notice, that over 90% of the primary energy comes from heavy fuel and diesel (fig 7), and that in 2015 the electricity production will be around 310 GWh with approximately 40 % coming from heavy fuel. It is also important to notice the governmental energy policy[8], which aims at electrifying all the heating of buildings and all the transportation on land. Together with the general increase in energy usage this will eventually lead to a rise in electric energy usage to about 1000 GWh/year. (see figur 8)

This is interesting in the cable context. First, because as can be seen in figure 9, there will be produced a lot of energy – maybe from 300 to 400 GWh/year with heavy fuel, even if the share of wind energy grows very much. This is mostly due to the fact, that in the summer months there is lack of both wind and rain, and the need for "secure" electricity from heavy fuel is big[9].

Accumulated need for "secure power" production in the period 2013 - 2022

			50 MW windpower in 2022		"secure power" production
	Usage	Hydro	Installed power	Production	
Year	[GWh]	[GWh]	[MW]	[GWh]	[GWh]
2013	299	110	7,3	21	168
2022	464	110	50,0	111	243

2022:	243 GWh/year produced from heavy fuel
	90 GWh/year "not used" windproduction
2030: ??	??? GWh/year produced from heavy fuel
	?? GWh/year "not used" windproduction

Figure 9 Scenarios of future powerproduction in the Faroe Islands

[8] Comprehensive Plan for Electric Energy in the Faroe Islands.
Vinnumálaráðið / Ministry of Trade and Industry 2011

[9] Etablering af nødvendig el-produktionskapacitet. Idéoplæg, Rev.6a, September 2013. Ingeniørfirmaet P.A. Pedersen

Secondly, it is interesting in a cable context to notice, that the future electricity production will be very much from wind energy. This is because the Faroes are among the best wind sites in the world (figure 10) and therefore existing wind turbines have a very high capacity factor (above 42% producing more than 3,9 GWh/MW/year. SEV 2015)

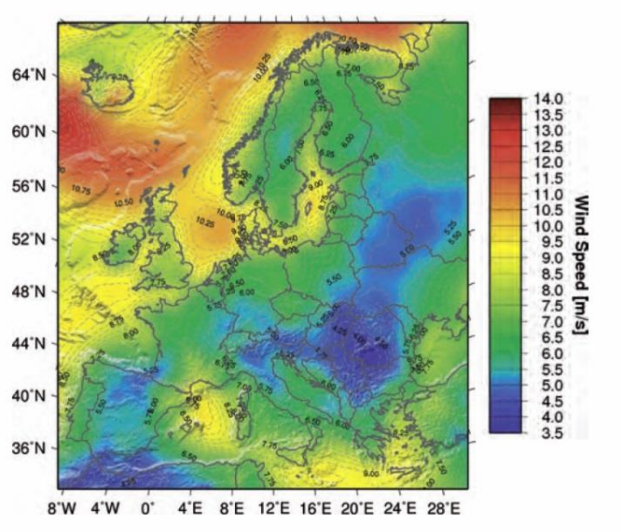

Figure 10. Windregimes in Northwest Europe[10]

As you can see from figure 9, with more wind turbines installed, there will be much more surplus wind energy that cannot be used because of the stochastic nature of wind energy and the mismatch between production and usage. The amount could be above 200 GWh/year and could be transmitted through interconnectors to other markets.
Now the last interesting fact in the cable context is to mention the possibilities that have been mentioned about making very big wind farms in the Faroes with the purpose to export renewable energy through one or several interconnectors. Figure 11 shows a slide from a presentation by Jarðfeingi, where a windfarm of 600 MW is placed in the area south of the capital Tórshavn. This farm could produce over 2000 GWh/year. Compared with a similar project in Shetland (Viking Windfarm[11]), the farm could generate an income of up to a billion DKK/year depending on energy prizes.

10

11 http://www.vikingenergy.co.uk/the-project

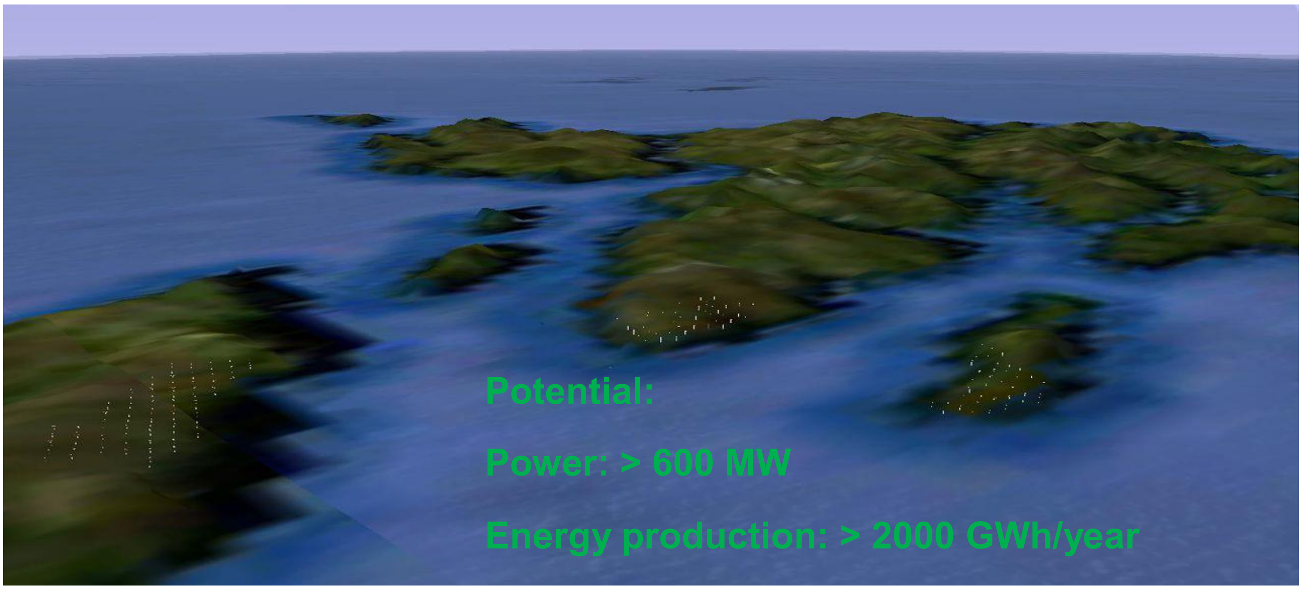

Figure 11. Imaginary windfarm south of Tórshavn, for export of windenergy.

Conclusion

The above mentioned cable scenarios can sum up to:

- A 100 MW IceFar cable is possible, but might be too small to be economically competitive.
- A 600 MW IceScot cable is possible, but also with doubtful economy.
- Faroe Islands and Shetland have "offshore wind conditions on land".
- Large windfarms in the Faeroes and Shetland need powerful interconnectors.
- A cable from Iceland to Scotland could be laid via the Faroes and Shetland, and made even bigger to be able to transmit both energy from Iceland and energy from the Faroes and Shetland to Scotland and Europe. A probable synergy effect could be to transmit hydropower from Iceland in summer and wind power from the Faroes and Shetland in winter.

Appendix B

North Atlantic Energy Network

Greenland

The Greenland Innovation Centre
construction • energy • environment

Greenland Innovation Centre

Arne Villumsen **November 2015**

Table of content

Conclusion.

Greenland has a big hydropower and solar energy potential, which is not known in detail. Further work is needed to map the potentials. It is suggested that a domestic electricity grid is established starting on the west coast with 3 cities (Nuuk, Maniitsoq, and Sisimiut). Hydropower potential within this area is better known and should be used for this grid. Industrial development including mining should benefit from the grid and the hydropower. Future enlargement of the domestic grid to cover most of the west coast of Greenland where the cities are can be foreseen. For distant cities and settlements focus should be on local sustainable energy sources and on reduced energy consumption f.ex.via improved insulation of houses and the use of heat pumps. Due to lack of infrastructure and experience a cable connection between Greenland and the neighbouring countries is not realistic in the nearest future. The use of the energy potential should be managed as flexible as possible – f.ex following the Icelandic way some 50 years ago, where an industrial partner "exported" energy via processing imported raw materials for metal production and gave the economic base needed for grid development. Cooperation with the North Atlantic Countries and with Nunavut and Labrador should continue and be strengthened for exchange of experience and for an optimal development and use of the enormous energy resources which are available in Greenland.

Introduction.

Greenland – figure 1 - is the biggest island in the world. It is a part of the North American Continent. Kap Morris Jesup, the most northerly situated locality in Greenland is 740 km from the North Pole, and Kap Farvel, the southern tip of Greenland is at the same latitude as Oslo. From north to south the distance is 2670 km; from east to west on the widest place is 1050 km. (Statistisk Årbog 2015)

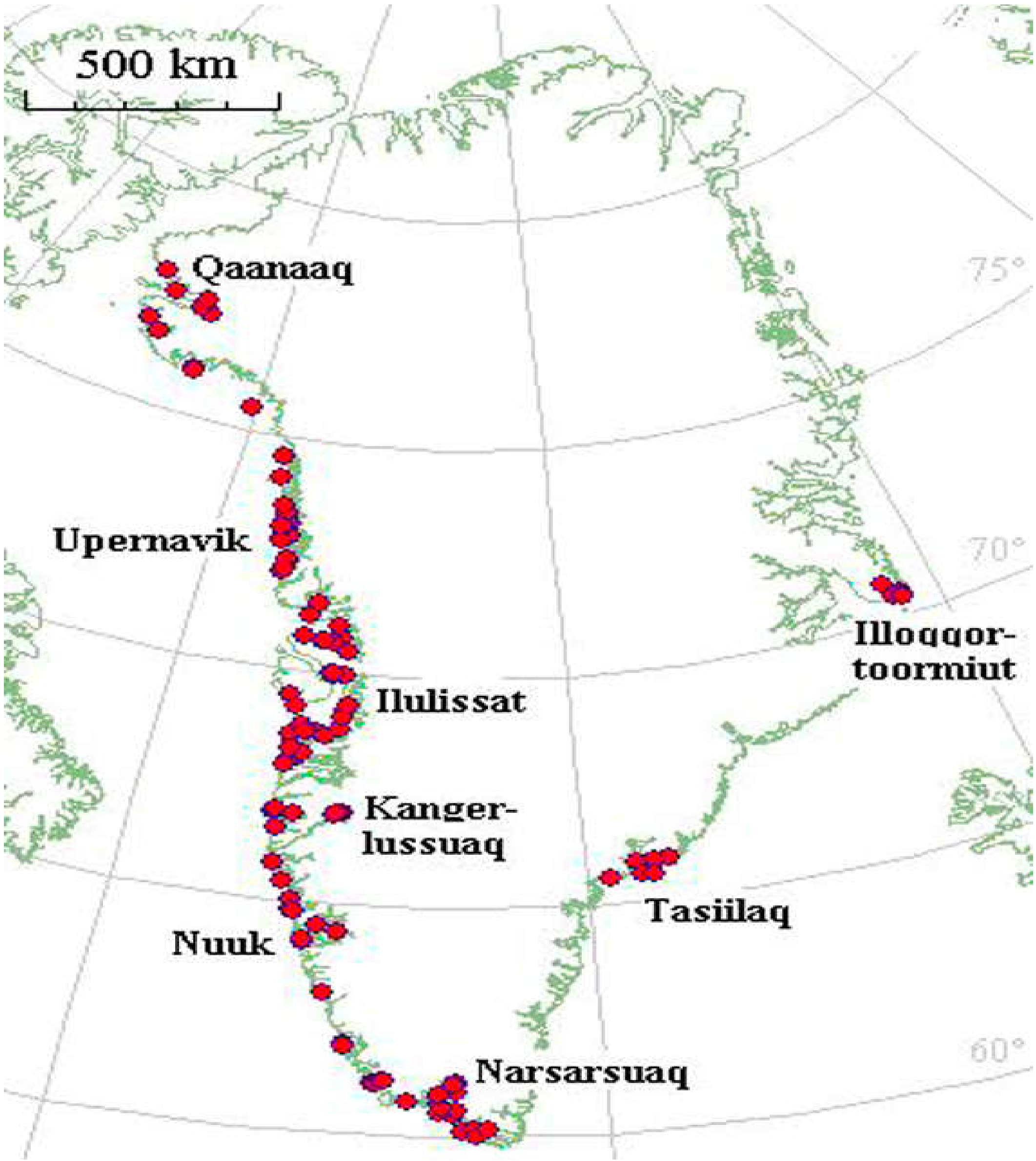

Figure 1. Greenland. Red dots = cities or settlements. Most people live on the west coast

The total area of Greenland is 2.166.086 km² of which 81 % is permanently covered by the icecap. 19% - corresponding to 410.449 km²- is ice free. (Statistisk Årbog 2015)

Greenland belongs to the Arctic climate zone with an average temperature in the warmest month below 10 C° Celcius. Ocean currents around Greenland are responsible for lower temperatures on the east coast (high arctic climate) and elevated temperatures on the west coast where harbours as far north as Sisimiut are free from ice throughout the year.

As a consequence of this most people are living on the west coast of Greenland – in 16 cities and 60 settlements. January 2013 Greenland had 56.370 inhabitants in total.

Grønlandsk	Dansk	Beliggenhed	Indbyggertal
Nanortalik	Nanortalik	Syd (vest)	ca. 2.300
Qaqortoq	Julianehåb	Syd (vest)	ca. 3.400
Narsaq	Narsaq	Syd (vest)	ca. 1.700
Paamiut	Frederikshåb	Sydvest	ca. 2.000
Nuuk	Godthåb	Midt-syd(vest)	ca. 15.000
Maniitsoq	Sukkertoppen	Midt-syd (vest)	ca. 3.000
Sisimiut	Holsteinsborg	Midt (vest)	ca. 6.000
Aasiaat	Egedesminde	Midt-nord (vest)	ca. 3.000
Qasigiannguit	Christianshåb	Midt-nord (vest)	ca. 1.300
Ilulissat	Jakobshavn	Midt-nord (vest)	ca. 4.500
Qeqertarsuaq	Godhavn	Midt-nord (vest)	ca. 1.000
Uummannaq	Uummannaq	Midt-nord (vest)	ca. 1.300
Upernavik	Upernavik	Nord (vest)	ca. 3.000
Qaanaaq	Thule	Nord (vest)	ca. 660
Tasiilaq (Ammassalik)	Tasiilaq	Syd (øst)	ca. 3.100
Illoqqortoormiut	Scoresbysund	Midt (øst)	ca. 530

Figure 2: Greenlands towns. (“indbyggertal “ = number of inhabitants)

Infrastructure

There are **no roads** between cities and settlements in Greenland except for in South Greenland where there are some unpaved tracks/roads between sheep farmers. About 380 km of roads in total are inside the towns.(Statistisk Årbog 2015)

Transport of passengers and goods is by ship or airplane.

Supply of water, heat and electricity

For the Greenlandic society the company Nukissiorfiit (Greenlands Energy Supply- owned by the Government of Greenland) is responsible for the public supply of water, heat and electricity in towns and settlements. The first public electricity plant was for Nuuk (1949). The last town to get a plant was Kangaatsiaq (1975). (Statistisk Årbog 2015)

There are no transmission grid connections between the towns.

Before the first hydropower plant was introduced (in 1993 for Nuuk) the supply of electricity was based on a diesel fired plant and a supply grid for each town. Many plants are small and emergency sources of power are installed and ready for operation in every *town*. This will of course increase the production costs of electricity.

Public heat supply was introduced in 1960 where Maniitsoq established a combined power and heat supply plant. At present Nukissiorfiit runs district heating in 12 towns.

To-day Greenland has 5 hydropower plants which supply 6 towns with electricity (Nuuk, Sisimiut, Qaqortoq, Narssaq, Ilulissat, and Tasiilaq). Part of the produced electricity is used for electrical heating (in Nuuk, Sisimiut, Qaqortoq, and Narssaq).

Figure 3. A settlement in Greenland.

In the *settlements* the power supply is less stable compared to the towns because there are no emergency generators. Instead there are normally 3 diesel generators. In case of brake down of one, the two remaining shall take over the supply. Outside the public areas supplied by Nukissiorfiit there are private farmers and others who run their own generators. There is no public heat supply in the settlements. The houses are heated by oil burners or central heating systems based on oil. At some small localities bottled gas or kerosene (petroleum) is used for heating.

The public water supply began in 1950 (in Narsaq). To-day Nukissiorfiit supplies all the towns and 51 of the settlements with water. The drinking water is normally taken from lakes. In 9 settlements reverse osmotic plants are installed. In the settlements water is not normally installed in the houses. Public drinking water tap facilities are instead available.

Energy production and use

In Greenland the main part of the public energy supply is delivered by Nukissiorfiit as electricity and district heating. Up to 1993 oil was the only fuel for the production of electricity and heat. Still oil is the dominating fuel but its share is getting less from year to year. The public energy supply is around 1/3 of the total inland energy consumption.

Since 1993 Greenland has been partly self - supplying with energy thanks to hydropower plants and the use of heat from waste incineration. Although there has been an increased self-production, Greenland is still depending on imported oil, primarily *gas oil, kerosene and petrol*.

Greenlands total inland energy comsumption was in 2013 8979 TJ(2500 GWh). Sustainable energy reached in 2013   the highest level ever - 15,5% - of the total energy consumption. (Grønlands Statistik 2014)

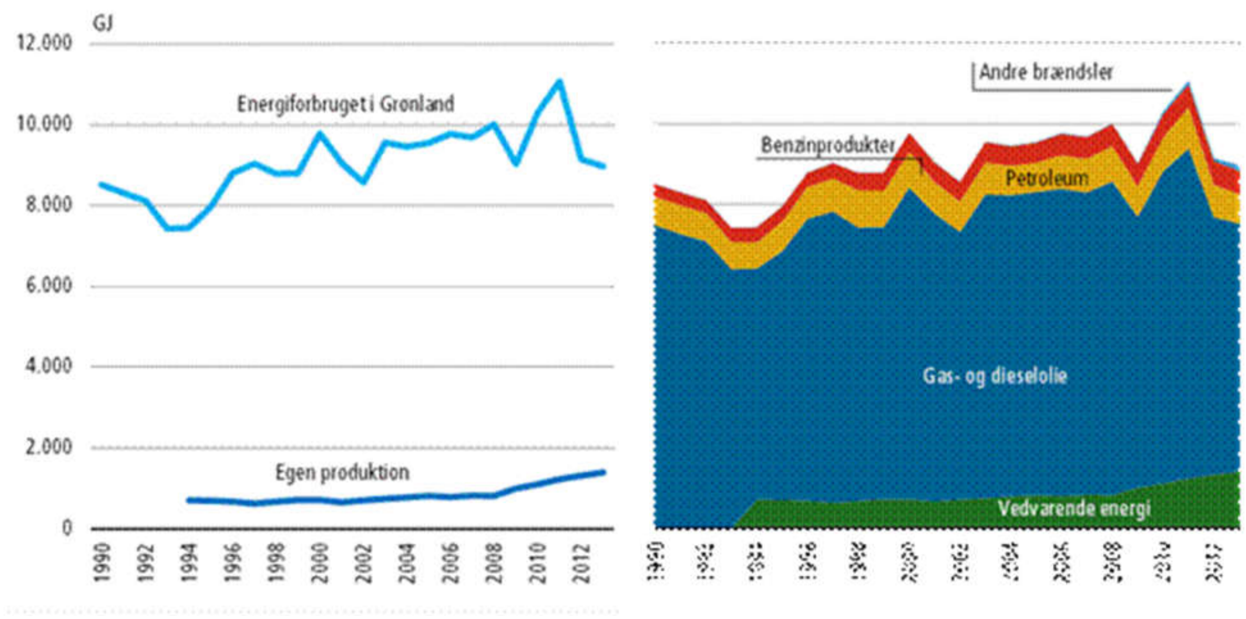

Figure 4. Energy consumption in Greenland. Light blue curve : total consumption.Dark blue graph: self- production. The right part of the diagram shows the fuels applied.Green:sustainable energy; blue: gas- and dieseloil;orange:kerosene;red : motor- and aviation petrol.

The fluctuations in the energy consumption – figure 4 - have different explanations- one of these is the 20% increase in 2010 and 2011 due to exploration drillings for oil and gas .

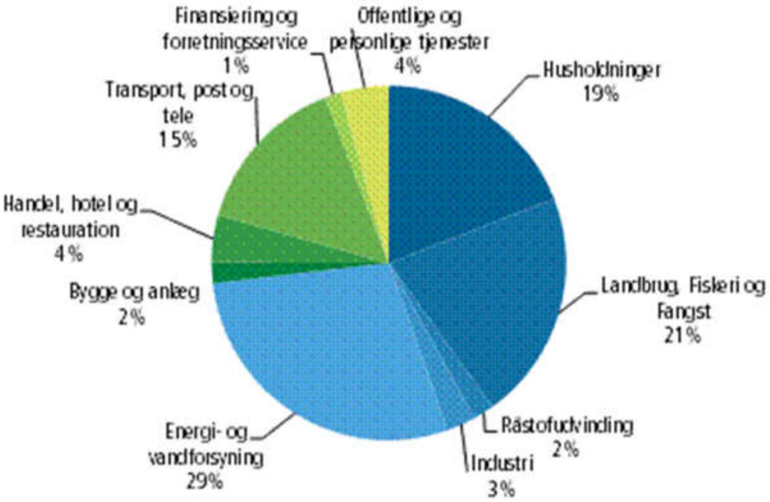

Figure 5. Energy consumption in different sectors. Energy- and water supply uses 29%; agriculture, fishery, and hunting 21 %; households use 19% and transport,post,tele 15 %

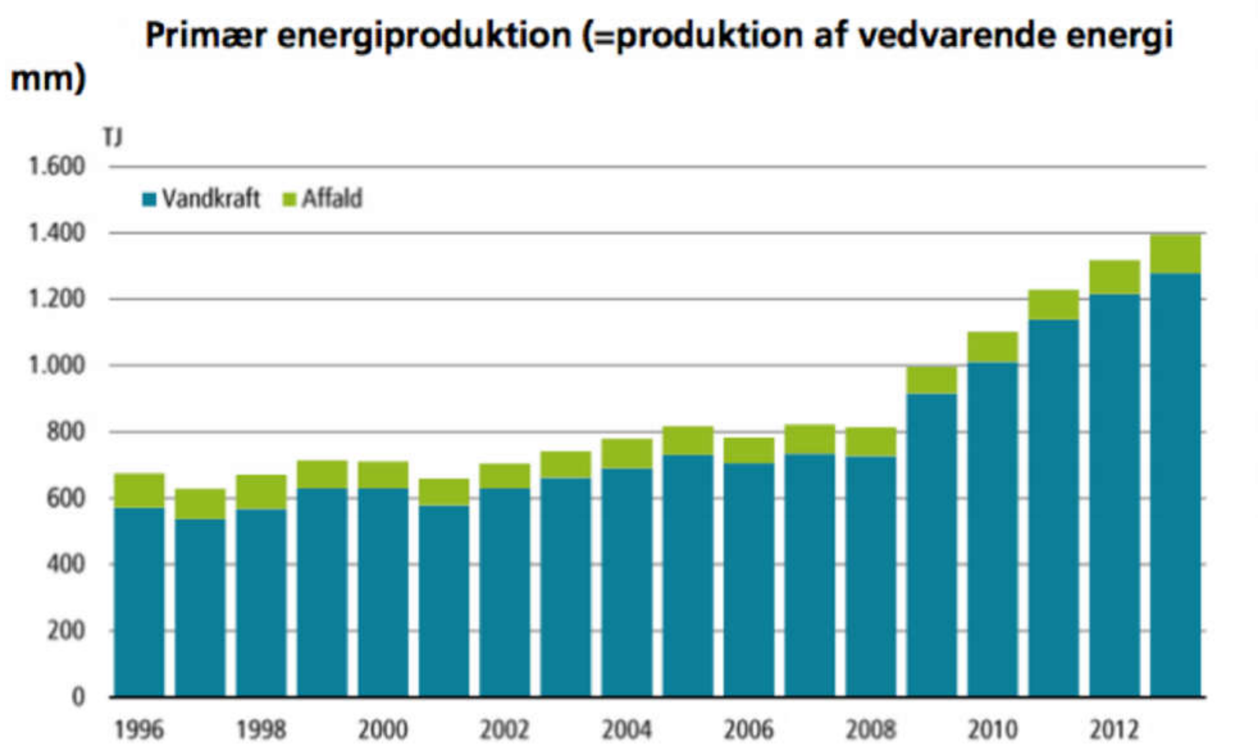

Figure 6. Greenlands production of sustainable energy: hydropower (blue color) and energy from incineration of waste (green). Solar- and wind energy is not included in the figure.

In 2013 the production of sustainable energy was **1395** TJ(388 GWh) including loss in transmission system from hydropower plants. Heat from waste incineration was **117** TJ(33 GWH) in 2013.

Hydropower production was in 2013 **1278** TJ(355 GWh) (incl loss in transmission system) (Buksefjord : 861 TJ; Tasiilaq , Qorlortorsuaq , Sisimiut , and Ilulissat :20 – 86 – 184 – and 128, respectively (incl. loss in transmission system

Energy prices

The electricity is sold to different prices depending on type of customers and locality in the country.

An average price for all the electricity sold in Greenland (2013) is 2,44 DKK/kWh. (Grønlands Statistik 2014)

In 2013 a total of **1145** TJ(318 GWh) electricity was used. In this number electricity for heating is a little above 300 TJ(83 GWh).

The electricity was (2013) sold to different customers:

Normal consumers (households): 702 TJ(195 GWh)

Fishing industry (land based) : 119 TJ (33 GWh)

Electricity for heating (only Nuuk): 324 TJ(90 GWh)

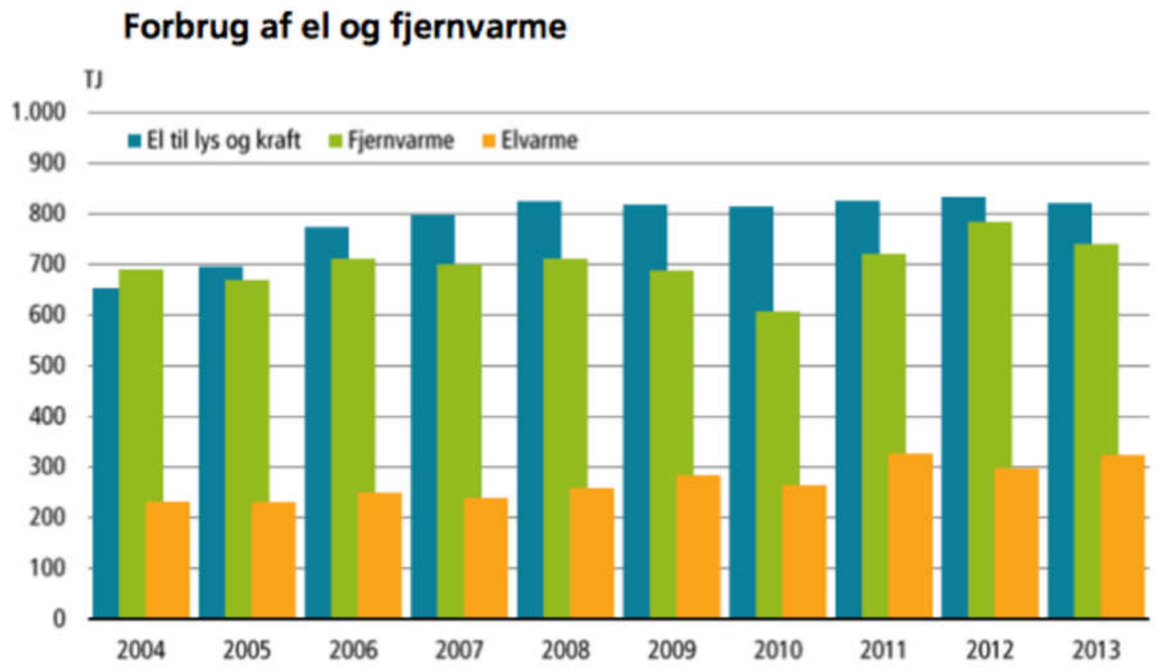

Figure 7. Consumption of electricity for lighting and power (blue), electrical heating (orange) and consumption of district heating (green)

Until 2004 the prices were the same for electricity (like for heat and water) all over the country – but since 2005 a gradually change towards real cost prices has been in progress. In 2013 the highest price was 3,24 DKK pr kWh and the lowest 1,60 DKK- both prices for "normal consumers". For the fishing industry the highest and the lowest price was 3,24 and 0,66 DKK respectively. Electricity for heating is about 0,80 DKK.

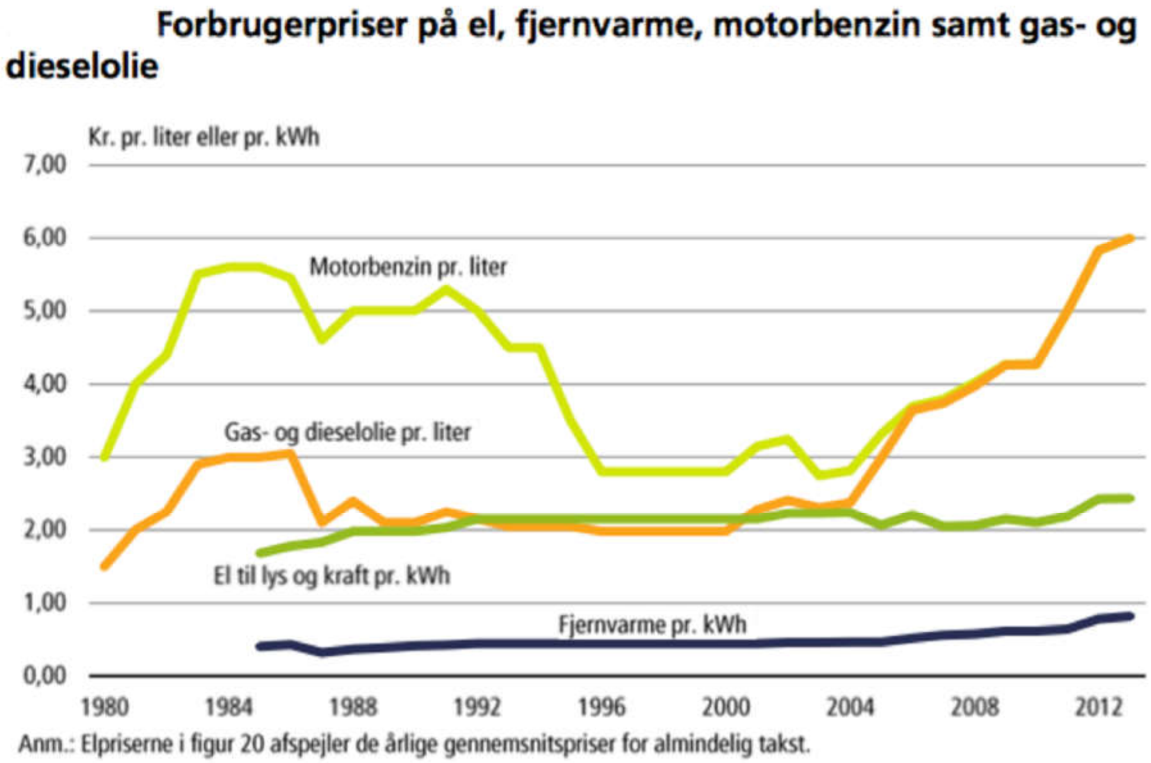

Figure 8 . Consumer prices for different types of energy. Light green graph: motor petrol DKK /L;orange: gas- and diesel oil DKK/L; dark green:

price for electricity for lightning and power DKK/ kWh; black: price for district heating DKK/kWh.

Salg af elektricitet til alm. takst inkl. gadelys men ekskl. elvarme (kWh)

	2009	2010	2011	2012	2013
			kWh		
Samlet salg	**189.301.257**	**187.674.666**	**194.151.260**	**195.990.247**	**195.079.541**
- heraf salg i byer	171.107.711	170.943.320	176.907.221	178.450.549	177.837.552
- heraf salg i bygder	18.193.545	16.731.346	17.244.039	17.539.697	17.241.989
Kommune Kujalleq	**23.267.647**	**22.383.639**	**22.403.024**	**22.438.107**	**23.609.200**
- Nanortalik by	3.441.669	3.473.986	3.466.838	3.347.785	3.245.907
- Qaqortoq by	11.889.111	10.997.831	11.019.055	10.918.718	11.842.530
- Narsaq by	5.053.150	5.357.861	5.316.160	5.619.284	5.995.550
- Bygder	2.883.717	2.553.960	2.600.971	2.552.320	2.525.213
Kommuneqarfik Sermersooq	**79.369.824**	**80.809.036**	**82.392.005**	**84.647.888**	**84.425.019**
- Paamiut by	4.626.961	4.510.682	4.348.419	4.275.169	4.127.445
- Nuuk by	64.193.232	66.136.622	67.814.461	69.716.562	69.918.861
- Tasiilaq by	5.543.486	5.291.845	5.398.215	5.591.490	5.532.753
- Ittoqqortoormiit by	1.539.104	1.439.663	1.449.606	1.421.088	1.459.014
- Bygder	3.467.041	3.430.224	3.381.304	3.643.578	3.386.946
Qeqqata Kommunia	**30.426.674**	**30.030.325**	**31.558.604**	**31.048.744**	**30.439.698**
- Maniitsoq by	8.748.789	8.431.769	8.255.925	8.160.098	7.769.422
- Sisimiut by	19.241.448	19.431.894	21.044.828	20.582.928	20.407.028
- Bygder	2.436.437	2.166.661	2.257.851	2.305.718	2.263.248
Qaasuitsup Kommunia	**56.237.112**	**54.451.667**	**57.797.627**	**57.855.508**	**56.605.624**
- Kangaatsiaq by	1.449.006	1.488.919	1.626.729	1.467.092	1.451.213
- Aasiaat by	11.426.809	11.271.007	12.379.567	12.339.865	11.881.956
- Qasigiannguit by	3.603.670	3.794.955	3.518.773	3.563.678	3.543.225
- Ilulissat by	16.375.156	15.412.705	17.284.578	17.210.242	16.731.822
- Qeqertarsuaq by	3.114.373	2.971.777	3.020.779	3.096.221	2.956.318
- Uummannaq by	4.533.781	4.291.311	4.516.794	4.538.724	4.531.314
- Upernavik by	3.987.003	3.991.652	3.907.175	3.951.619	3.794.428
- Qaanaaq by	2.340.962	2.648.840	2.539.320	2.649.985	2.648.767
- Bygder	9.406.351	8.580.501	9.003.913	9.038.082	9.066.582

Kilde: Nukissiorfiit

Figure 9. Electricity sold for “normal consumers” (excl electrical heating).First upper column gives the total amount (“samlet salg”)- the two next columns is the amount sold in cities and settlements , respectively.

The figure illustrates where in Greenland the consumption is. The total consumption in the settlements is less than 10% of the consumption in the towns.

CO_2 Emission

Almost all CO_2 emission (94%) in Greenland comes from the energy consumption. Waste incineration is considered CO_2 neutral in the statistics in Greenland. For 2013 the emission was in total 555.000 ton CO_2 equivalent . The variations with time can be seen in figure 10.

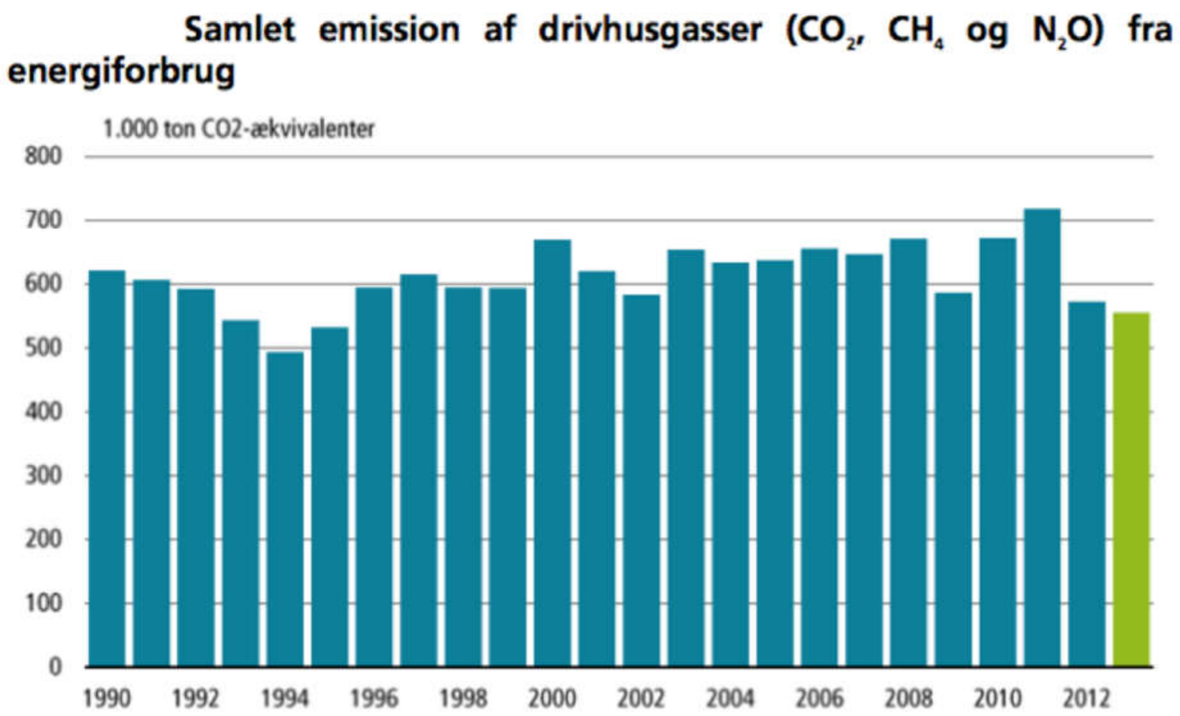

Figure 10. Total emission of green house gases from energy use. CO_2, CH_4 and N_2O are recalculated to CO_2 - equivalents.

Potentials : Hydropower

From roughly 1975 and onwards estimates on the hydropower potentials have been made regularly (Thomsen 1996). In the beginning the purpose was to produce estimates on the biggest potentials to find energy for energy demanding industries such as mining, production of fertilizers and aluminium . During the 1980´ ies the priorities were changed and the hydropower studies were concentrated on “city- near potentials”and minor basins which could replace or supplement the existing energy production which was based on diesel for the Greenlandic cities.

The work was carried out by Greenland Technical Organisation (GTO), which in 1989 was replaced by Nukissiorfiit (Greenlands Energy Supply).Since then Nukissiorfiit has been responsible for the use of hydropower in Greenland in a cooperation with Asiaq (Greenland Survey) and Greenland Geological Survey – now GEUS.

Most of the studies have only estimated the potentials in South Western and Western Greenland (up to Uummannaq) and in a minor area in Eastern Greenland where most towns and settlements are located -see figure 11.

A total of 16 catchment areas with an annual potential of 13.000 GWh(46800 TJ) are shown in this figure. In the same area 15 minor catchments are present and these are estimated to add 620 GWh/year(2200 GWh) to this value - given a total of a little less than 14.000 GWh /year (50000 TJ) in this part of Greenland. Although this estimate is based on many years research work it must be stated that especially the contribution of melt water from the ice cap is determined with great uncertainty. It is recommended to update the estimated potentials for hydropower since there has been major climatic changes through the latest years.

Geological Survey of Greenland (now GEUS) estimated in 1994 a theoretical maximum potential (“gross theoretical capability”) for *the ice cap* in Greenland. The estimate implies that all natural

water is taken from the locality where it is formed and via turbines transported to sea level. A very theoretical value,of course.
The result was about 470 Terawatthours/year.(1692000 TJ)

This type of estimation gives results far from the real available hydropower energy, which can be applied only when the water comes into hydrological catchment areas where hydropower plants in reality can be constructed.
At the same time Asiaq (Greenland Feasibility Study) estimated 350 Terawatthours/year (1260000 TJ) for the *ice free part* of Greenland. (Thomsen 1996).

Figure 11 : Hydropower potentials in West Greenland (Thomsen 1996) Blue areas indicate hydropower basins, black squares possible locatilities for hydropower plants and black circles are observation localities for water flow estimates operated by GEUS. (Geological Survey)

Potentials: Solar energy

Solar energy delivered to an area with optimum tilting in Greenland (Sisimiut) is roughly the same as in Denmark (Copenhagen), namely about 1160 kWh/m²year(1.7 MJ) (Andersen et al. 2007)- see figure 12.

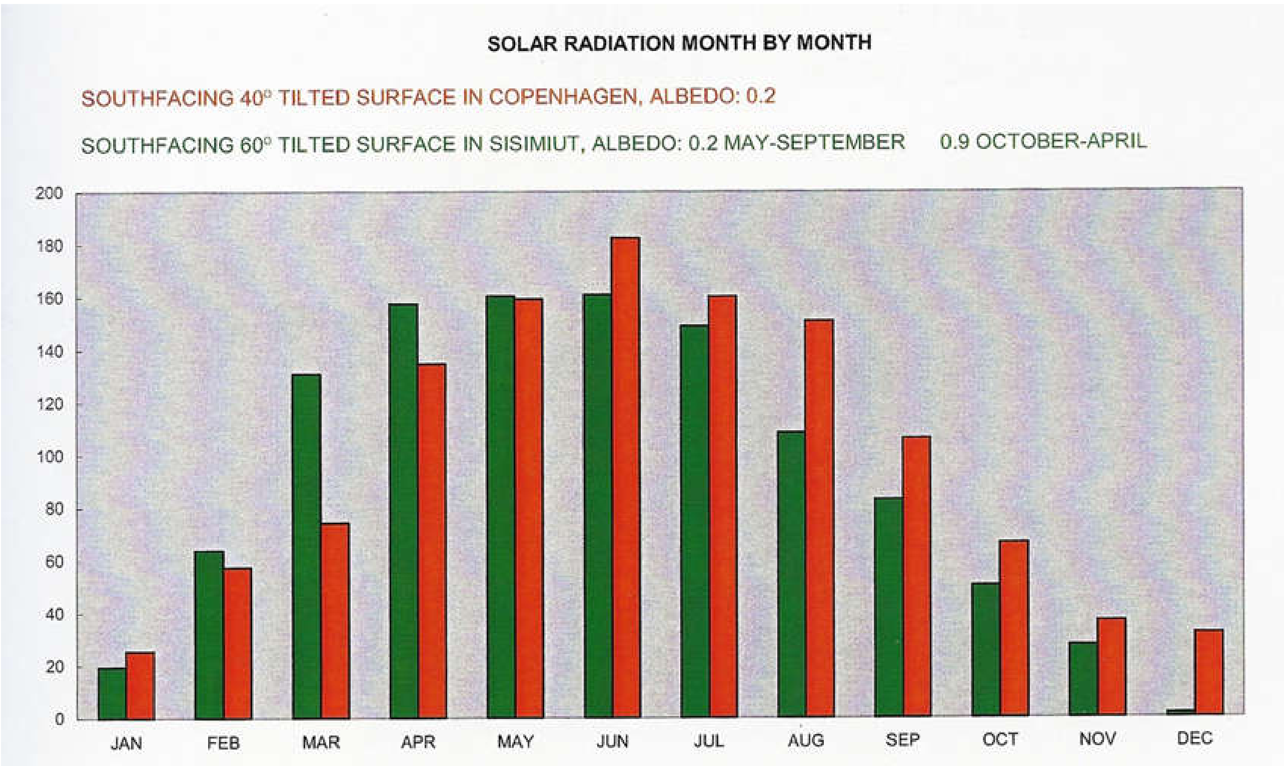

Figure 12: Comparison of monthly solar radiation in Copenhagen (red) and Sisimiut (green).

The global radiation potential is high in the Arctic as indicated in figure 13. (Andersen et al. 2007)

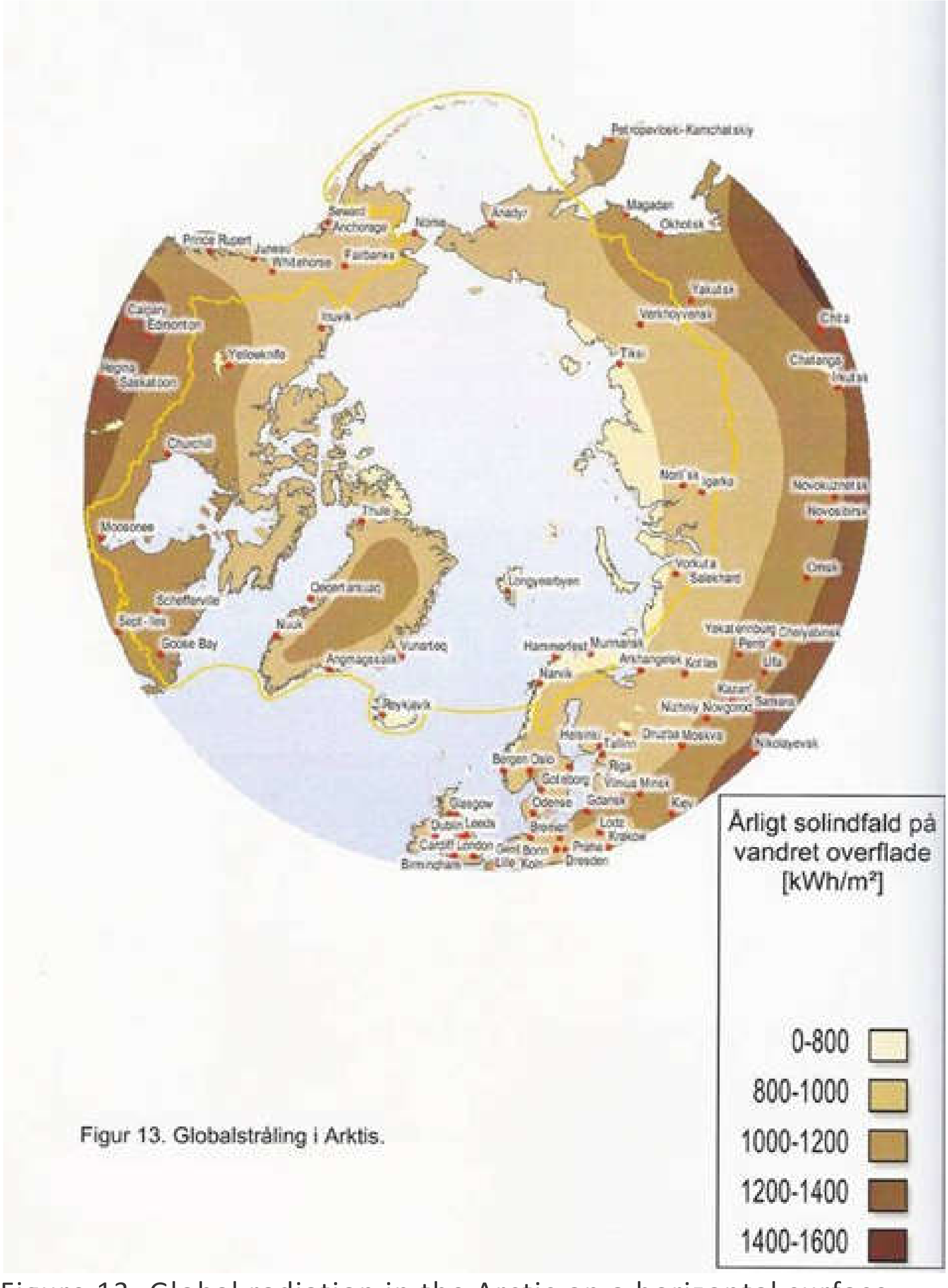

Figure 13: Global radiation in the Arctic on a horizontal surface.

Case story for a grid connected PV system in Sisimiut,Western Greenland:

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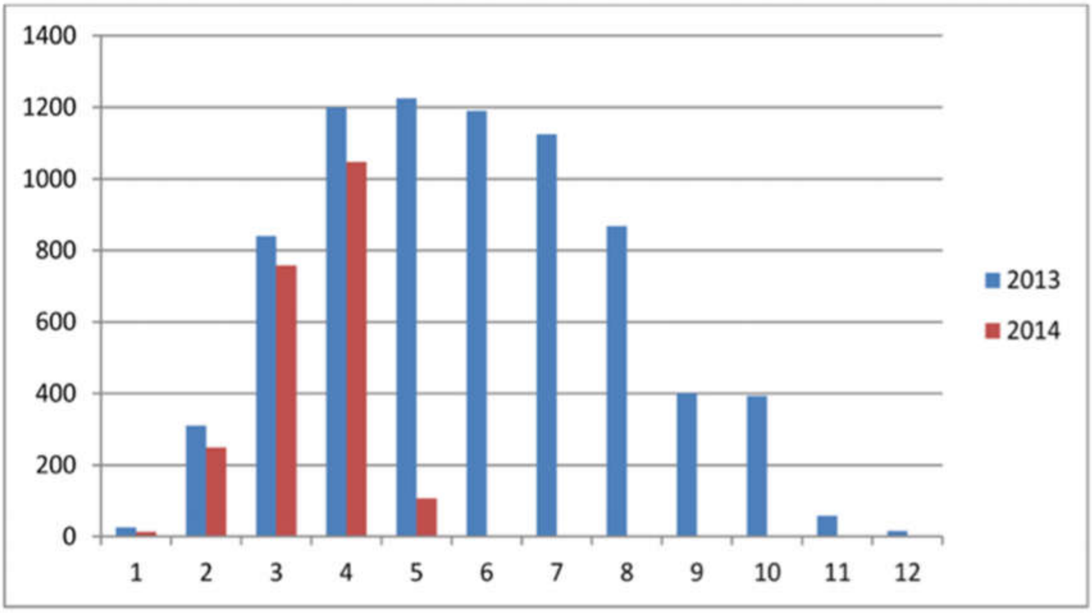
Månedlig produktion i 2013 og 2014 delvis



På KNI's hus (45˚ taghældning) har vi en produktion på 1,04 – 1,09 kWh / Wp, dvs årligt har vi produceret mere end 1000 kWH/kWp installeret solcelle. I DK forventes typisk mellem 0,85 – 1,0 kWh/Wp.

2015-09-10/Esben Larsen

Figure 14. The monthly production of electricity is high during spring and summer. Total annual production is around 7500 kWh (2013 and 2014) which is 1,05 kWp/Wp . In Denmark you can typically expect 0,85- 1,0 kWh/Wp. The house in Sisimiut has an optimal localization: roof tilted 45 degrees, facing to the south and close to the sea which gives a god refleksion. (data for 2014 not fully illustrated) (Larsen 2015).

Potentials: Wind energy

The wind energy potential has been studied to some extent in Greenland (Andersen 2007). The potential is considered *in general* to be of minor interest.

Only the southern part of Greenland lies in an area with constant wind load. The potential is not well known, however.

Local wind conditions governs in the rest of the country. Wind velocity change from periods without wind to very heavy storm periods. The precise placement of a wind turbine must be based on local (expensive) measurements and the cost for the erection of a turbine is high – due to infrastructure.

Consequently at present wind energy is – except for Southern Greenland - considered to be only of local interest.

Greenlands data cable connection

"Greenland Connect" is the name of a sea cable project which was carried out 2007 / 2008. (http://www.tele.gl/da).Alcatel Submarine Systems got the job to establish the data transmission cable (price 734 MDKK). It has a length of 4780 kilometers and links Nuuk/ Qaqortoq to New Foundland (Milton) and Iceland (Landeyarsandur) – see figure 15.

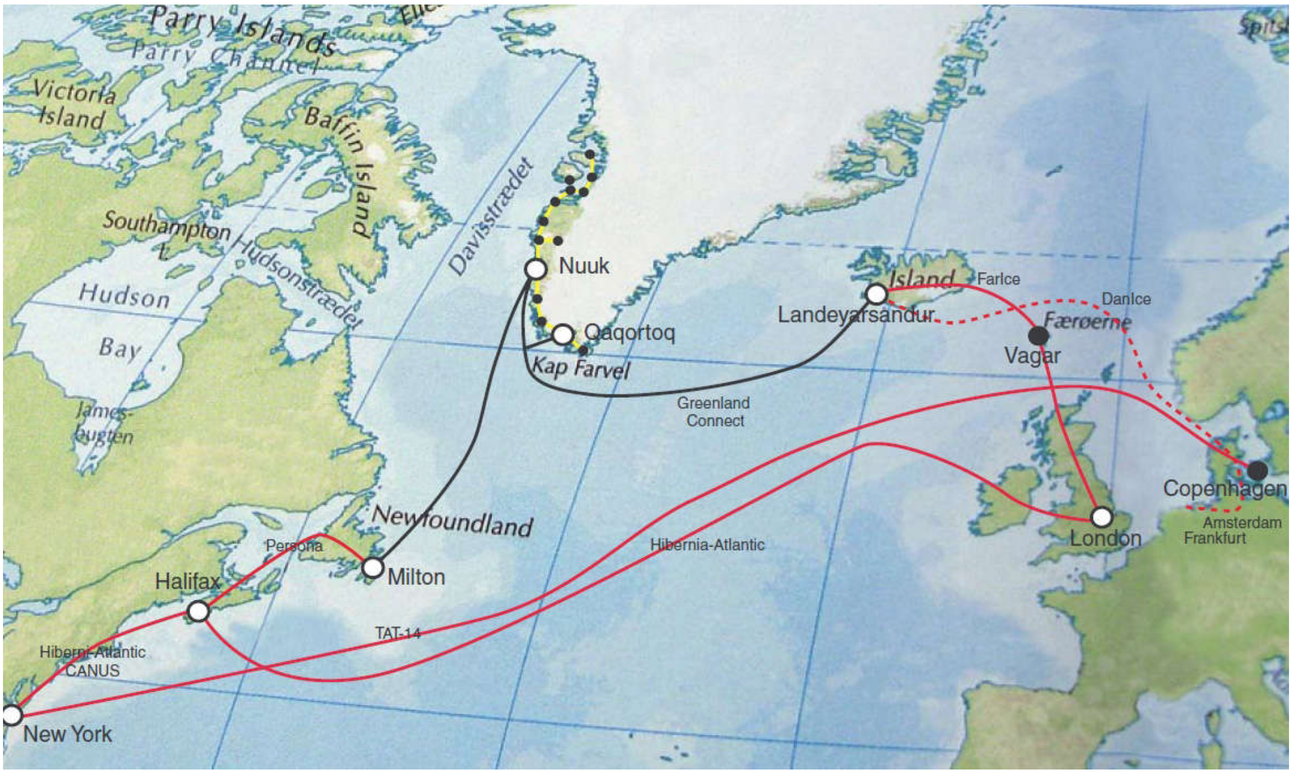


Figure 15: Data transmission cable (black) connects Greenland to the west and to the east.

Future cable for transport of electricity.

1. Connection to the West

Iqaluit/Nunavut:

Probably inspired by the above mentioned data transmission cable and the technical development of the HVDC concept ideas have been described in Greenland for export of electricity either to the neighbours to the west or probably to Europe – of course via Iceland. Also earlier connections between Greenland and the neighboring countries have been suggested.

Support was given (some 10 years ago) from the Nordic Council of Ministers to a Nordic Working Group for "Renewable Energy in Sparsely Populated Areas". The group mapped renewable energy potentials in the West Nordic Countries and arranged a symposium entitled " Energy from the Edge" in 2007. The overall focus for the Nordic Countries was to stimulate the energy cooperation with Shetland Islands and Canada (Nunavut) – the neighbour to the West (Sørensen 2008).

In the NAEN pre- feasability study we have decided to follow up on this topic:

Looking to the west- Nunavuts capital -Iqaluit - is 800 km from Nuuk.

The population in Nunavut is small (about 23.000 people of which 5000 live in the capital - Iqaluit) - and there is a strong need for energy . Further investigations and discussions with the authorities of Nunavut are needed to describe the potential, the social acceptance , and rentability of a connection between Greenland and Iqaluit.

Figure 16 . Relatively short distance to the neighbour to the west. The distance between Nuuk and Iqaluit - capital in Nunavut- is about 800 km .

Cable connection to Labrador:

Another target for a cable connection to the west might be to the area in Labrador/Newfoundland where a major hydropower plant is under construction (Muskrat Falls Project). If a connection from Greenland could be established there would be a possible link to the North American grid and of course a huge market for selling energy from Greenland. However the distance from Greenland is long (1000 km +) and the ocean water depth is 2- 4 km. Also here further considerations and studies are needed to support a link between Greenland and Labrador.

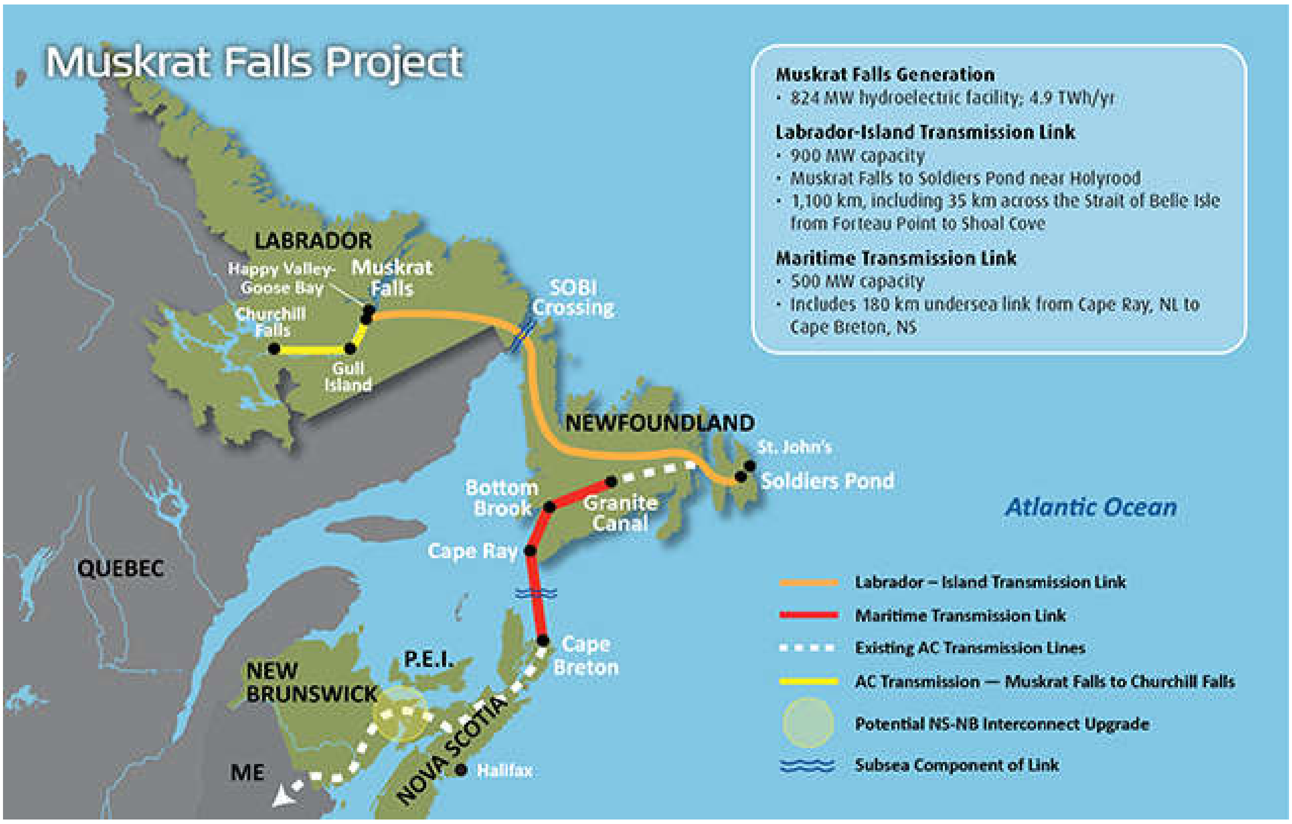


Figure 17. Muskrat Falls hydropower project. A possible connection from Greenland to North America?

2. Cable connection to the East.

Connection to Iceland.

The NAEN project mainly aims at creating connections between countries east of Greenland. The distance between East Greenland and Iceland (from Tasiilaq to Isafjordur) is about 500 km and the water depth is not critical for the cable (800 m max). However there is at present only a small hydropower plant in operation for the supply of Tasiilaq – and sparse knowledge on the energy potential in East Greenland. If energy should be transported from Iceland to East Greenland there are only few consumers in Eastern Greenland.

A continuation of a cable connection from Iceland via East Greenland to West Greenland where there are more consumers is a possibility. In western Greenland there is a known and high potential for hydropower- see fig 11.There might be found hydropower potentials in East Greenland too in the future - but there is more than 500 km between Tasiilaq and the southern cities in Western Greenland . The investments for a connection between East Greenland and South/West Greenland will be huge. However it should not be let out of the visions for the future.

3. Domestic cable connection in West Greenland.

We should remember that the main reason for linking the North Atlantic countries with a cable is not to sell electricity to each other but rather to reach other markets with energy developed in each of the countries.

Another possibility is to attract energy demanding industries and raw materials to North Atlantic areas with big energy potentials.

These are long term perspectives for Greenland, of course. The efforts to attract Alcoa to place an alumina smelter in West Greenland is part of this scenario.

On a closer horizon another possibility, namely a domestic connection between cities on the west coast seem to be more realistic for Greenland.

As earlier mentioned mapping of the hydropower potential in Greenland has focused on “city-near “ localities. The annual production from city near catchment areas was estimated to 400 GWh/year(1440 TJ) (Teknologirådet, 2002) which is of course low compared with the total potential in West Greenland of 14000 GWh /year (50000 TJ) which was mentioned earlier.

In the area between Nuuk and Sisimiut the potential has been further investigated and more precisely described during the last ca 10 years to evaluate if the potential would be sufficient for a major hydropower plant for industrial purpose (Alcoa alumina smelter).

Recently Alcoa has expressed a decreasing interest in applying the hydropower potential for aluminium production- and other potential users are now been looked for.

An estimate based on precipitation and ablation from the icecap for 3 major catchment areas says that the potential is in total ca 4500 GWh/year(16200 TJ)for the area between Sisimiut and Nuuk. This potential is included in the total potential of 14000 GWh/year shown in figure 11 – but it represents a better and more precise estimate on which the planning could based .The 3 areas could be developed one by one with hydropower plants depending on the need of electricity.

The map figure 19 below shows the area.

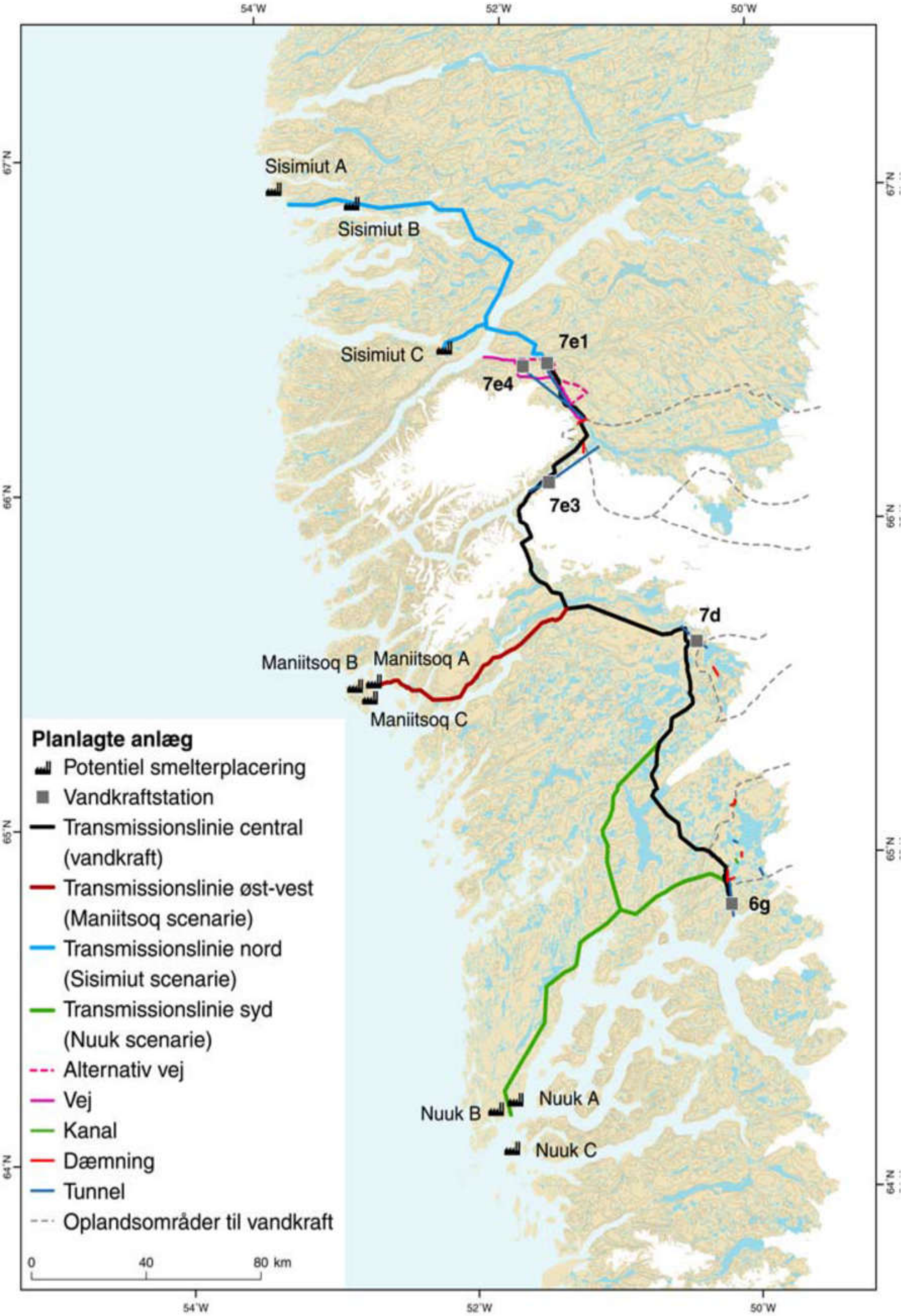

54°W
52°W
50°W
67°N
66°N
65°N
64°N
Sisimiut A
Sisimiut B
Sisimiut C
7e1
7e4
7e3
7d
6g
Maniitsoq B
Maniitsoq A
Maniitsoq C
Nuuk A
Nuuk B
Nuuk C
Planlagte anlæg
Potentiel smelterplacering
Vandkraftstation
Transmissionslinie central (vandkraft)
Transmissionslinie øst-vest (Maniitsoq scenarie)
Transmissionslinie nord (Sisimiut scenarie)
Transmissionslinie syd (Nuuk scenarie)
Alternativ vej
Vej
Kanal
Dæmning
Tunnel
Oplandsområder til vandkraft
0
40
80 km

Figure 19. Possible first phase of a domestic cable connection in Western Greenland connecting Nuuk, Maniitsoq, and Sisimiut.

The figure shows an area in western Greenland between Nuuk and Sisimiut, where a detailed study of the hydropower potential has been carried out. The purpose was to find sufficient energy potential for an alumina smelter. Catchment areas are indicated by dotted lines. 5 possible localities for hydropower plants (grey squares) are shown together with transmission lines (black/ green/red/blue).Localities for the alumina smelter (9 in total) are shown with a dark "industry signature".

It seems natural to look for a domestic and stable use of this potential via a common grid for the city inhabitants in a combination with industrial use (smelters to handle imported raw materials , mining in the area, production of building materials etc).

A HVDC connection or another type of connection between the cities on the west coast – starting with Sisimiut, Maniitsoq, Nuuk would have many benefits. Settlements close to the siting of the cable should be connected to it , thereby giving an improved energy supply situation.

Benefits of a domestic cable.

The following points can be considered beneficial for the consumers linked to a domestic cable in Greenland:

- A more stable grid i.e. improved "quality " of the electricity for all categories of consumers
- An expected lower price for electricity – which will give better possibilities for heating houses directly or by using heat pumps.

- Lower consumption of oil for electricity production and for district heating.
- Lower CO_2 emission
- Industry development a.o. the fishing industry will be stimulated due to easier access to electrical energy
- Greenhouse production of food articles which are imported to-day could be economic attractive by cheaper electricity.
- Land transport could favour electricity as energy source for cars. Without road connections between cities the distances for cars etc to drive are small and hence the recharging will not impede the daily use of electrical vehicles.
- Sustainable and clean energy supply for future mining industry in the area –e.g the Isua iron occurrence close to the icecap near Nuuk, possible nickel mining near Maniitsoq ,and the anorthosite mine already under upstart between Maniitsoq and Sisimiut.

The cost of the cable and the construction of the hydropower plants are two very essential factors. An economic plan is outside the scope of this report. Pay back time for an investment that will last 40 years or more should delineate the length of the cable and thus which parts of Greenland could be linked within the project.

A further enlargement of the cable connection with the cities from South Greenland to the Disko Bay area will need at least 1000 km of cable . Nuuk – Maniitsoq – Sisimiut should be the first cities to be connected. (40 % of the Greenlandic population lives here).

A combination of societal use and industrial use of the electricity would be optimal. Iceland was in the same situation 30 years ago as Greenland is to-day as for solving the investment issue. An agreement with a major industy consortium was part of the solution in Iceland. It started in 1966 with a contract with Alusiuisse regarding building a smelter ÍSAL in Straumsvík for about 33.000 tons/year of aluminium. This contract enabled Landsvirkjun to build its first large hydro power plant Búrfellsvirkjun as the bulk of the electricity was already sold to Alusiuisse.

The settlements in Greenland which are closest to the cable should of course be connected to it. But there will still be remote areas (cities and especially settlements) in Greenland outside the new grid. These areas should have improved the energy supply based on local sustainable energy sources. Long connection lines and few customers may give bad economy in part of the grid – such as it was demonstrated by a hydropower rentability study in the area between Aasiaat and Qasigiannguit (Disko Bay area) (Sørensen 2015).

Legal aspects

Hydropower is regulated by a Greenlandic law (from 2009) . The Greenlandic Government has a monopoly on the investigation and use of hydropower resources. This is valid for potentials higher than 1 MW. The government can allow companies to carry out investigations of potentials. Results including data shall be reported to the government when the study ceases.

Asiaq (Greenland Feasibility Study) has as a primary goal the study of non- living resources as for example the study of hydropower potentials.

Nukissiorfiit (national company responsible for energy and water supply). Main goal is the energy and water supply to cities and settlements and not for energy demanding industry outside existing cities and settlements.

Final remarks and conclusions.

Greenland has a very big energy potential related to hydropower and solar energy. Wind potential is considered to be of only local interest. The abundant sustainable energy resources in Greenland are at the moment stranded due to the isolated location of the country. Norway and Iceland both started their energy export of power through heavy industry. Greenland could follow this way.

The energy potentials are not known in details for Greenland as a whole and more studies are needed to support and justify future investments. However the hydropower potential in South West Greenland can be estimated to 50000 TJ (14000 GWh/year). Compared to the *total* energy consumption in Greenland which is (2013) a little less than 9000 TJ (2500 GWh/year) it is an enormous potential.

For an area between Nuuk and Sisimiut the hydropower potential is known in more detail compared to the rest of Greenland.

Solar energy potential is high and at the same level as in for example Denmark (1160 kWh/year pr m^2).

The present project has focused on the future sustainable energy use by connecting the North Atlantic Countries by HVDC (high voltage direct current) cables.

It is technically possible to link either to the West – to Nunavut or Labrador with a possible further connection to North America or link to the East via Iceland and thereby with a possibility to reach the European market. Greenland is at present not able to use these options due to lack of economy and energy infrastructure.

The above mentioned better known hydropower potential between Nuuk and Sisimiut is recommended used for establishing a first phase of a Greenlandic national electricity grid. The first cities and settlements to be connected should be Nuuk, Maniitsoq, and Sisimiut and the settlements in this area .Connected to this grid should be mining and fishing industry, and other heavy energy demanding industries which f.ex. upgrade imported or local raw materials. The grid shall - depending on the need and economic capability- in a later phase be enlarged to cover the cities and settlements in the west coast of Greenland. A national grid will have a lot of benefits for the country – such as a more stable electricity supply, less CO_2 emission, reduced oil consumption, lower price for electricity, and improved possibilities for new energy demanding industries.

An electrical grid as described here is expensive to establish and it is not realistic that it can- within a foreseeable future - be covering all of the country. Therefore focus should be also put on the development of local sustainable energy solutions to be used in remote cities and settlements. Included in this work should be improved insulation of houses as an example of reduced energy demand.

Acknowledgements.

Economical support to the project has been given by Nordic Council of Ministers and by the Greenlandic “VEK – pulje” (Governments grant for supporting development of sustainable energy).

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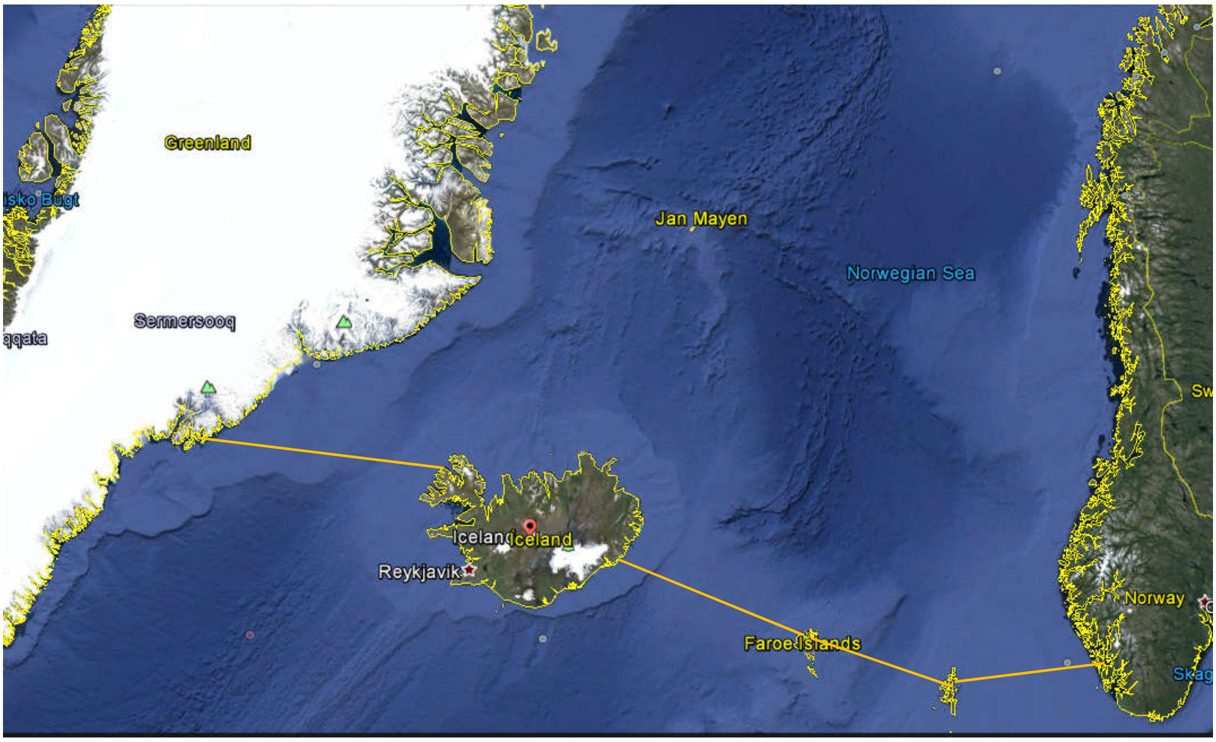
ORKUSTOFNUN

Appendix C

North Atlantic Energy Network

Iceland



Orkustofnun (OS) - National Energy Authority of Iceland

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Introduction

This report is an appendix to the report North Atlantic Energy Network (NAEN), on various alternatives for connecting the electrical systems of Greenland, Iceland, Faore Islands, Shetland and Norway via subsea electric cables.

Iceland is an island in the middle of the North Atlantic Ocean, the settlement of which dates back to around 870. Iceland has about 330,000 inhabitants and the majority, or over 200,000 people, are located in the southwestern part. Iceland is 103,000 km^2 and it is both difficult and expensive to build up infrastructure like roads and a transmission system that cover long distances.

Iceland’s electricity production is almost 100% from renewable sources and there are possibilities to increase its installed capacity in hydro, geothermal and wind power. Iceland also has potential for tidal power but this has not been explored on a commercial basis. This report gives an overview of the production, transmission and prices of electricity in Iceland, and sheds light on what needs to be investigated further if a cable connection to other parts of the world is to be realized.

Conclusions

It is technically possible to connect all of the neighbouring countries around Iceland with subsea cables. Iceland now produces about 18 TWh of electricity per year and could have the potential to double production from geothermal and hydropower alone. This could be constrained by economy and environmental and socio economic aspects. The total capacity of power generation for wind has not been explored and the same can be said about other renewables such as tidal and solar power. Electricity from Iceland could significantly contribute to saving CO_2 emissions in other European countries even if it will always be only a limited part of the European system.

There are many unclear aspects that need to be investigated further to draw a full picture of the pros and cons of interconnectors from Iceland. The legal and regulatory framework must be in place before a project of this kind can be realized. Even if we had social acceptance for increased electricity generation, a long term investment such as this requires stable economical conditions secured by the governments involved. The alternative is to move energy intensive processing industries to Iceland as has been done successfully in the past.

The largest unknowns are energy politics and policies in Iceland and Europe. Social and environmental issues also need to be looked into in more detail. Export of electricity from Iceland would implicate a certain environmental cost. More data is needed to be able to verify if the environmental and social cost is outweighted by financial gain and positive environmental impact in the receiving countries.

In the beginning of the project, the idea was to find out if a 100 to 200 MW cables were a feasible choice for interconnectors. It turned out that (see main report) that because of the cost of laying the cables and the losses it is not financially feasible for long stretches to lay cables with low capacity.

As the current installed capacity in Iceland is 2,500 MW, adding a cable of 1,000 MW is a large increase in comparison to the existing electricity market in Iceland and the risk involved needs to be mitigated. At least three different types of contracts are possible; a regulated cable, merchant cable and a cap and floor model. The ownership and contract type can make a big difference in regards to what the outcome will be.

Norway is a leader in long distance subsea interconnectors with the largest cable NorNed between Norway and Netherlands. The power system in Norway is fourteen times larger than the system in Iceland with installed power of 34 GW. The relative risk for the economy and system operation in

Iceland by adding a cable of 1,000 MW is much larger than for Norway. However, an interconnector could improve the energy security and efficiency of the electricity production in Iceland. Cable connection from Iceland to other parts of the world gives rise to opportunities to utilize the renewable energy potential of Iceland and can also enhance the energy sercurity. In an island system the installed power needs to match peak demand which otherwise is unused throughout the year. This excess capacity could be put to good use through a subsea cable.

Extensive grid reinforcements are needed to support export through a cable at a single connection point in Iceland. Even if a converter station provided fast acting reactive power and thereby supported the transmission system by regulating the voltage power factor, the main problem of the Icelandic power system would not be cured. Transmission between areas within Iceland is limited to 100 MW in the current system which thus can not support export through a 1,000 MW link, except for production stationed close to the landfall.

Earlier investigations and ideas

For over half a century there have been discussions regarding a cable connection between Iceland and UK. Iceland has potential for additional 35 TWh of renewable energy and UK is in search of renewable resources. A 1,000 MW connection to UK is under discussion and a survey between Iceland and UK was conducted last summer (2015) by a company called Atlantic Superconnection Corporation.

In June 2012 a counceling group was established by the Minister of Commerce and Industry, with the role of investigating the socio-economic aspects of a subsea cable as well as technical, environmental and legal aspects. The group delivered a report in 2013 (Iðnaðarráðuneytið, 2013) where, among other things, it was established that an interconnector between Iceland and Europe could be profitable, but the outcome had a very large, reflecting all of the still existing uncertainties for the prerequisites.

The parliament, Althingi, discussed the report and decided that the matter should be investigated further. Consequently, the Ministry of Industries and Innovation defined eight different tasks which are being looked into in more detail, an administrative committee was established for that purpose.

The eigth tasks are:

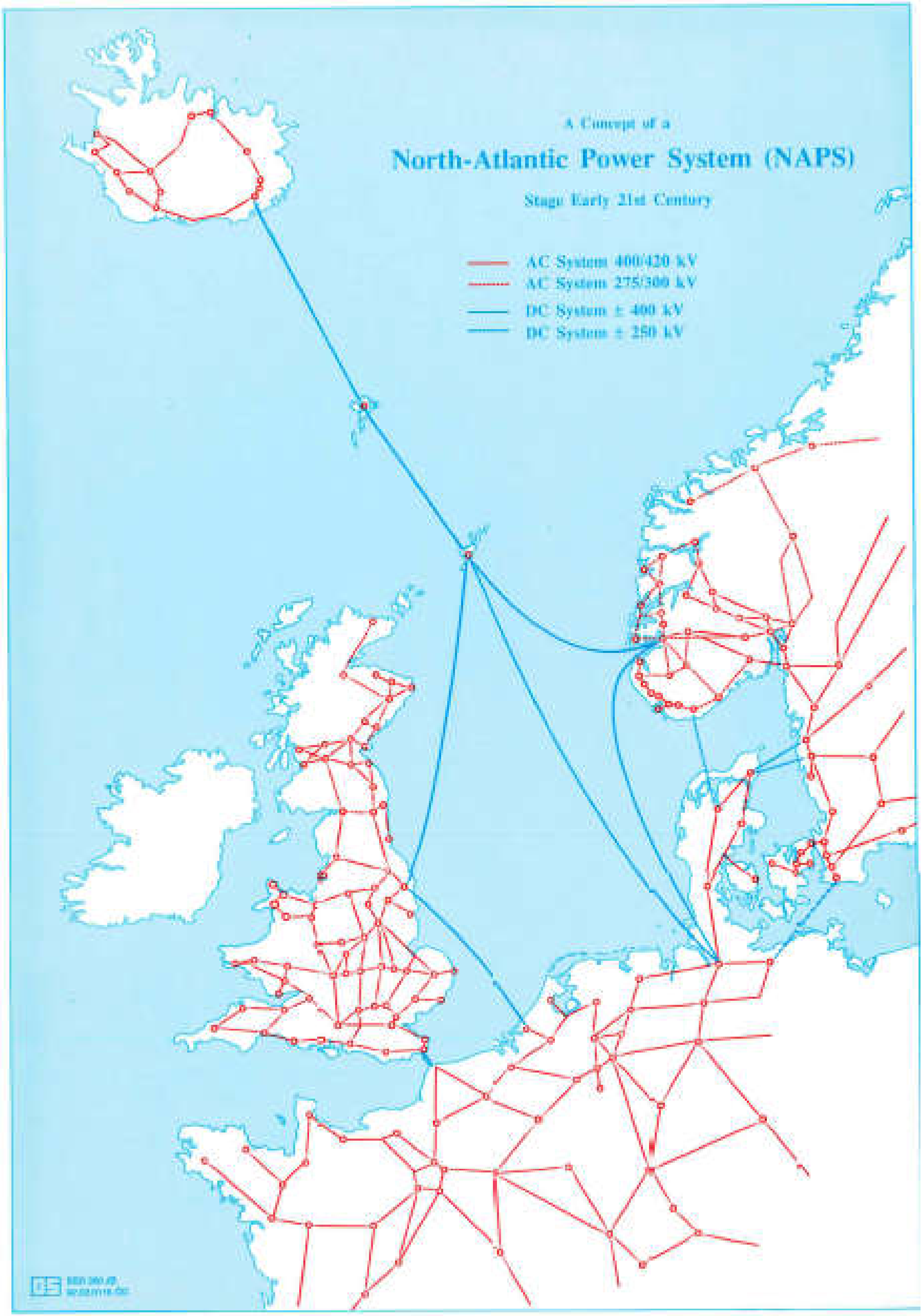
1. A thorough estimate of the influence of a subsea cable on commerce, industries and homes, based on cost and benefit analysis.
2. Environmental assessment according to Act No. 105/2006 on Strategic Environmental Assessments.
3. An estimate of the electricity needs of current companies, heavy industry and new establishments in the coming years.
4. An estimate of how many power plants need to be built, if and how present power plants can be better utilized with the existence of a subsea cable and what power plants would be needed to sell electricity through a subsea cable.
5. A study of different scenarios regarding the development of the energy market in Europe.
6. A study of technical issues regarding laying a subsea cable and possible contribution by the other party.
7. An investigation of Norway's experience with subsea cables.
8. An estimate of the utilization of land and operation of small power plants.

On the 28th of October 2015 the Prime Ministers of Iceland and UK, Sigmundur Davíð Gunnlaugsson and David Cameron, agreed to launch a working group to investigate the possibilities for an interconnector between the countries. Consequently, the administrative committee for the eight tasks described above was expanded by two members, one from the Ministry of Finance and one from the Prime Minister's Office and the reformed group will take on the role of this working group on behalf of Iceland as the ninth task. The completion of all these tasks is estimated to be May 2016.

The Icelandic government is not the only one looking into the idea of a subsea electrical cable between Iceland and UK. The British Icelandic Chamber of Commerce organized a public seminar in September 2015 called: Interconnecting interests aimed to examining the issues surrounding a potential submarine cable that might supply the UK and Europe with Icelandic green energy. The speakers at the meeting were Bjarni Benediktsson, Minister of Finance; Dr. Douglas Parr, Chief Scientist and Policy Director at Greenpeace UK; Edward M. Stern, President and CEO of PowerBridge, LLC; Charlotte Ramsay, Head of Commercial Regulation & New Business at National Grid, European Business Development; and Hörður Arnarson CEO of Landsvirkjun.

The representatives from UK were all in favour of a cable connection between Iceland and UK, including the representative of Greenpeace. Mr. Stern from USA stated that conditions for financing a cable were favourable today, and he was positive that with the right expertise and partners it could be financed in such a way that the project would prove to be profitable. Two additional public meetings regarding interconnectors have been held in Reykjavík since this seminar and the interest regarding the subject seems to be growing.

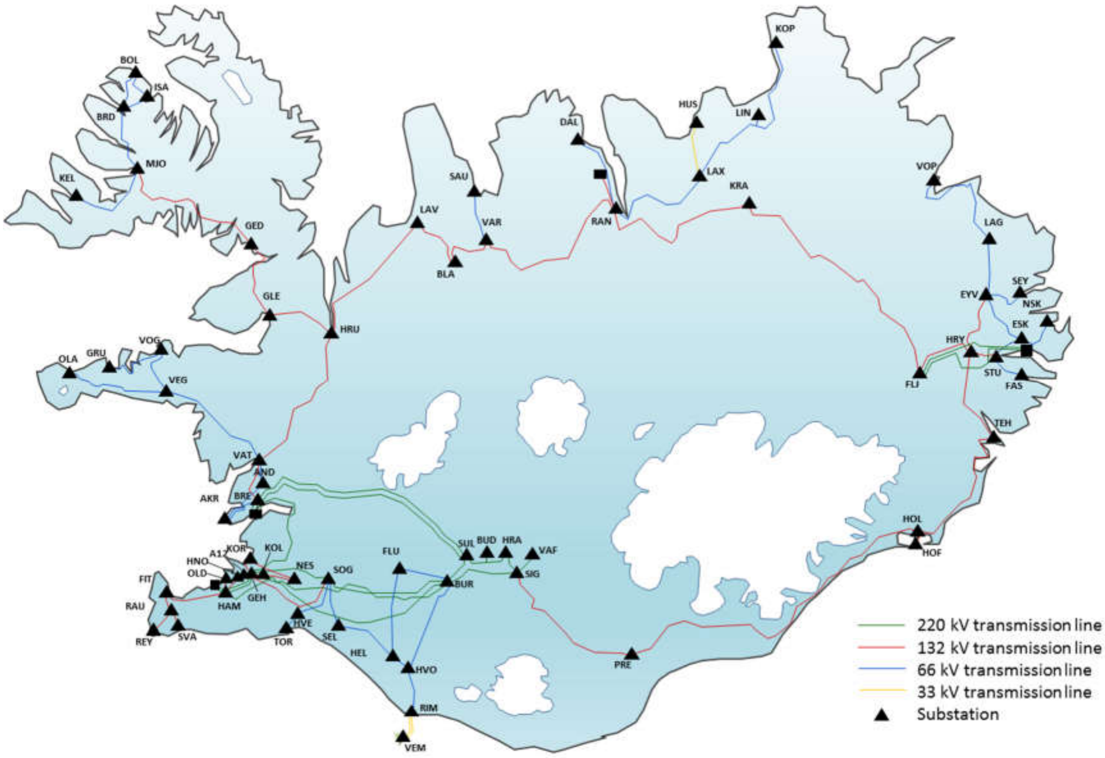
The idea of a cable network like the NAEN project is not new. The CEO of Orkustofnun at the time, Jakob Björnsson (Björnsson, 1993), wrote an article titled North-Atlantic Power System (NAPS). The article describes an interesting multi-terminal HVDC system, consisting mostly of submarine cables and AC/DC converter stations connecting the DC system to the AC system of the countries involved. This is a very ambitious idea which is best described with a picture from the article.



North-Atlantic Power System (NAPS): Orkustofnun (National Energy Authority). 1993. A Concept of a North-Atlantic Power system (NAPS). (Björnsson, 1993).

Transmission system in Iceland

Landsnet owns and operates all major electricity transmission lines in Iceland. The bulk transmission system ("the grid") consists of power lines with voltages of 66 kV and higher, some 33 kV lines and all major substations in the country.



The Icelandic transmission system in 2015.

The total length of the transmission lines in Landsnet's system is about 3,200 km where two thirds belong to the main system that connects production to usage. The transmission system is characterized by a strong 220 kV network in the south-west part of the country, a weak 132 kV circle with long transmission lines around the country and some local 66 kV networks. Also in the east, where the chosen landfall for the NAEN project is, there is a strong 220 kV "island" with a 690 MW hydro power plant and an aluminium smelter.

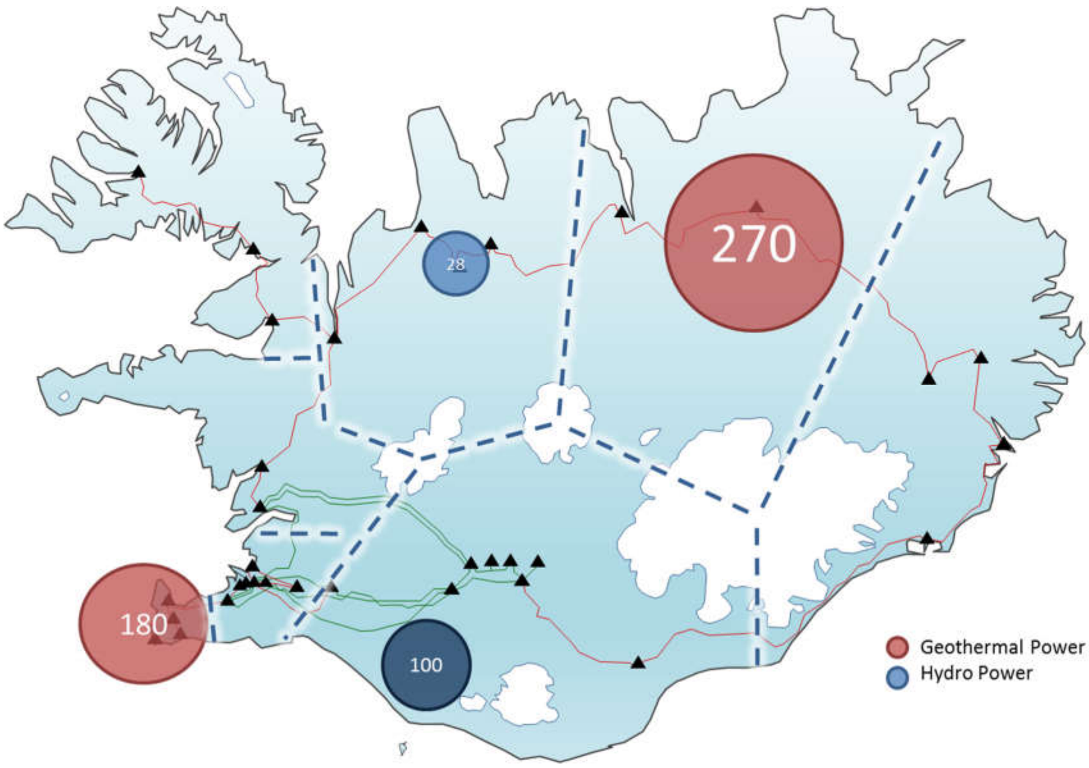
The installed power capacity of the power plants connected to the grid is 2,593 MW where 80% is generated with hydro power and the rest is thermal power. Over 60% of the power production is in the south-west part and over 30% in the north-east.

Transmission reinforcement and cost for a connection in the eastern part of Iceland

The chosen landfall in this analysis for the NAEN-Link is in the eastern part of Iceland. Due to the location of the landfall with respect to the production scenario, some reinforcement of the transmission system is required to be able to deliver up to 150 MW to the interconnection and fulfil an N-1 level of security. The reason for this is that the transmission capacity between regions in the present transmission system is insufficient due to low transmission capacity in transmission lines between the north and south east parts of Iceland.

Production scenario

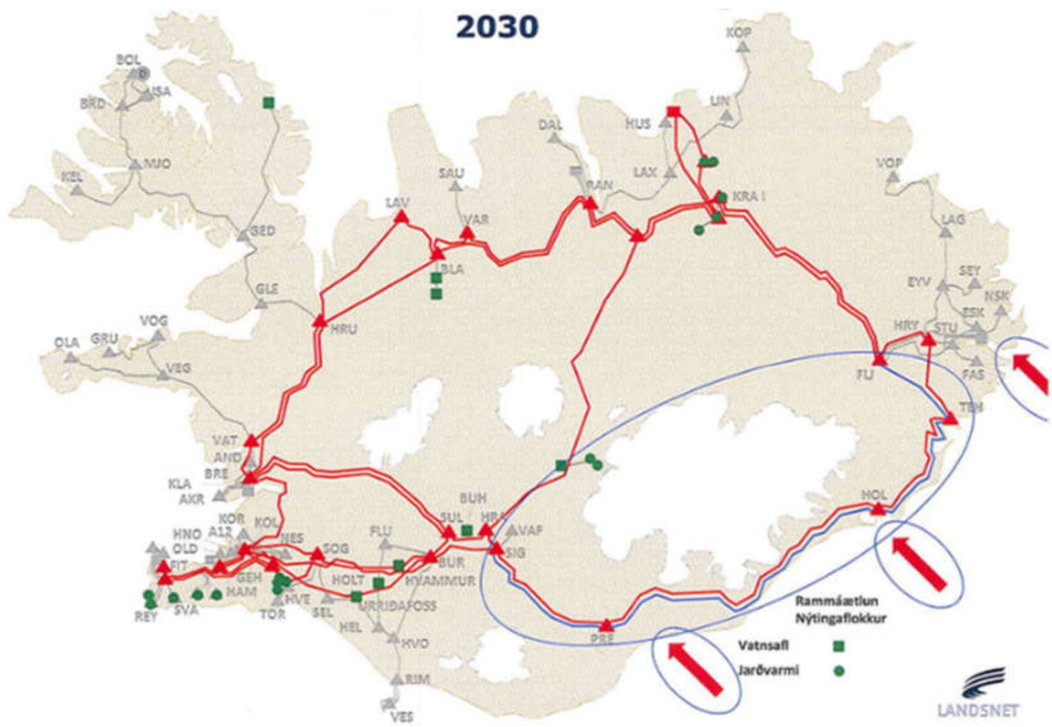
In order to estimate the production needed to supply the NAEN-Link, the link is treated as a 100-150 MW user. For this size of a user it is assumed that the power can be delivered from the grid. This evaluation is based on the present Master Plan for Hydro and Geothermal Energy Resources in Iceland, if 50% of the feasible energy resources according to the present Master Plan are realized. The 50% of the feasible energy resources is one of the scenarios that Landsnet bases their grid reinforcement plans on and is one of the scenarios that could provide the NAEN-Link with energy.



Estimated production increase in MW if 50% of feasible energy resources are realized.

The landfall of the HVDC link

In this study a landfall in the eastern part of Iceland has been chosen as it is the most natural position of such a connection. However, in previous studies on an HVDC link to Iceland, three different landfalls have been investigated. The two additional landfalls are located on the South-East Coast and on the South Coast of Iceland.



Three possible landfalls.

The connection on the southern shore connectes to a stronger point in the Icelandic power system, but a connection on the eastern shore makes the sea-cable shorter.

Grid reinforcement

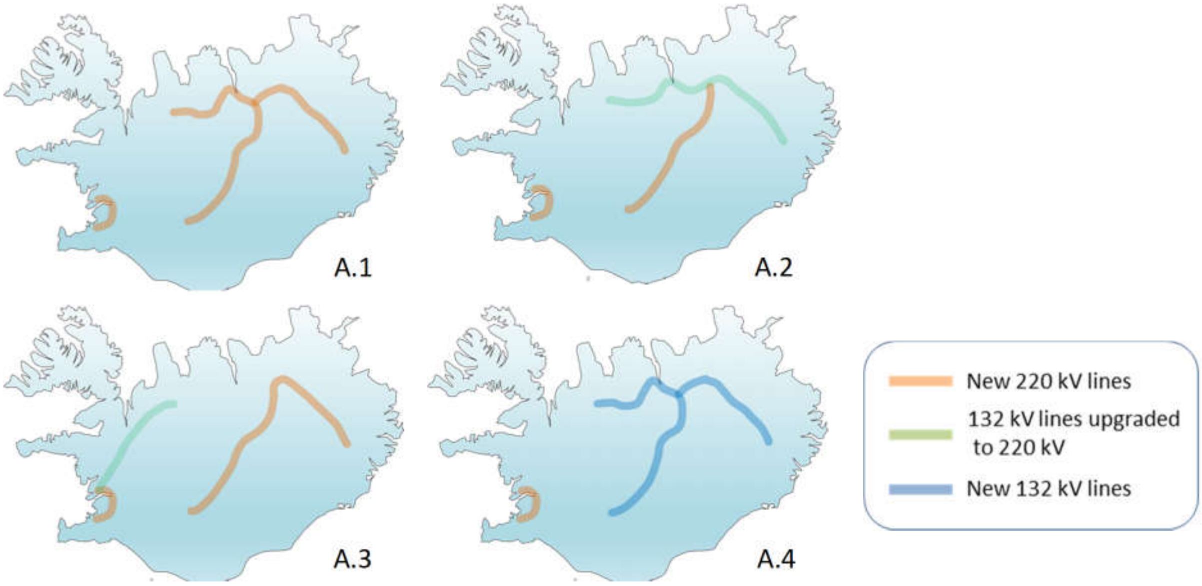
Landsnet is already planning to reinforce the grid with a 220 kV connection between the north-east area and the south-west area. There are two main options for this reinforcement with some variations:

A. The Highland connection where new transmission lines connect the southern, northern and eastern part of the system crossing the highland.
B. Rebuild the circle around the country.

The options and variations are evaluated with regard to stability, flexibility, power delivery, short-circuit power, security, proximity to power production and losses.

The Highland connection

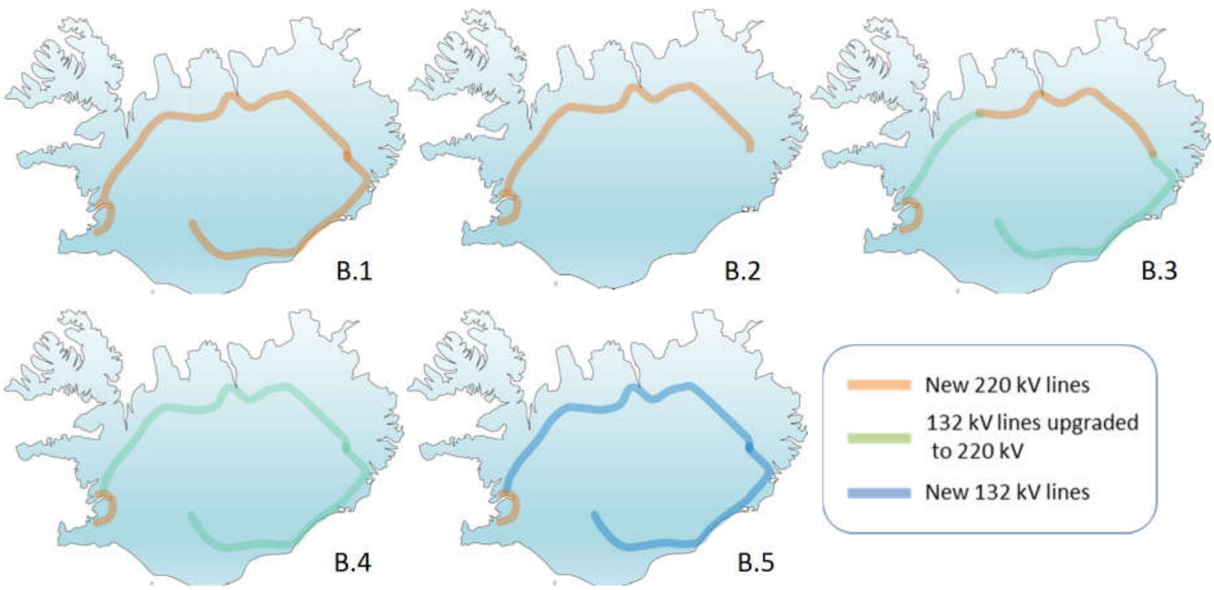
The Highland connection is based on new transmission lines across the highland of Iceland as illustrated in the following figure. The first variations (A.1) scores highest in the evaluation whereas the other variations are less viable.



Variations of option A, the Highland connection.

Reinforcement of the current 132 kV circle

This option is based on reinforcment of the existing 132 kV circle around the country, the variations include either new 220 kV or 132 kV transmission lines parallel to the existing ones, upgrade of the existing lines to 220 kV or combination of both variations.



Variations of option B, Reinforcement of the current 132 kV circle.

Here the B.1 scores highest in the evaluation.

Cost for the connection

A rough cost estimate for options A and B indicates that the total cost for option A is about 40-50 bn ISK whereas option B costs around 60-70 bn ISK. The main reason for this cost difference is that the transmission lines needed to reinforce the grid in option B are much longer than in option A. The variation in the estimation is due to different technologies used, e.g. underground cables or overhead lines.

Pros and cons for the Icelandic transmission system

The main advantage of the NAEN link for the Icelandic transmission system would probably be the implementation of an HVDC converter station to the grid. The converter station would provide fast-acting reactive power on the transmission system and thereby support it by regulating the voltage, power factor and harmonics.

The main problem with the Icelandic transmission system is, as mentioned before, the limitation on transferrable energy between areas. In order to maintain the reliability and stability of the system it is necessary to strengthen the transmission capabilities of energy between areas, especially between east and west. As the main system around the country consists of rather long and weak 132 kV transmission lines, a single failure somewhere in the system can cause severe instability problems if the transmission lines are heavily loaded.

The disadvantage of the link for the current transmission system would be during energy export with the link. Any export through the link would increase the loading of the transmission system thus increase the risk for any instability issues. This disadvantage will be reduced should any of the grid reinforcement plans be realized in the near future.

Landsnets role regarding Interconnectors

Currently Landsnet has no role regarding interconnectors. According to the Icelandic Energy Law 65/2003 its role is to develop the transmission system in a cost effective manner, taking into account the safety, efficiency, reliability of supply and quality of electricity.

Interconnector up to 1,000 MW

A 100-150 MW interconnector may not be feasible due to its relatively small size. Thus a 1,000 MW interconnector has also been investigated. This is relatively small compared with the largest connections, although it is a fairly large part of the installed capacity of power plants in the current grid (which is around 2,500 MW). This alone makes it impossible to directly replicate methods used elsewhere into the local environment.

Throughout the years, Landsnet has pointed out that the current electrical transmission system is at its tolerance limit, and its renewal and reinforcement are necessary, whether a marine cable abroad is constructed or not. Ideas for future development are, for the most part, variations of two basic paths; on one hand the connection between North and South Iceland across the highlands, along with the further development of the transmission system in the North and the North-East; and on the other hand the development of a new circle transmission network around the island.

The premises for these two basic paths do not include a marine cable, with a transmission capability of 1,000 MW, to be connected to the transmission grid. Landsnet has been working on system analyses and research to map out the need for necessary reinforcements for connecting to a marine cable, apart from the two possible paths included in the Grid Plan. The production premises for these analyses are largely based on the utilization category of the Master Plan for nature conservation and energy.

Landfall and the effects on the grid's development

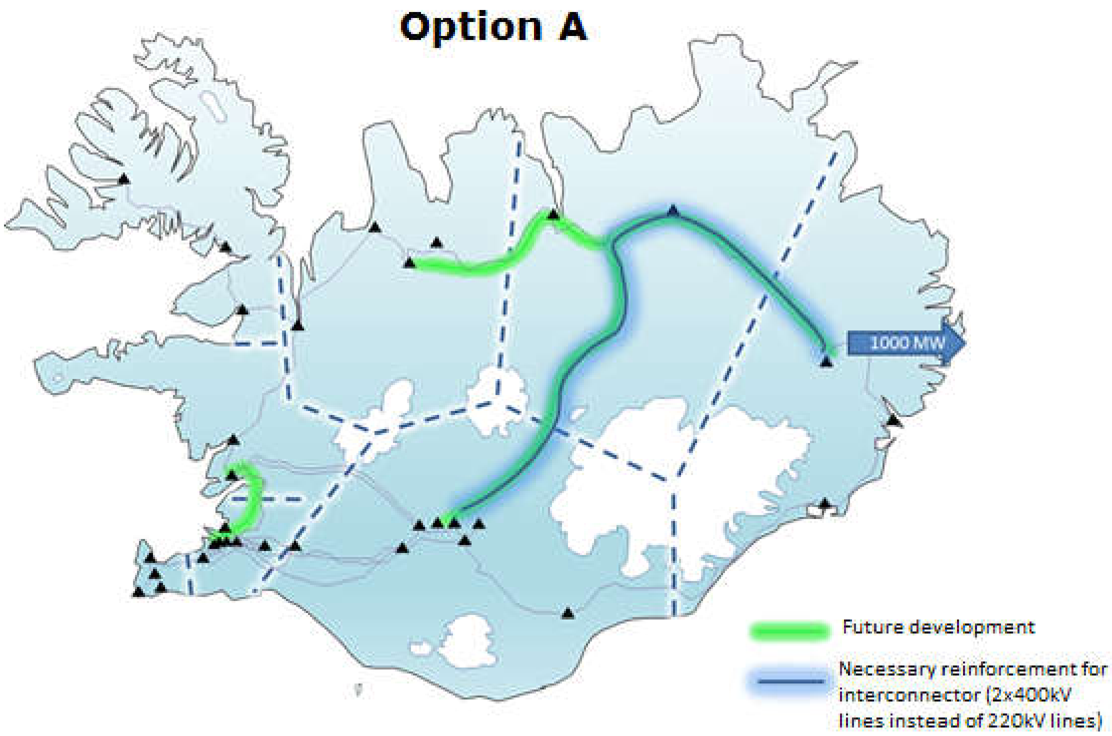
Several possible landfalls for a marine cable have been looked at, from the Eastfjords of Iceland and along the southern coastline. A landfall in the Eastfjords would be economical in terms of the overall length of the marine cable. However, a landfall there would demand great reinforcements for the transmission system, as the majority of new power harnessing options, which the research is based on, are located in the South-West and North, and current grid connections from there to the East are weak. A landfall in the South, however, would mean a significantly longer marine cable route, but less reinforcement of the grid as a landfall in the Eastfjords would entail, as the South is the strongest part of the grid, and the area also contains the most power harnessing options. Other options fall in between the two.

How to secure the necessary strengthening of the grid, in order to maintain full security of supply through the marine cable, has been researched with these possible landfalls in mind. The focus has been on the necessary development of the grid between the regions. Reinforcements that might be necessary within each region have not been elaborated on, as a realistic estimate would require further information on the power harnessing plants and the harnessing options that would be utilized. An estimate regarding the arrangement of the connection between the landfalls and the grid has not been made.

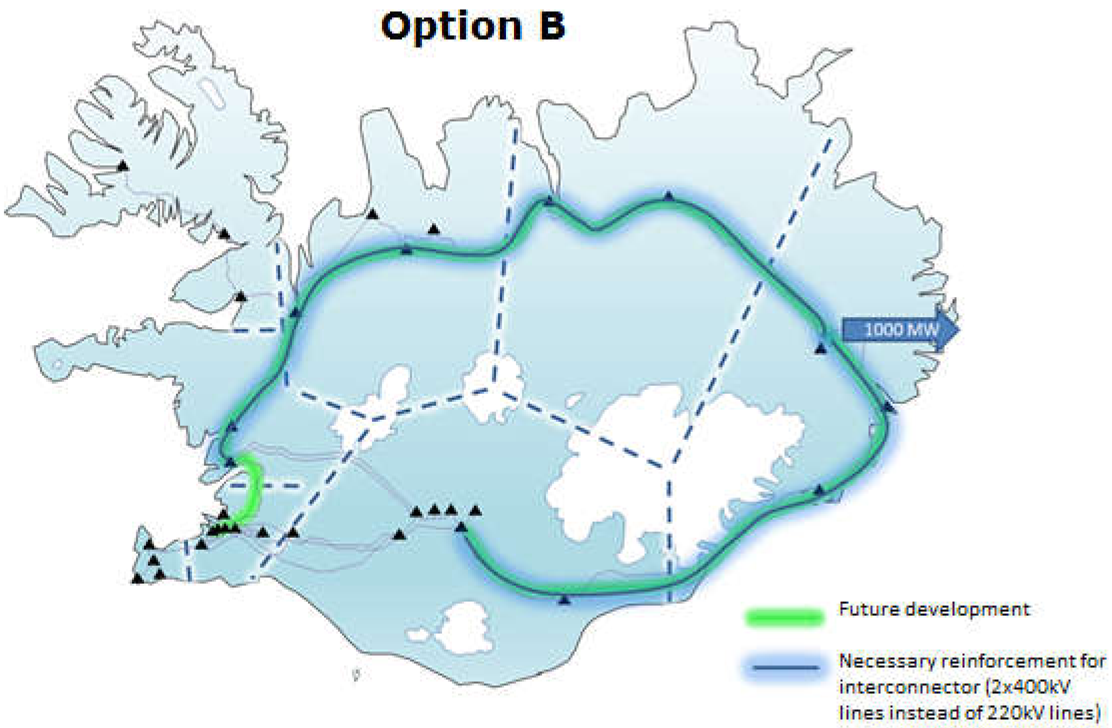
Landfall in the Eastfjords

Development options of the transmission grid, vis-a-vis a landfall of a marine cable in the Eastfjords, have been investigated, both from the point of view of a highland route and an inter-regional circle line on the other. These routes are based on the same premises as the future development of the grid. The aim of the analysis was to evaluate if, and then how much, the grid would need reinforcement above and beyond these basic grounds, so that it would be able to handle the transmission required for the marine cable. Due to the demand for full security of supply to the marine cable, it is necessary to maintain a double connection to the landfall, even though a 400 kV transmission system were to be constructed. Transmission of up to 1,000 MW to the cable is so great that using a 220 kV system is not realistic, if the landfall were to be in the Eastfjords. The reason is the amounts of voltage drop in the system, as so much of the energy needs to be transmitted from the southern parts of the country. Building two 220 kV lines that could carry a greater load is not a solution either, double 400 kV lines must be constructed, instead of single 200 kV lines.

Next figures show how development options for marine cables comply with plans for the future electrical grid.



The development of the grid, taking a marine cable into account and the future grid (option A), Landfall in the eastfjords.



The development of the grid, taking a marine cable into account and the future grid (option B). Landfall in the eastfjords.

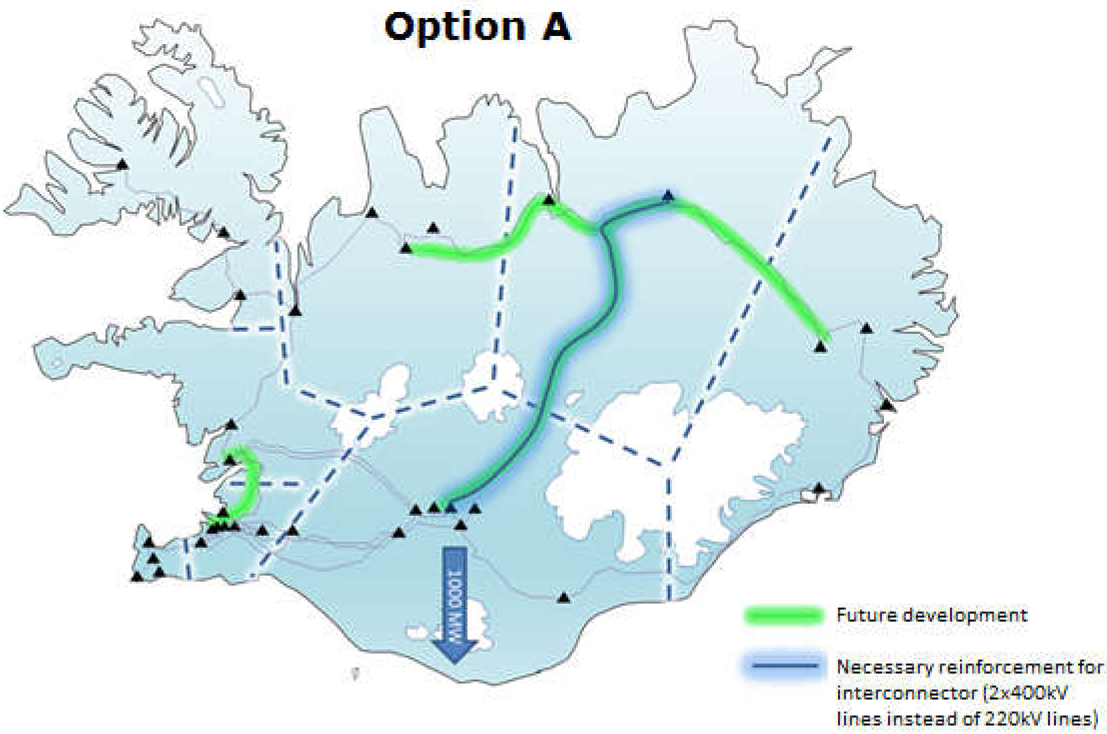
In both cases, the grid must be significantly reinforced beyond what is included in the planned future development. Given that the maximum power, 1,000 MW, and the demand for N-1 security of supply to the line, the results of the analysis show that there would always be a need for double 400 kV lines, instead of simple 220 kV lines, from the South and/or South-West to the landing area in the Eastfjords. Power requirements call for the voltage level and the security of supply of a double line. By relaxing the demand for N-1 security of supply, one could get by on a single line, but it would nonetheless have to be 400 kV.

Landfall in the South

Delivery to a marine cable, which would be connected to the grid in the South (a non-specific location in the Thjórsá-Tungnaá area), was analyzed, using the same premises as for a possible landfall in the East. As mentioned earlier, connecting a marine cable into the grid in the South is well suited in terms of available power harnessing options.

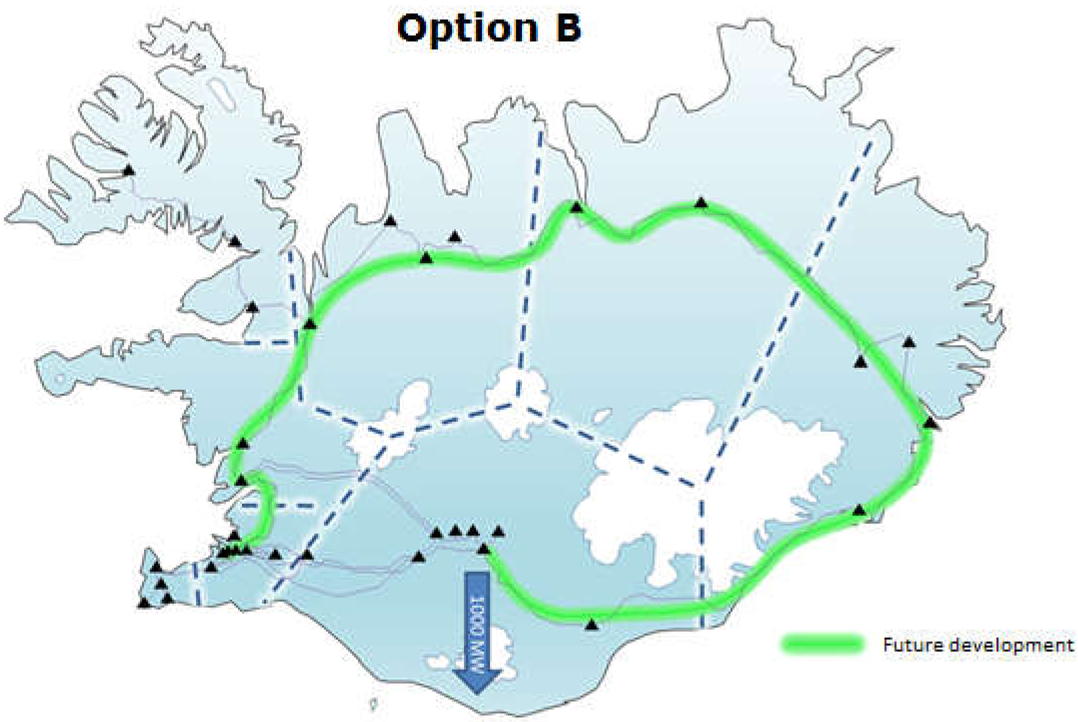
For the transmission of up to 1,000 MW, it would suffice to build 220 kV lines between the regions (the North-East and the South). To maintain an N-1 security of supply through the cable, they would have to be doubled, but their transmission capacity wouldn't have to be more than is already planned in the Grid Plan premises (i.e. given the production premises).

If a highland option were chosen, the 220 kV connection would have to be doubled between the power harnessing areas in the North-East and the South with 400 kV lines instead of 220 kV, as shown in next figure.



The development of the transmission grid, taking inot account a marine cable and future grid (option A) Landfall in the south.

The Inter-Regional Transmission Network is, by its very nature, a double connection between the power harnessing areas in North-East and South Iceland. Analyses have shown that there is no need for further strengthening, above what is already planned for future development based on option B, given that the Network is completed in full. The variations of option B that include a voltage level upgrade of the current Network to some or full extent are ruled out.



The development of the grid, taking into account a marine cable and the future grid (option B). Landfall in the south.

Necessary reinforcements of the 220 kV grid in the South and the South-West are not discussed here, as this would depend on the exact location of the marine cable's connection to the grid as well as the location of new power harnessing options. One can assume that such reinforcements will be needed, first and foremost to increase the transmission capacity. Neither has it been investigated how the transmission from the landfall to the grid would be arranged.

Other landfalls

As mentioned earlier, one can assume that other landfalls, between the South and the Eastfjords, would be a varying mixture of the two options. The landfall would always require a double connection, both of which would have to be able to handle all of the transmission.

What is mentioned here above is vis-a-vis the export of electricity through a marine cable. All plans for the operation of the marine cable assume that for the majority of its operational period, the electricity will be exported. The domestic system, however, must be prepared for import. For the most part, the same principles apply when energy is transported into the country. The majority of energy is used in the Southwest corner of the country, and to transmit energy to that area from the landfall, one would need the same kind of transmission system as for export.

Things to be concidered

The debate in society on whether or not to construct a marine cable to other countries has become more prominent over the past few seasons. People have varying opinions on the construction of such a cable, and therefore it is important that all decision be based on as trusty a ground as possible. Landsnet's research has been concentrated on analysing the big picture domestically, that is to say to compare a few options based on the same premises, and taking into account the need for future developments of the grid. These studies have not included possible changes in electricity use, beyond what is set forth in the electricity forecast. The exact implementation of how the marine cable should be connected to the grid has not been examined. Neither has there been an in-depth analysis of which harnessing options need to be activated due to the project, nor their future connections to the grid.

A demand for higher security of supply to the cable, that is to say that the required energy is available on a N-1 principle, means that the delivery point must have two connections, as discussed earlier.

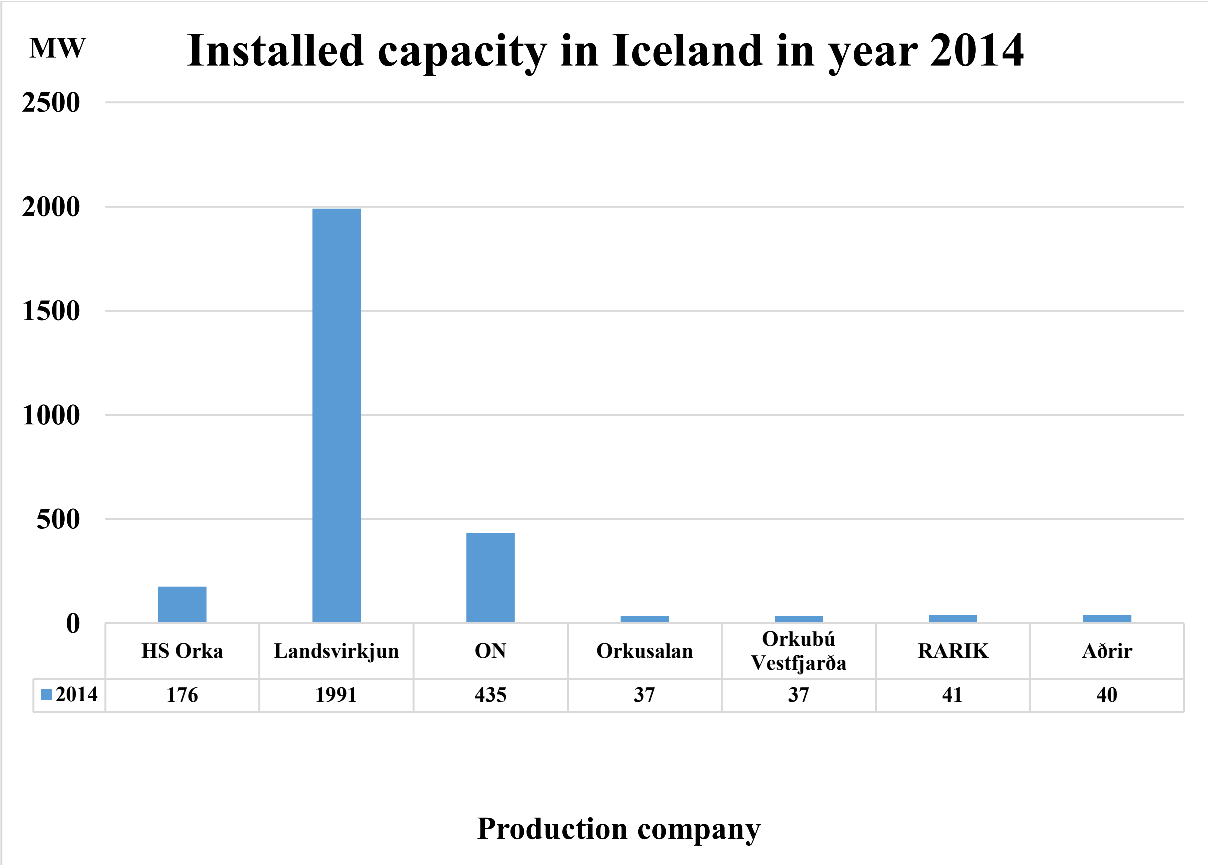
A more in-depth analysis is needed as to how the Icelandic electricity system can react due to sudden changes in the cable's operations, for example how quickly the flow could be reversed (from export to import) and also, if the cable were suddenly to become disabled during a time of great export. It is important that domestic electricity users be not overly disturbed by such events. In reality, the marine cable would be comparable to a power-intensive consumer, although it would be somewhat larger than the biggest users within the current system.

According to the rough picture revealed here, the Icelandic grid must be reinforced if it is to be able to handle transmission to the landfall of a marine cable, given the premises listed here. The grid reinforcements needed, i.e. above the ones already suggested by Landsnet for the future development of the grid, range from relatively minor to quite significant. However, it must be emphasised that there are still many unclear variables regarding the project. Location, size, and the nature of new power harnessing plants (i.e. wind, hydro, or geothermal), can significantly impact the need for reinforcement. Also important are points of view regarding, on the one hand, a lesser reinforcement to the grid and, on the other hand, a longer marine cable. Furthermore, factors such as the quality of the landfall and environmental effects on both sea and land must be considered. The analysis that Landsnet has concluded is only in terms of the necessary strengthening of the domestic grid.

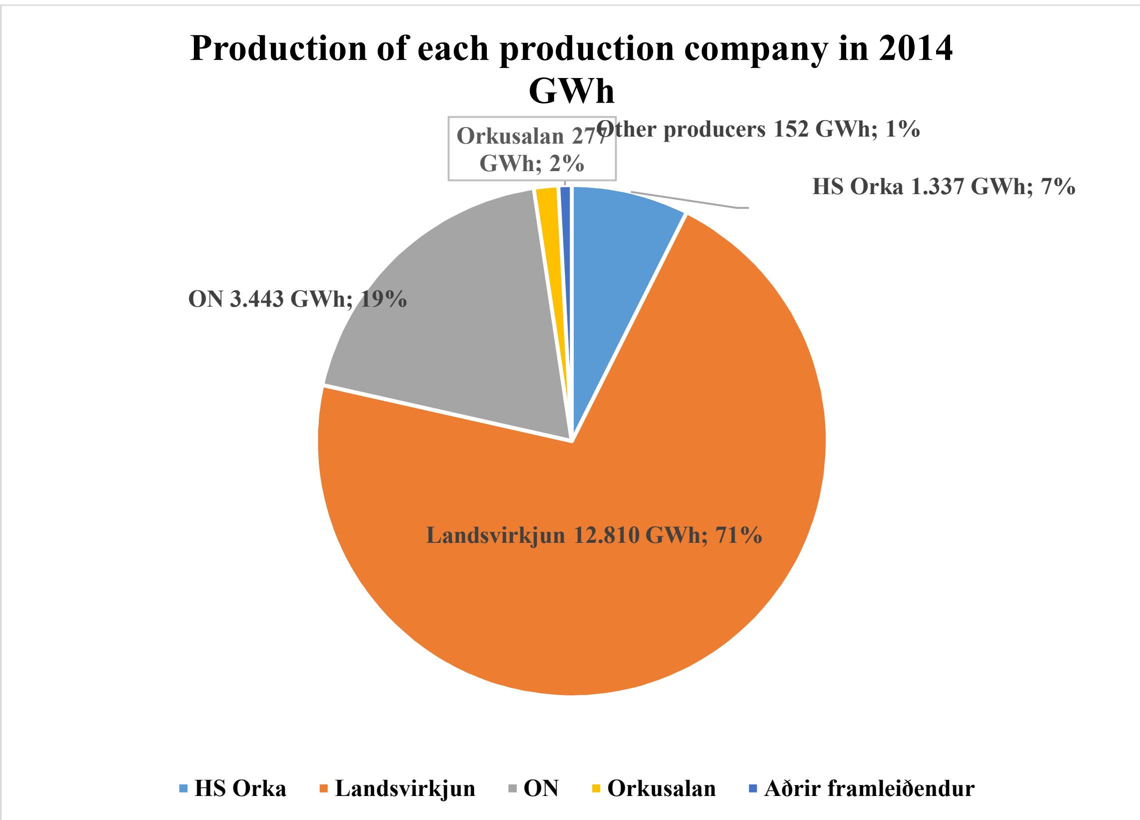
It should not be forgotten that this strengthening of the grid would also be beneficial in addressing the increased domestic load. Dependability and security of supply of the grid would significantly improve in general, and it would become better equipped to receive electricity and deliver it to the end users.

Electricity production

The capacity of renewable electricity production in Iceland is a little less than 2,000 MW in Hydro power, 665 MW in geothermal power and 3.2 MW in wind power. Diesel power accounts for about 0.01 to 0.02% of electricity production in Iceland and is mainly used for backup power. Hydro power provides around 13 TWh, Geothermal about 5 TWh which gives about 18 TWh of electricity production. Utilisation of wind power started in the year 2011 but research has shown that there is a great potential for harvesting wind power on land. The majority of electricity production in Iceland is in the hands of three companies, Landsvirkjun, ON and HS Orka. Landsvirkjun owns the majority of the hydro power plants but the main source of energy for ON and HS Orka is geothermal. Capacity belonging to RARIK is purely diesel generators for backup power.

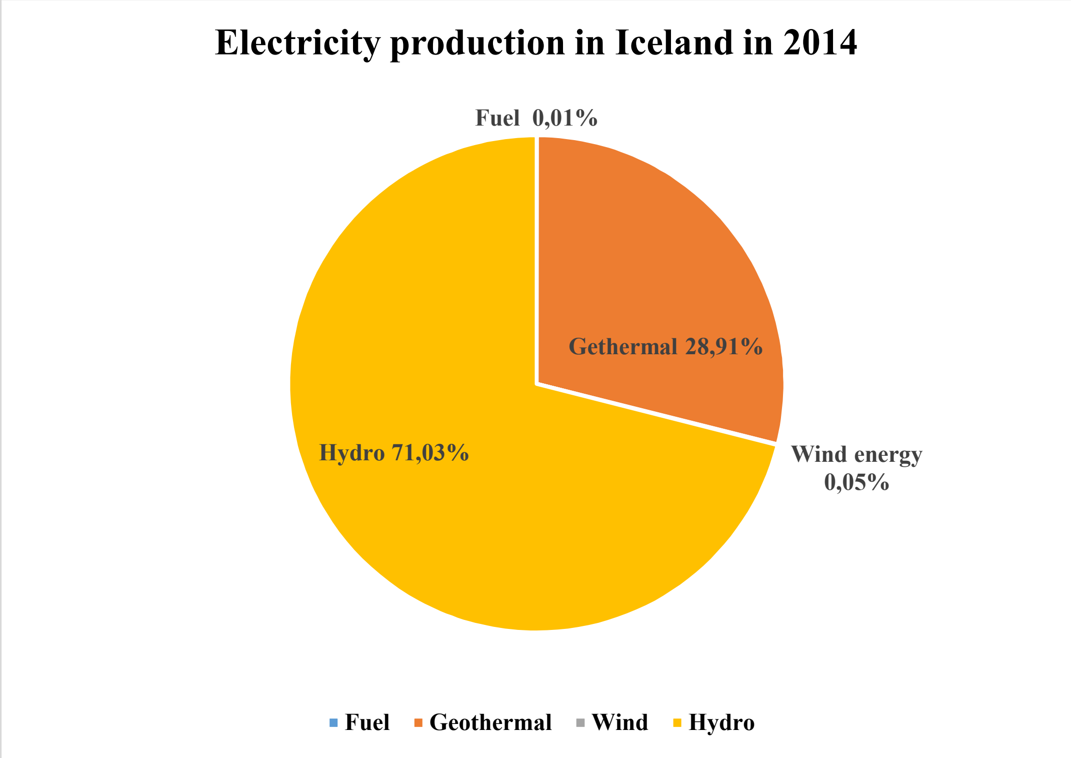


Installed capacity in MW of each production company in Iceland in year 2014.

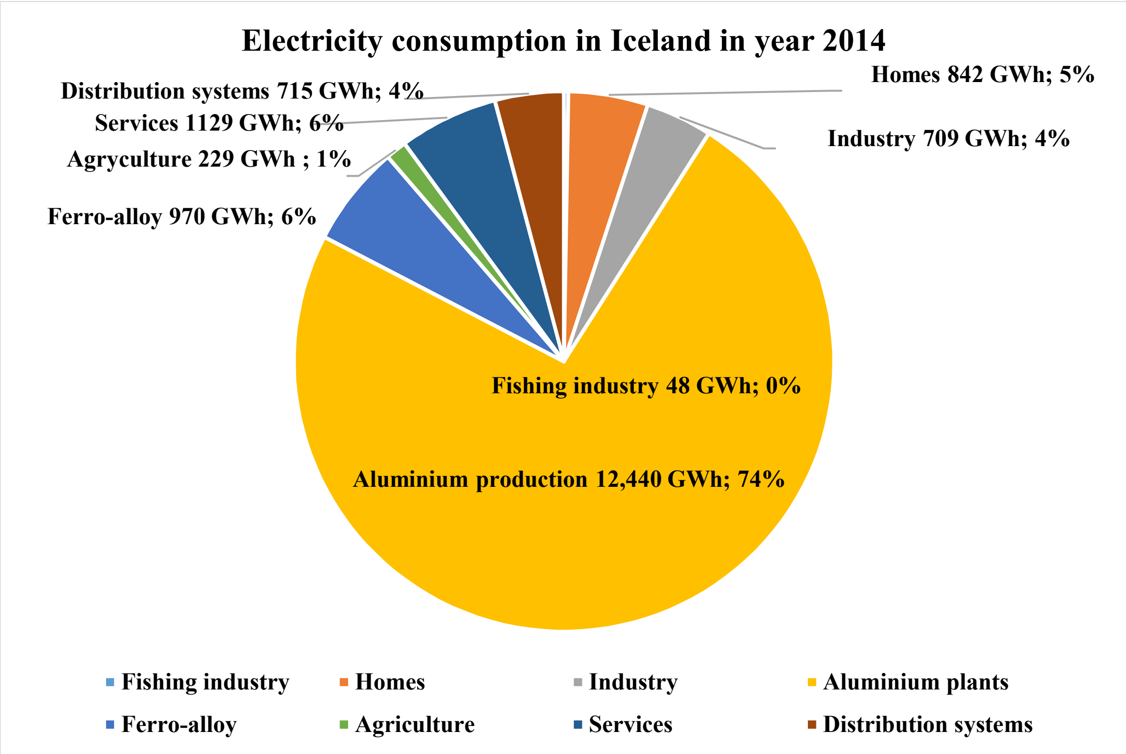


Production in GWh of each production company in Iceland in year 2014.

Landsvirkjun, the largest power company in Iceland, produces 71% of all the electricity used in Iceland and the majority of that power is hydro power.

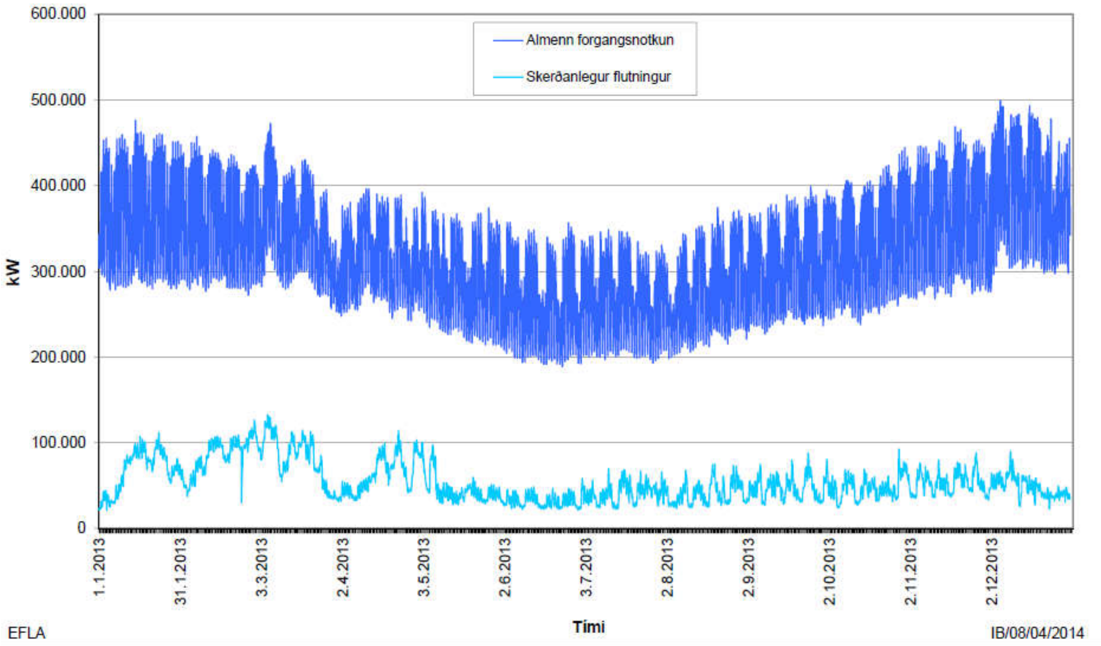


Origin of the electricity production in Iceland in year 2014.



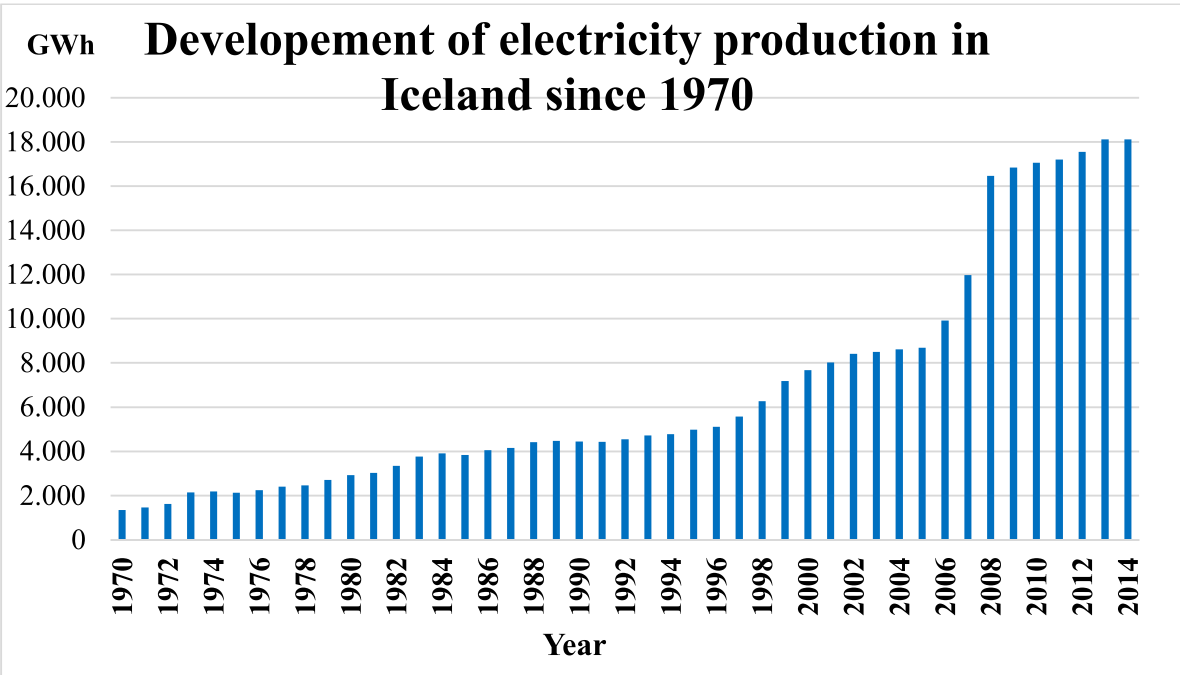
Electricity consumption in Iceland in year 2014.

Aluminium production in Iceland accounts for 74% of all the electricity usage in the country and is a way of exporting the natural resources without a subsea cable connection. This has many advantages as the usage is very steady, based on long term contracts and the bulk load in the system is rather even through days and seasons.



Energy load in the power system in Iceland in year 2013 (Orkustofnun, 2013).

The dark blue pattern in the figure, Energy load in the power system in Iceland in year 2013, shows the priority load in the system and the light blue line shows the controllable load. As can be seen 200.000 kW out of max 500.000 kW load are steady throughout the whole year.



Development of electricity production in Iceland since 1970.

The electiricity production in Iceland has been growing steadily since 1970 and in 2007 there is a jump in the graph when the third aluminium plant in Iceland started ramp up to full product production in 2008.

Electricity market

Market prices are not publicly available in Iceland except for homes; the price pr. kWh for Icelandic homes is about 5.3 ISK (0.27 DKK or 0.036 EUR). Most of the production capacity is tied up in long term contracts so the market as a whole is not very active.

Benefits

The benefits of a North Atlantic Energy Network for Iceland may wary in light of how it will be built up and how market conditions develop. Different parts of the network have different benefits for Iceland and all the other countries involved in the NAEN project.

Iceland is an island and therefore the electrical system is also an island system. As the capacity of the power plants in Iceland is over 2,500 MW a connection through the NAEN network is not seen as a backup power unless the cable capacity is considerable. None the less if some catastrophic events would happen in the geologically active mid-section of Iceland where the majority of power production is today it might be very helpful to be able to have access to some power through a cable connection.

Electricity prices in Iceland are low compared to the rest of Europe and market conditions are those of oligopoly. A real, well functioning market could emerge if an interconnector of a sufficient capacity opened up business to other parts of Europe. The downside of an interconnector is mainly twofold; very likely the prices of electricity would go up and the energy sold through a cable would not be used to contribute to the labour market in Iceland.

The benefits for Iceland largely depend on how the profit and risks in a project like this are distributed.

Potential

Iceland has a potential for increased use of geothermal, hydro and wind power. As the wind intensity is highest in the winter time in Iceland when water level in the reservoirs is going down, the combination of wind and hydro can be profitable for the power system.

As windfarms may have different production capacity at a given time in Iceland, Shetland and Faroe Islands, combining production of wind power from different locations with hydro power in Iceland, Norway and possibly Greenland may give favourable results. The Met Office (Nawri et al., 2013) in Iceland estimates that a preliminary study of existing data to show if and how average wind changes between areas could be prepared in a couple of weeks.

Landsvirkjun has introduced plans for a 200 MW windfarm in the vincinity of Búrfell power plant at a place called Hafið and a 100 MW windfarm in the vincinity of Blanda power plant. Iceland's potential for using wind power has been documented in a wind atlas provided by the Met Office (http://vindatlas.vedur.is/). The report, Wind Energy Potential of Iceland (Nawri et al., 2013), also gives a clear overview of the possibilities for wind power.

The two biggest wind turbines in Iceland that Landsvirkjun has set up at a location called Hafið have been producing electricity since February 2013. Operations have been reported by Landsvirkjun to be beyond expectations, with average capacity factor approximately 44% and operational availability nearly 98%.

Timescale for each energy source

The timescale for building geothermal and hydro power plants is a couple of years (three to four years) following thorough research which again may take decades. The timescale for setting up a wind turbine can be relatively short and basic research on wind energy potential is available for all of Iceland.

Lifetime for power plants of these different energy sources is 40 years for hydro, 25 to 30 years for geothermal and 20 to 25 years for wind turbines.

Environmental issues concerning a submarine cable

A submarine cable can influence its environment in many ways (OSPAR, 2009). The influence differs between different periods in the cable lifecycle. The impact is short term during laying, repair or removal of a cable but long term during the operation of the cable.

Impacts during operation are mainly from electromagnetic fields and heat. The electromagnetic impact diminishes rapidly with distance and the cable type and how it is laid can make a difference. The electromagnetic impact can be minimized by using the correct type of cable with a bipole configuration, by burying the cable and keeping a minimum distance between cables.

Increase in temperature very close to a cable can effect living organisms and it is necessary to take this into consideration during the design of the cable.

Environmental impact is more complicated during laying, maintenance, repair and possible removal of a cable. Possible environmental impacts include disturbance at the seabed, visible influences, noise, exhaust, waste from ships and tools for laying the cable.

It is very difficult to prevent disturbance at the seabed during the laying of a cable. Therefore, it is crucial to choose the route carefully and avoid areas where it takes living organisms a long time to regrow. Areas that are crucial for reproduction of living organisms should also be avoided.

A cable route in areas of soft sediment will lead to artificial introduction of hard substrates. The submarine cables themselves will also provide a solid substrate for variety of species.

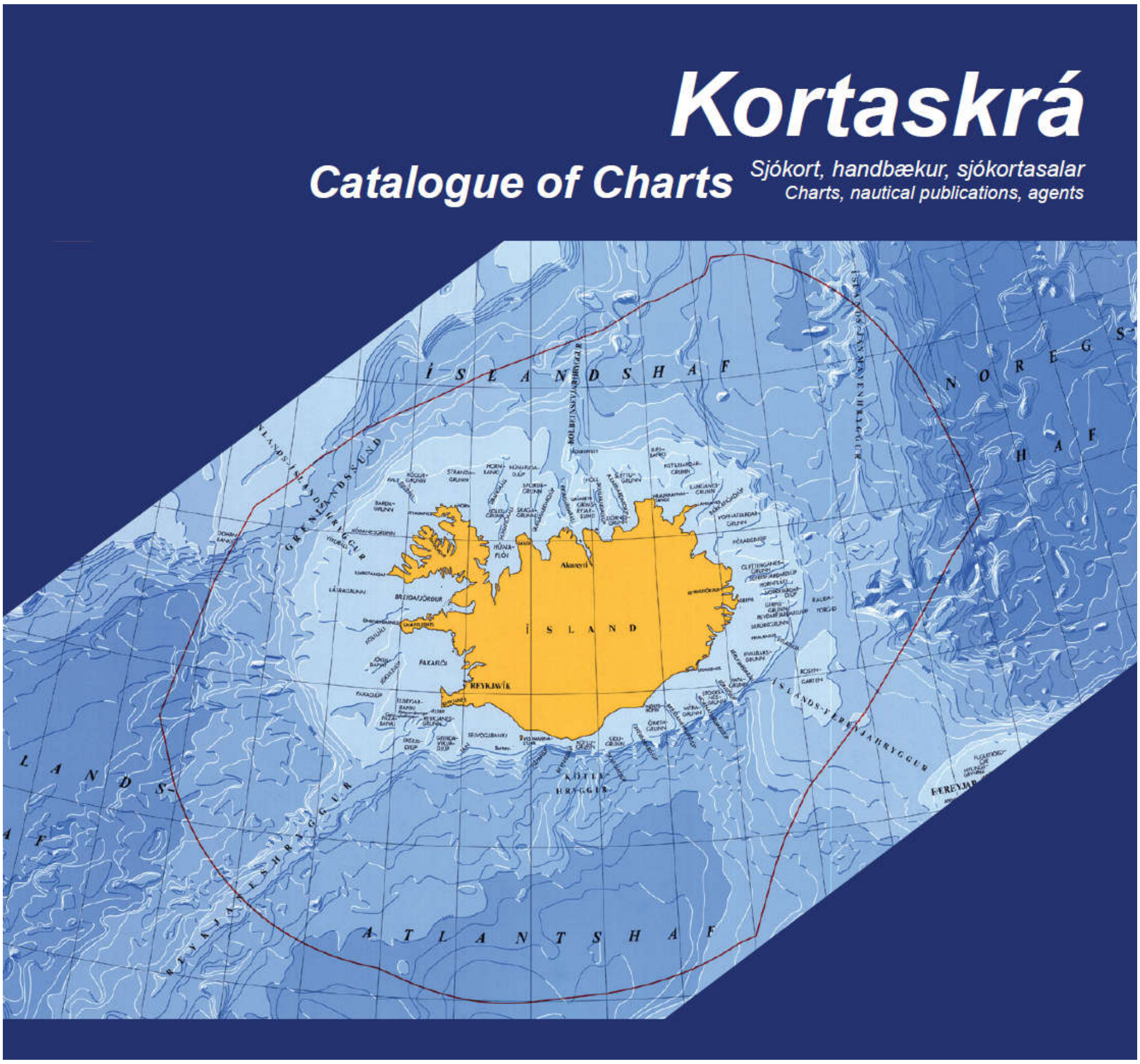
Information regarding the ocean around Iceland is limited in regards to the seabed and living organisms. Possible routes for cables in this area must be investigated thoroughly to try and avoid cold-water coral habitats and other biologically important areas, as well as areas that are important to the livelihood of fish stock like spawning grounds etc.

In the conclusions of the OSPAR report (2009), there are guidelines as to mitigation measures and removal of cables when they are out of operation.

Regarding various topics that need to be looked into, it is unclear what data are available concerning various issues. At best the data available are fragmentary. A committee regarding these issues is being formed and these matters need to be clear at least for the routes under consideration for cables from Iceland. As for this project, the first step to investigate who has relevant data is underway. Many institutions have parts of the available information, such as the Marine Research Institute, the Icelandic Coast Guard, the Environment Agency of Iceland, the Icelandic Road and Coastal Administration, the Directorate of Fisheries and the Icelandic Institute of Natural History. A full overview of the available data is not yet complete.

Borders

National and administrative borders are clear as Iceland is an island and has custody over the area shown in the map below from the Icelandic Coast Guard.

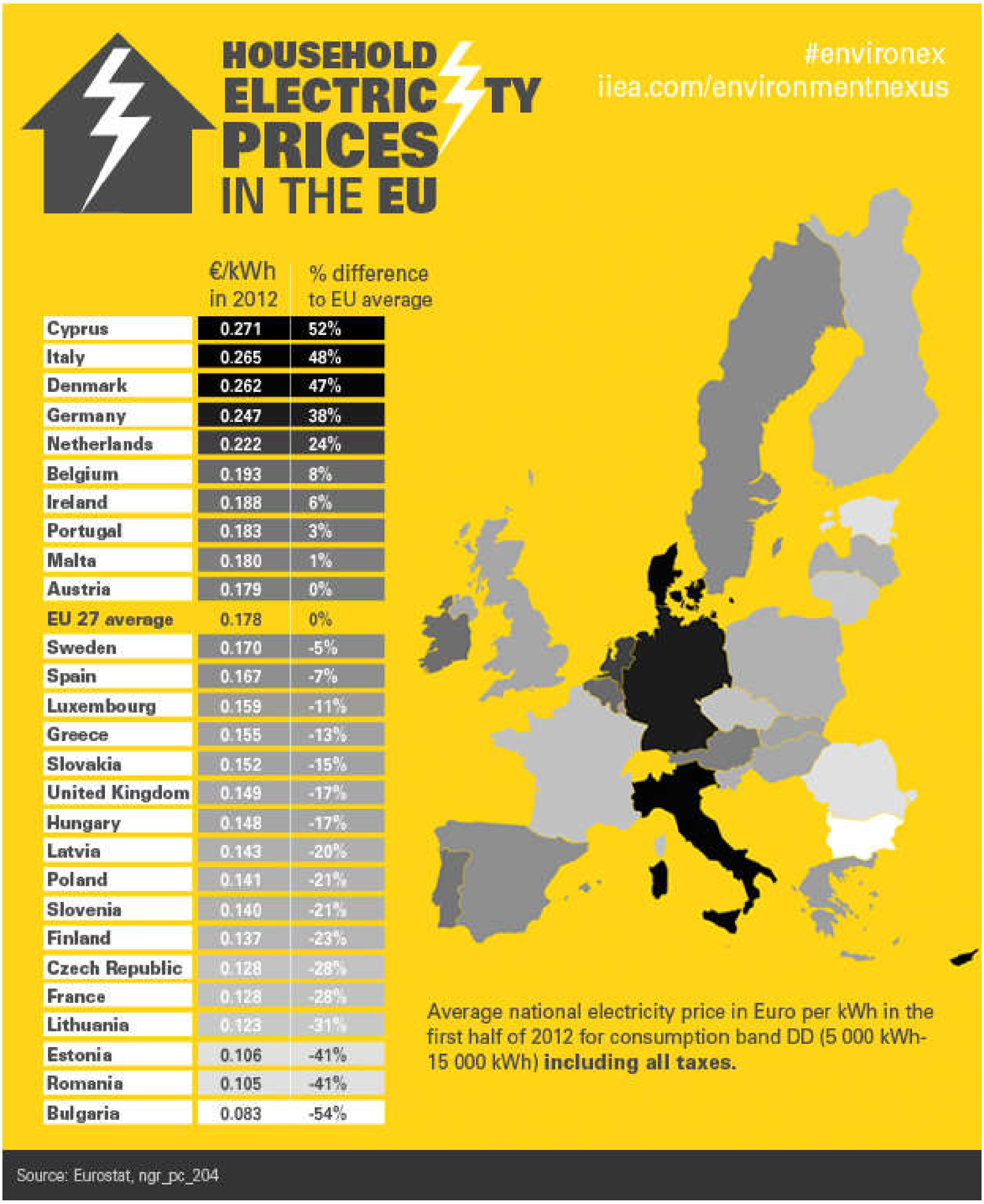


Map of of the Icelandic Exclusive Economic Zone (Landhelgisgæslan, 2015).

Economic gain

Looking at the household prices in Europe in 2012 according to http://www.iiea.com and comparing them to the prices in Iceland, reveals a huge price difference (IIEA, 2014). The weighted average price for consumption band DD was 14,74 ISK in 2012, which, with an exchange rate of 160,7 ISK pr. EUR, amounts to 0,092 €/kWh. The average price of the 27 EU countries was at that time 0,178 €/kWh, and thus the electricity prices to households in Iceland were only half of the EU prices in 2012.

This price difference can amount to profit for energy sold through interconnectors from Iceland if the connection cost itself is less than the price difference. This again may cause opposition from the general public as one of the pluses of living in Iceland are low electricity prices.



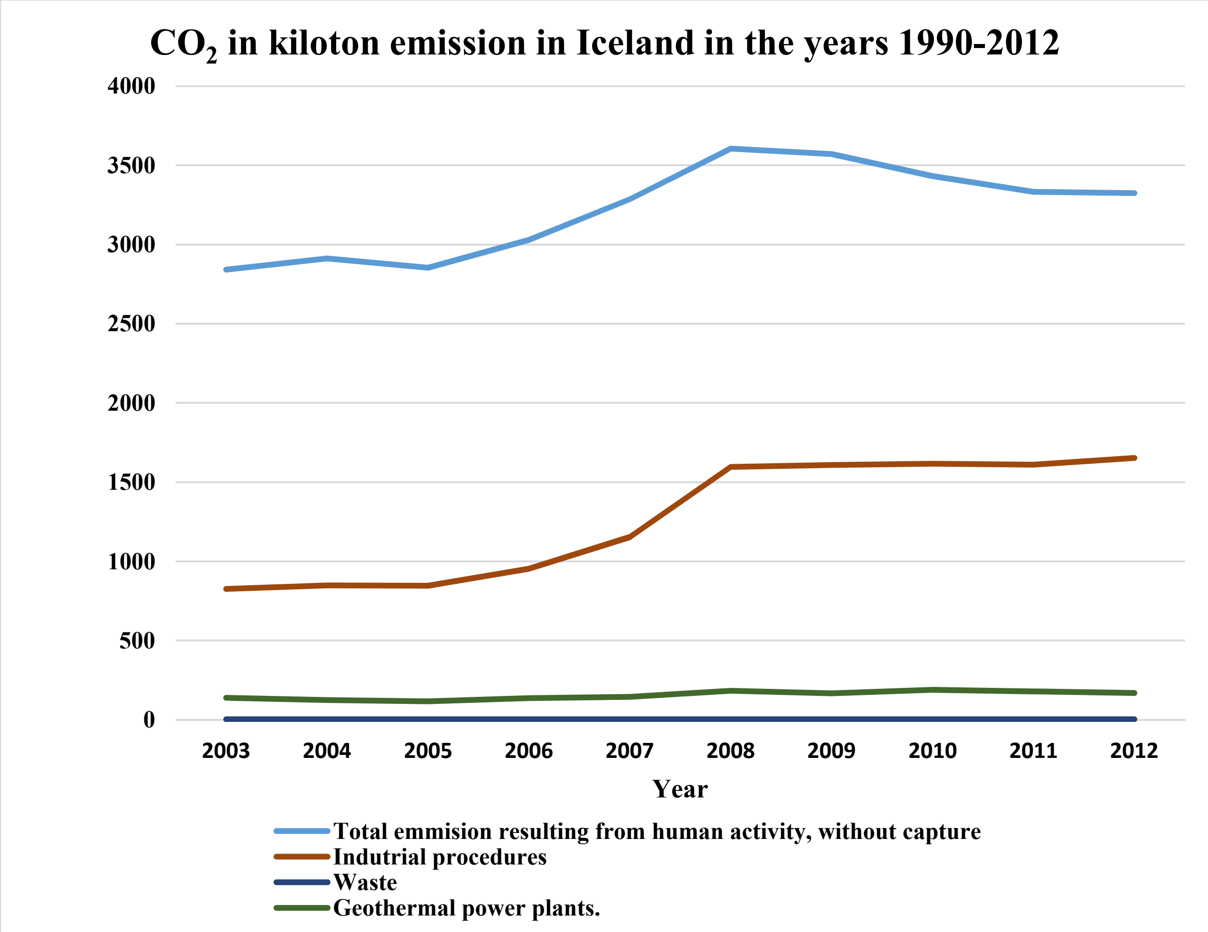
	€/kWh in 2012	% difference to EU average
Cyprus	0.271	52%
Italy	0.265	48%
Denmark	0.262	47%
Germany	0.247	38%
Netherlands	0.222	24%
Belgium	0.193	8%
Ireland	0.188	6%
Portugal	0.183	3%
Malta	0.180	1%
Austria	0.179	0%
EU 27 average	0.178	0%
Sweden	0.170	-5%
Spain	0.167	-7%
Luxembourg	0.159	-11%
Greece	0.155	-13%
Slovakia	0.152	-15%
United Kingdom	0.149	-17%
Hungary	0.148	-17%
Latvia	0.143	-20%
Poland	0.141	-21%
Slovenia	0.140	-21%
Finland	0.137	-23%
Czech Republic	0.128	-28%
France	0.128	-28%
Lithuania	0.123	-31%
Estonia	0.106	-41%
Romania	0.105	-41%
Bulgaria	0.083	-54%

Houshold electric prices in the EU.

CO_2 emission

CO_2 emission from electricity production in Iceland is not seen as a great problem as the majority of electricity comes from hydro power and a large portion is geothermal power where sulphur is more of a concern than CO_2.

One of the largest power companies in Iceland, ON, runs a project called CarbFix, which has the primary goal of imitating the natural storage processes of CO_2 already observed in basaltic rocks in Icelandic geothermal fields. This project may help mitigating global warming as basaltic bedrocks with potential for storing CO_2 are widely found on the planet.



CO_2 emission in Iceland in the years 1990 – 2012.

The increase in CO_2 emission in the years 2006 through 2008 is mainly due to the ramp up of the third Aluminium factory on the East Coast of Iceland.

Legal perspectives

In Iceland, there are no specific laws regarding high voltage electrical cables in the sea. Act No. 41 from 1979 regards the territorial waters, economic zone and continental shelf, and according to Paragraphs 9 and 10, research regarding these waters are required to be approved by the Icelandic government.

Act No. 65 from 2003 covers issues regarding production licenses, transmission, distribution and business transaction in Iceland in regards to electricity. EU regulation regarding sale of electricity between countries have partly been enforced through EEA agreement.

In 2013, specialists on behalf of the Ministry of Industry and Innovation regarding laying of a submarine cable wrote a report (Iðnaðarráðuneytið, 2013) were it is stated that Icelandic law does not specifically cover the laying of a cable between two countries.

In the report, the legal issues in Europe are discussed along with models for a cable connection to the UK. Models mentioned are feed-in tariffs with contract for differences, bilateral long-term agreements, as well as the NEMO system.

Regulation of the operation of undersea cable

There is no legislation in Icelandic regarding the operation of an undersea cable.

Weather systems in the North Atlantic

Interest in harvesting wind power in Iceland is increasing so wind may potentially become a greater source of electric power in Iceland in the future. It would be interesting to investigate if there is an additional benefit to interconnect Iceland, Faroese Islands and Shetland from the point of view that weather conditions may be out-of-sync so that maximum production capacity by wind power may vary between these locations.

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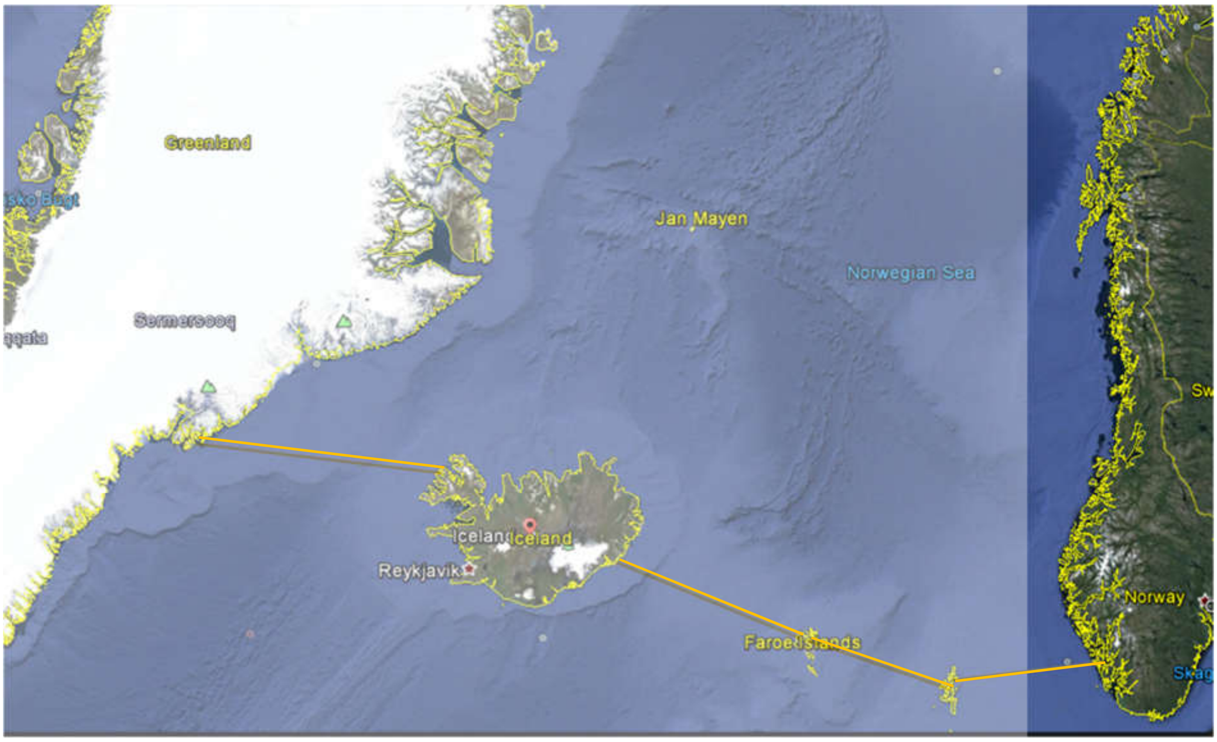
APPENDIX D

North Atlantic Energy Network Norway



Yngve Birkelund, UiT - The Arctic University of Norway

Cathrine Henaug, Rambøll, Tromsø

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Summary

Statnett is the system operator in the Norwegian energy system. It is stately owned, and responsible for the main power grid system in Norway. Their national grid development plan lays the foundation for achieving energy and climate policy objectives. International interconnectors have a high priority in Statnett as they contribute to the domestic supply security as the difference between dry and wet years becomes more challenging than before. The transition from fossil to renewable energy in Northen Europe also introduce power production dependent of sun and wind condition, which cannot be regulated upwords and downwords with the consumption, and the accees to the flexible Norwegian hydropower therefore plays an important role in the development.

The current subsea HVDC interconnectors, including the new cables to UK and Germany that are in the construction phase, have a yearly capacity of 45 TWh. The average yearly electricity production in Norway is approximately 120 TWh, with hydropower as the main resource (in 2013, 96%), and thermal gas power plants (2.5%) and wind power (1.4 %) as the remaining resources.

The renewable energy potential in Norway is large. Although most of the hydropower potential is already utilized, the possible new potential is estimated to approximately 30 TWh. The wind power potential, on the other hand, is very large, estimated to 250 TWh with a development cost between 0.03 and 0.044 EUR/kwh. Geothermal power (heat pumps for heating of building) and solar cells can increase the yearly surplus of electrical energy with 37 TWh and 4 TWh, respectively.

The electricy prices in Norway are low compared to European prices, with average household price in first quarter of 2015 close to 0,096 EUR/kWh. This difference has created a great market for international interconnectors. The NorNed cable between Norway and Nederland had an income during the first two months of €50M, exceding the expectation of a yearly income of €64M according to the budget.

The expectation for the new interconnectors to Great Britain and Germany is 25-35 TWh in new export from Norway/Nordic contries, development of new renewable energy power plants and correspondingly less coal power in neighbor contries.

Althourgh the NAEN project have discovered nice potential for introduction of electricity from renewable resources for both Shetland and oil platforms alond the cable rute, the economical benefit seems reduced with respect to Norwegian interest. Especially with the new HVDC subsea interconnector to Great Britain to be finished in 2021.

1. The North Atlantic Energy network

International subsea HVDC cables projects

Statnett are involved in several projects with international subsea HVDC cables, as shown in Figure 1. The first cable between Norway and Denmark was established in 1976, and that single cable connection has been increased to four HVDC cables between those contries with

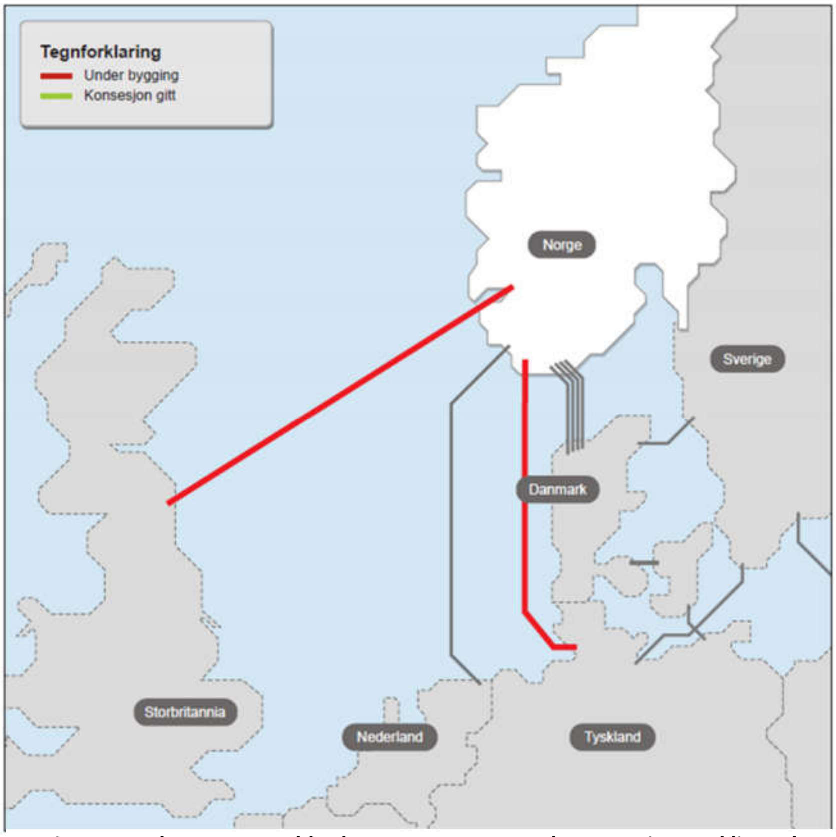

Figure 1: Subsea HVDC cables between Norway and EU contries. Red lines show connector under constructions.

at total capacity of 1700MW in 2014. The next connection was the NorNed cable between Norway and Netherland opened in 2008, with a capacity of 700MW. Early in 2015, the decision to build two additional interconnections was made: Nordlink cable to Germany, to be finished in 2019 with 1400 MW capacity, and the NSN link to Great Britain, to be finished in 2021 with 1400 MW capacity. The total yearly capacity for these cables is approximately 45 TWh.

Likely connection point in Norway

A possible connection point for the NAEN project HVDC subsea cable from Shetland (or Faroe) Island is between Bergen and Florø at the west coast of Norway The length from Shetland to Bergen is approximately 350 km. The new NSN link from Great Britain has a connection point at Kvilldal Power Station; about 120 km southeast of Bergen, but the exact location of a NAEN has to be investigated with respect to potential new renewable sources and the national power grid capacity. Statnett have pointed out that the Bergen region is vurnerable with respect to the current power supply security, and new renewable power production and the NAEN interconnector may increase the need for large upgrades to main grid inland and towards northen Norway.

2. Impacts

Baseline information for the influenced area on the Norwegian continental Shelf

Several environmental impact assessments (EIA) have been conducted for the North Sea. This includes regional EIAs and local assessments and monitoring. Hence, natural resources and environmental conditions in the North Sea are well documented and described. However, naturally the information are more detailed in the areas were petroleum fields are located, as these require different environmental studies throughout the different life stages.

Reports such as the Management Plan (Integrated Management of the Marine Environment of the North Sea and Skagerrak) and Regional Environmental Surveys can be used to retrieve baseline information for the influenced area (with respect to the North Atlantic Energy Network Project) on the Norwegian continental Self.

The North Sea is generally shallow, reaching the greatest depths (just above 100 m) in the northerly parts of the basin. The Norwegian Trench separates Norwegian coastal waters from the shallower parts of the North Sea further west and south. The coastal side of the Norwegian Trench slopes steeply to the deepest water just off the Norwegian coast, while the offshore side rises more gently to the North Sea Plateau west and south of the Trench (ref: white paper).

The Norwegian Continental Shelf is divided into 11 regions with respect to monitoring of the seabed. The Regional Environmental Survey for each region is performed every third year, and alternates between the different regions. The extent of the surveys is related to the offshore activity in the regions.

Particularly valuable and vulnerable areas are areas that on the basis of scientific assessments have been identified as being of great importance for biodiversity and for biological production in the North Sea-Skagerrak area.

The designation of areas as particularly valuable and vulnerable does not have any direct effect in the form of restrictions on commercial activities. Nevertheless, it indicates that it is important to show special caution in these areas. To protect particularly valuable species and habitats, it is for example possible to use current legislation to make activities in such areas subject to special requirements. Such requirements may apply to the whole of a particularly valuable and vulnerable area or part of it, and any exploration must be considered on a case-by-case basis.

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2013. Experience in transporting energy through subsea power cables: The case of Iceland. Svandís Hlín Karlsdóttir

2015 28. September . Ing.dk. http://ing.dk/artikel/740-kilometer-elkabel-skal-sende-dansk-stroem-til-england-179078?utm_source=nyhedsbrev&utm_medium=email&utm_campaign=daglig

3. Transmission system and Electrical energy production

Norwegian electricity production in 2013 was in total nearly 134 TWh and the consumption was about 142 TWh (Ssb 2015, table 08307). The production was distributed between hydro-, thermal- and wind power. Hydropower was responsible for the most of the production with 96.1 % (Ssb 2015, table 08307). Thermal power had the second biggest share with 2.5 % and wind power produced the remaining part of 1.4 % (Ssb 2015, table 08307). The total installed capacity was 33.486 TW in 2013 (Ssb 2015, table 10431).

The most recent data retrieved of the distribution of electricity consumption by consumer groups is from 2007 and does not show any changes in the distribution of any significance in the prior years. "Manufacturing, mining and quarrying" had the biggest share of about 44 % of the total consumption (Ssb 2015, table 05216). The second biggest portion belongs to "Households" representing 32 % and the third is "Services and construction" with 22 % (Ssb 2015, table 05216). The remaining part of about 2 % is consumed by "Fishing and agriculture" and "Transport" (Ssb 2015, table 05216).

Both the total production and the consumption of electrical energy is now nearly five times as much as it was in 1960 and the overall trend is that it has been growing gradually by a constant amount each year (Ssb 2015, table 09386). The peak of the year, both of the production and the consumption, is in January, as more power to heating is needed during this cold winter month (Ssb 2015, table 08583).

Energy production

Total production of energy

Figure 2 shows the primary energy production in Norway in the period 2009 – 2014. It tells us that the total production has decreased about 9% in just five years. The decrease is caused by the reduction in production of energy in the form of crude oil while the other energy sources have maintained more stable.

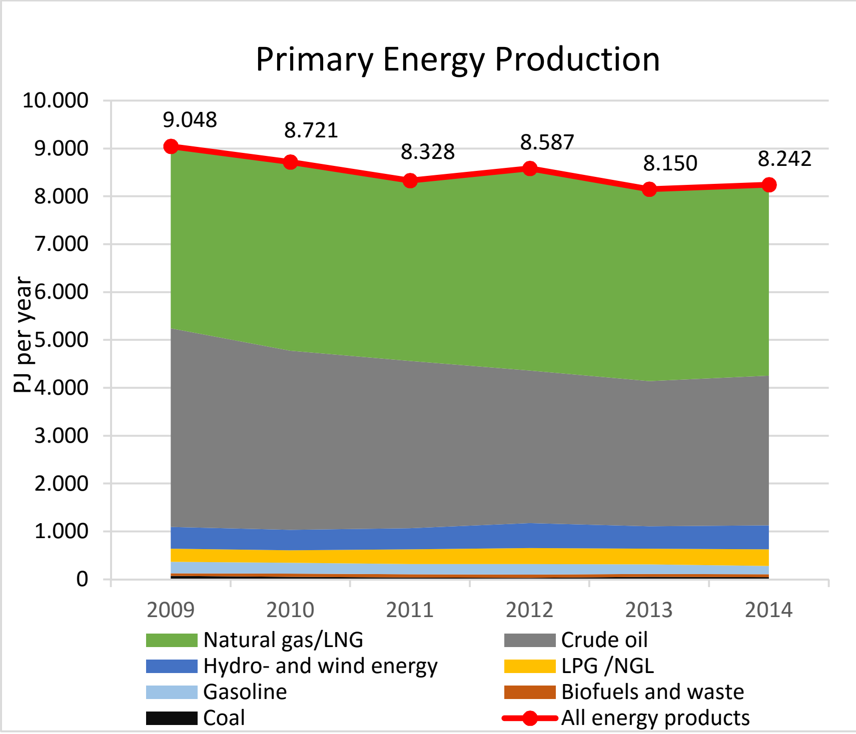

Figure 2: (Ssb 2015, table 09380)

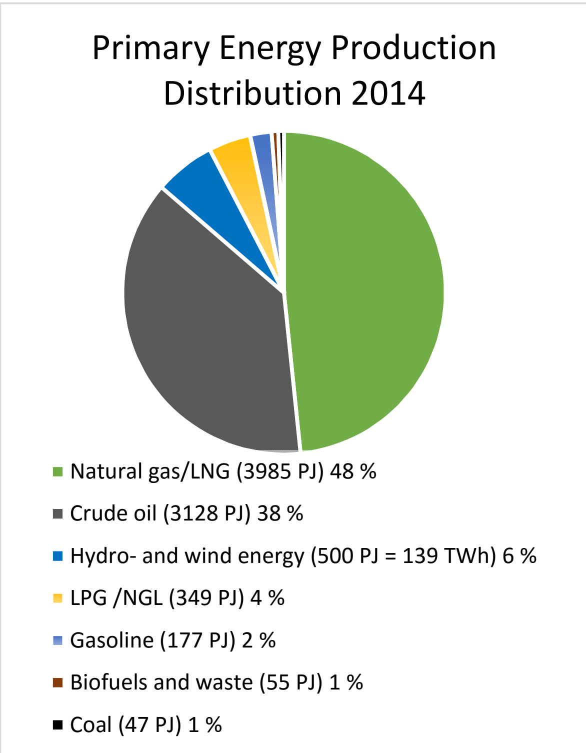

Figure 3: (Ssb 2015, table 09380)

The distribution of the primary energy production as it was in 2014 is presented in **Figure 3**. The pie chart shows that the most of the energy produced is natural gas/LNG and crude oil. A big share of it is exported to other countries. The third biggest energy source is hydro- and wind energy. This source is transformed to electrical energy and delivered to the power grid and is the reason why the energy is also given in TWh. Almost all of the hydro- and wind energy comes from hydro as this is a highly utilized energy resource in Norway as it has been for many years. A small fraction of the natural gas/LNG is also used for production of electric energy.

Total production of electrical energy

Figure 4 shows the total production as well as the import and export of electric power. The total production seems to follow a linear path from 1960 to 1990, it is growing steadily from year to year with some variations. From 1990 to 2014 the overall increase has slowed down and the variation from year to year is much bigger.

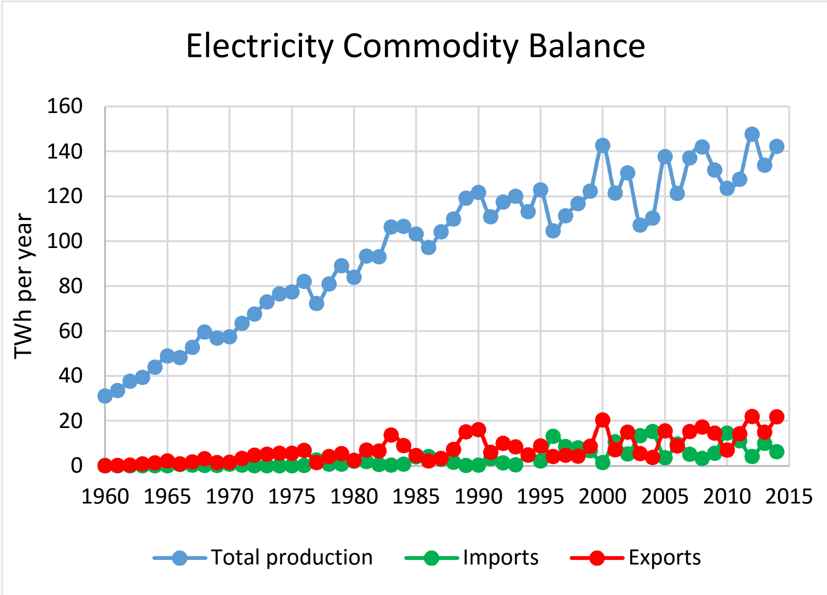

Figure 4: Ssb 2015, table 09386 and 08307)

In the same time period bigger variations also appears in import and export. This fluctuation has to do with the development of a bigger energy network where more and more regions and countries are connected in a bigger energy market. This market facilitates both imports and exports when necessary or profitable. E.g. is the annual production peak registered in 2012 (partially due to much rain resulting in filled water basins) responsible for the peak in export the same year and therefore also the low import of electrical energy. When the production in Norway is bigger than the consumption the price will decrease. To counteract this effect and to be as profitable as possible the energy is exported to a marked that has higher prices at the moment. The net commodity (or trade), imports minus exports, is shown in the figure below. Overall Norway exports more electricity than what is imported and those years are represented in red in **Figure 5**.

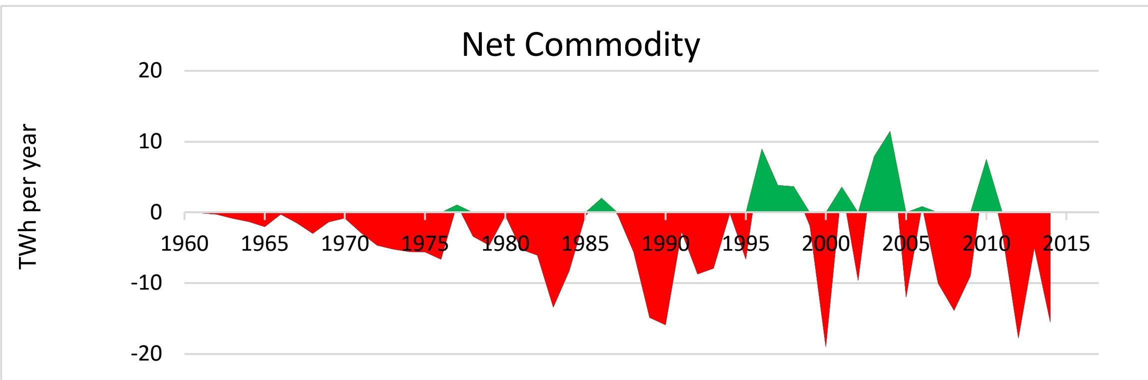

Figure 5: (Ssb 2015, table 09386 and 08307)

Installed capacity

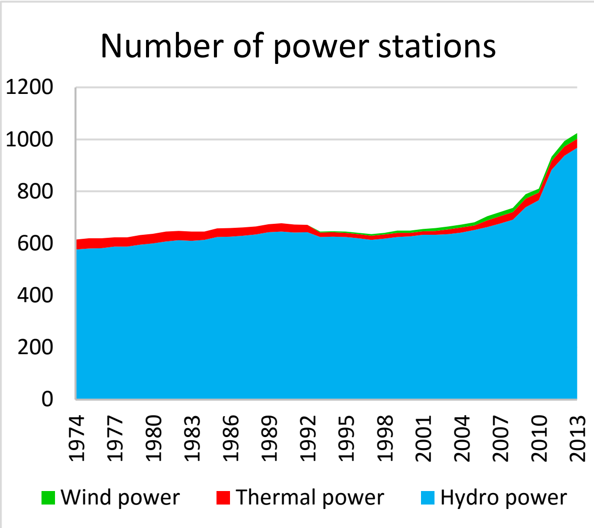

Figure 6: (Ssb 2015, table 10431)

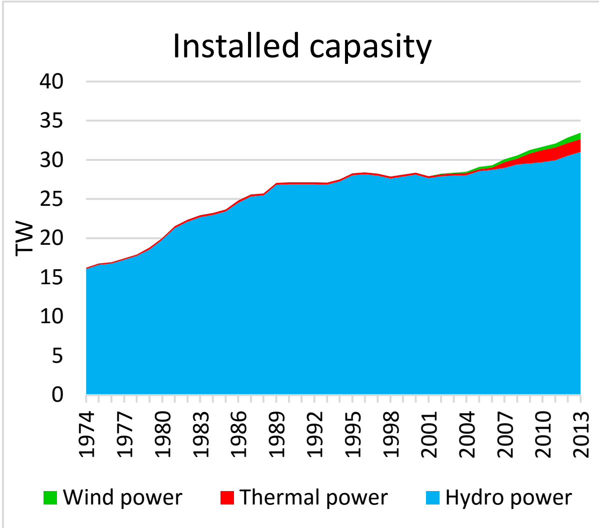

Figure 7: (Ssb 2015, table 10431)

As the figures above illustrates, the installed capacity has doubled in the last 40 years. In 2013 the total installed capacity was 33.486 TW (Ssb 2015, table 10431). The capacity has grown gradually and the contribution from thermal power plants has increased profoundly from 2006. The first operative wind power plant delivering electricity to the grid opened in 1993. Although the installed capacity has increased steadily for the past 40 years the number of power stations have stayed stable until about 2006. From 2006 to 2013 the number of hydro power plants increased by 46 %.

The electrical energy mix

General

Figure 8 demonstrates how important hydro has been for the production of electrical energy in Norway since hydro power plants really started to pop up after WWII. At the time about 61 % of the available hydro energy is being harnessed.

Much of the remaining non-utilized-energy is located in protected areas and cannot be harnessed. The efficiency of the hydro power plants are already high, often about 95%. Together these two factors make the expected production from hydro to flatten out. It will still increase for some years as a few more hydro power plants are under construction. Also it would vary from year to year as the participation changes.

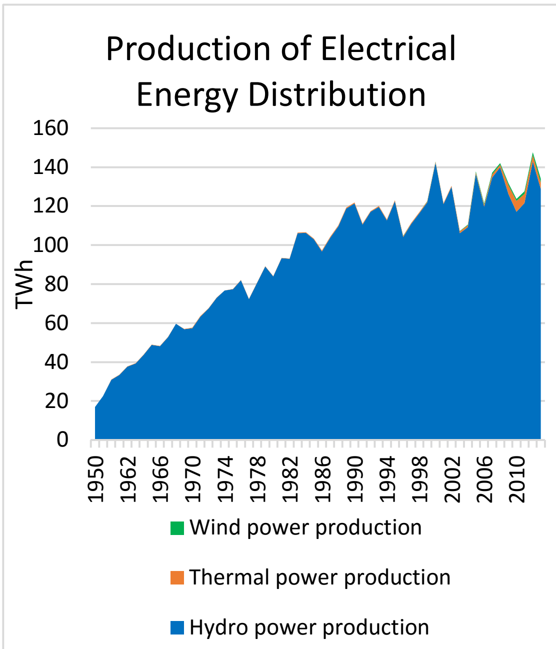

Figure 8: (Ssb 2015, table 08307)

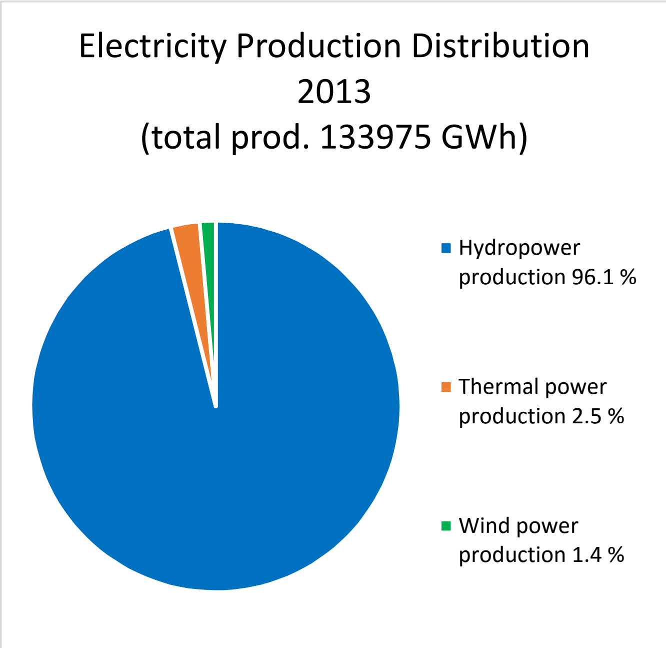

Figure 9: (Ssb 2015, table 08307)

However there is a way to utilize the hydro power plants even more. The way to do so is to take advantage of basins and dams by using them as big batteries by storing energy from other sources there. The principle is called pumped storage and more about it in section ref.

To keep the production of electric energy increasing it is necessary to keep developing more power plants that utilizes other sources of energy, preferably renewables. Figure 9 shows that this is happening, but it is still at a very moderate level compared to hydro. The share “Thermal power production” mostly comes from gas turbines using natural gas/LNG.

Hydropower

Norway’s electricity production is highly dependent of hydropower as previously mentioned. Figure 1.8 shows that in 2013 hydropower was responsible for 96.1% of the total production of electricity. The installed capacity was 31033 MW which constitutes for 92.7 % of the total capacity (Ssb 2015, table 10431). This big share makes the supply system vulnerable to longer periods without a sufficient water inflow.

The precipitation and the useful inflow varies quite much throughout the different seasons and also the regions. It also varies from year to year and in the past 23 years it has varied by about 60 TWh (Norwegian Ministry of Petroleum and Energy 2014, p.24-25). Even though it can be a lot of precipitation in the winter months the inflow to the hydro power plants are low due to the downfall usually comes as snow and does not melt until the spring. In the spring the inflow is therefore at its highest and declines towards the end of the summer. Usually the inflow increases again in the autumn.

Compared to other renewables hydropower is very flexible. When consumption is low much of the potential energy of the water can be stored in reservoirs while generating enough electricity for the consumers. Those reservoirs are established in lakes and artificial basins. In Norway the consumption of electricity is higher in the winter due to more energy used for heating. In those months the generation of energy can be adjusted to the increased demand by letting more of the stored water go through the generators.

Hydro used as energy storage

The high level of flexibility hydropower has can be utilized by using the excess energy produced by other energy sources to pump up water to reservoirs with a greater head. The energy is stored as potential energy and can be transformed to electrical energy when the demand is higher. This technique is called pumped storage and already existing reservoirs and hydro power plant can be used.

Building pumped storage enables other less flexible renewable energy sources to be a bigger part of the market. E.g. solar power does not yet deliver any power to the grid in Norway, but is expected to arise in the future. Solar cells (PV) will produce most electricity when the demand in the region is at its lowest, in the summer. If the production of electricity is higher than the demand, this excess energy can simply be stored using pumped storage without much loss of energy to friction. The reservoirs are usually at their lowest during the summer allowing much energy produced from other sources to be stored there without risking full reservoirs.

Norway is ideal for pumped storage as it has allot of elevations and the installed capacity of hydro is already high. New reservoirs and generators can be made, but by using more of the capacity of the existing reservoirs and hydro power plants will enable a lot of energy to be stored. In 2013 the capacity of hydro power plants was 31.033 GW (Ssb 2015, table 10431) and the produced energy was 133 975 GWh (Ssb 2015, table 08307). On average throughout the year 49.25 % of the total capacity was being used. The calculation is presented below.

$$I : Average\ used\ capasity = \frac{133\ 975\ GWh/year}{31.033\ GW\ \cdot (24 \cdot 365.25) h/year} \cdot 100\ \%\ \approx 49.25\ \%$$

Thermal power

Thermal power in Norway comes mainly from power plants using natural gas. Norway pump up and export allot of oil and gas and most of the thermal power plants are associated with refineries onshore. When producing electricity from gas quite much CO_2 is emitted and the power plants have faced opposition from environmentalists. The government has planned to install carbon dioxide capture and storage facilities on one of the power plants.

In 2013 thermal power was responsible for 2.5 % of the total production of electricity in Norway (Ssb 2015, table 08307). The share increased severe in 2007 (see figure 1.7) when the number of thermal power plants almost tripled from the year before (Ssb 2015, table 10431). The same year the installed capacity was 1635 MW accounting for 4.88 % of the total capacity in Norway (Ssb 2015, table 10431).

Gas-fired power plants are highly flexible and is primary used when the demand is bigger than the supply from other types of power plants. As a backup Norway has two gas-fired power plants only to be used in special situations and require permits from the Norwegian authorities. Together they have a total capacity of 300 MW. (Norwegian Ministry of Petroleum and Energy 2014, p.24).

Wind power

Norway generally has good wind resources. A lot of it has to do with the long coastline to the Norwegian Sea. In the coast the average annual wind speed 50 meters above ground is usually between 7 to 9 m/s (Norwegian Ministry of Petroleum and Energy 2014, p.28). An average annual wind speed of more than 6.5 m/s (Norwegian Ministry of Petroleum and Energy 2014, p.28) is considered to be sufficient for establishing wind farms. The good conditions both onshore and offshore leads to a big potential for wind power in Norway. However, the great potential remains almost unutilized as the start-up cost are still high, especially offshore. Wind power plants have not yet been commercially profitable in Norway and are heavily dependent on public funding (Norwegian Ministry of Petroleum and Energy 2014, p.28).

In 2013 wind power was responsible for 1.4% of the total production of electricity in Norway (Ssb 2015, table 08307). The share is not big, but as the installed capacity increases rapidly, so does the production of electricity from wind farms. Figure 10 shows how the capacity of the installed wind power plants has developed since the first power plant was operative in 1993. In 2013 the installed capacity was 818 MW accounting for 2.44 % of the total capacity in Norway (Ssb 2015, table 10431).

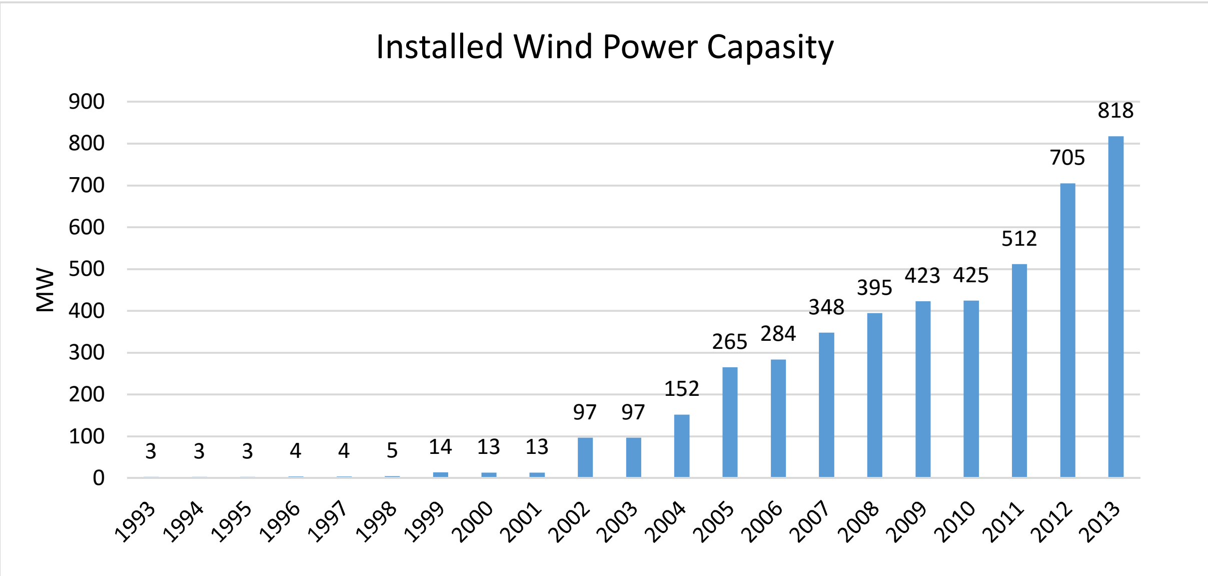

Figure 10: Norwegian Water Resources and Energy Directorate (NVE). 2015. “Vindkraft - Produksjon i 2014.” Accessed 28. of July 2015. http://publikasjoner.nve.no/rapport/2015/rapport2015_18.pdf

In opposition to hydro is wind power very inflexible. The power plants produce electricity when the wind speed at hub height is from a gentle breeze (3-4 m/s) and up to storm (25 m/s) (Norwegian Ministry of Petroleum and Energy 2014, p.27). In the operative region of wind speed the output varies tremendously as the power of the wind increases by the cubed of the wind speed. The kinetic energy that passes the rotor blades at 25 m/s any given moment is almost 600 times more than at the lowest operating speed 3-4 m/s.

Total consumption of energy

Figure 11 shows the energy consumption in Norway in the period 2009 – 2014. It tells us that the total consumption and also the distribution of the different energy sources have maintained relatively stable over the five year period.

In 2014 the total consumption was 759.5 PJ and is only 9.21 % of the total energy produced the same year.

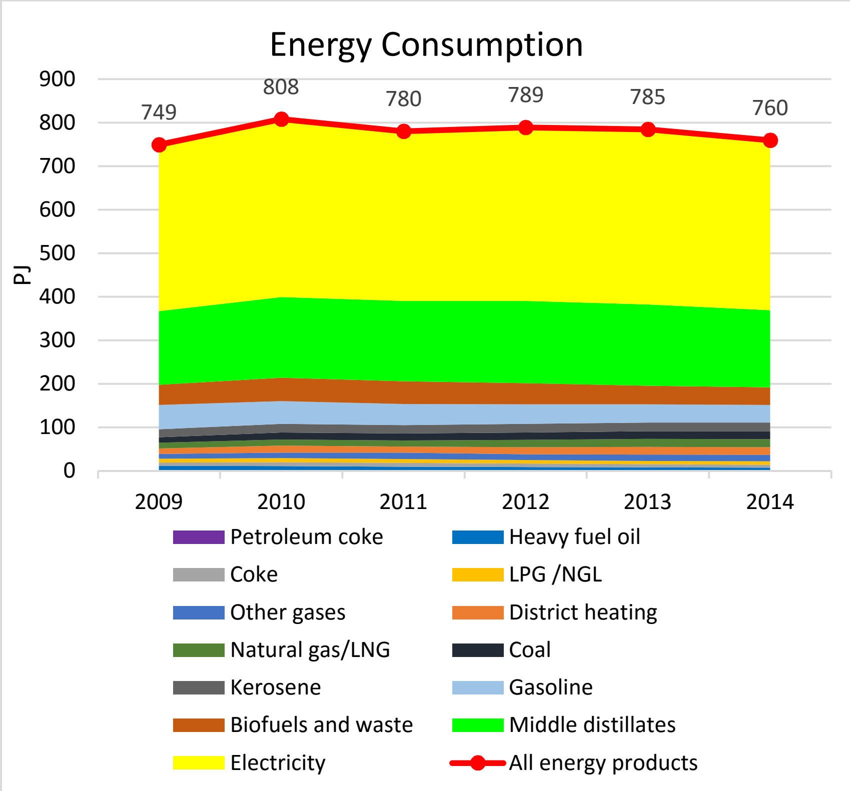

Figure 11: (Ssb 2015, table 09380)

The distribution of the energy consumption as it was in 2014 is presented in the figure below. The pie chart shows that half of the energy consumption is electricity. One quarter is middle distillates which is a generic term for oil refinery products in the middle distillation range.

The renewable share

Figure 12 shows the overall renewable energy share in Norway from 2004 to 2013. Consumption in all sectors are included e.g. industry, transport and households. The share seems to be quite stable and the trend is a slightly increasing renewable share over the period. The share of electricity gross consumption from renewables is very high. In some years it is even more than 100 % which can be explained by a high export of electricity that year. The share of renewable energy sources in heating and cooling is much lower and has a big potential of improving.

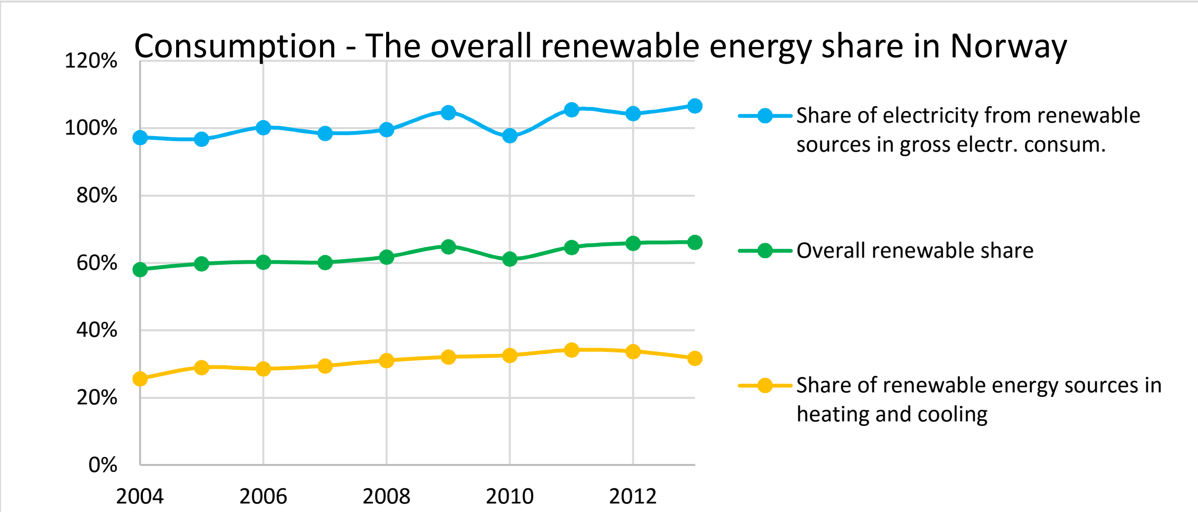

Figure 12: (Ssb 2015, table 10842)

Total consumption of electrical energy

Figure 13 shows both the total consumption and the total production of electric power. The two graphs are following each other pretty well. The reason for this coherence is simply that the production is being adjusted to the demand. Generally the consumption is a little less than the production and the excess power is exported. The total consumption is more stable and does not fluctuate as much as the production.

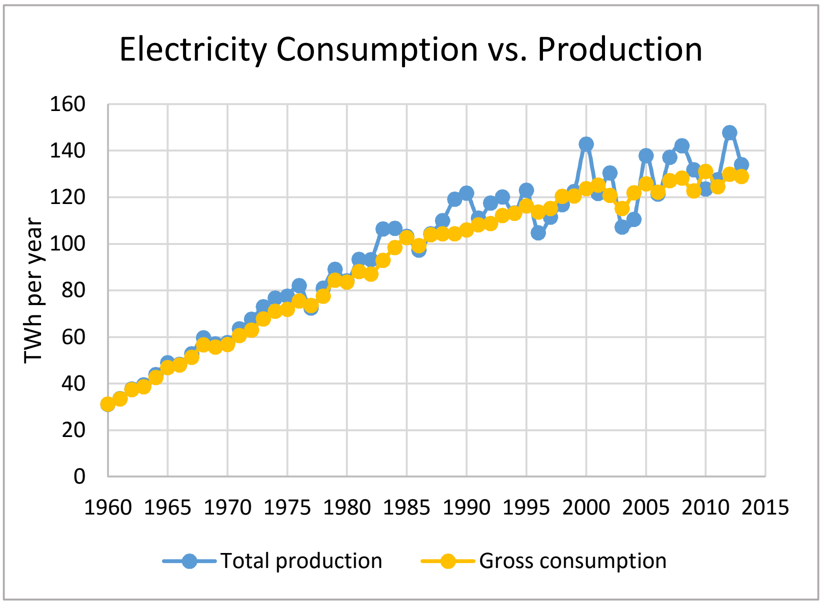

Figure 13: (Ssb 2015, table 09386)

Consumption of electricity by consumer groups

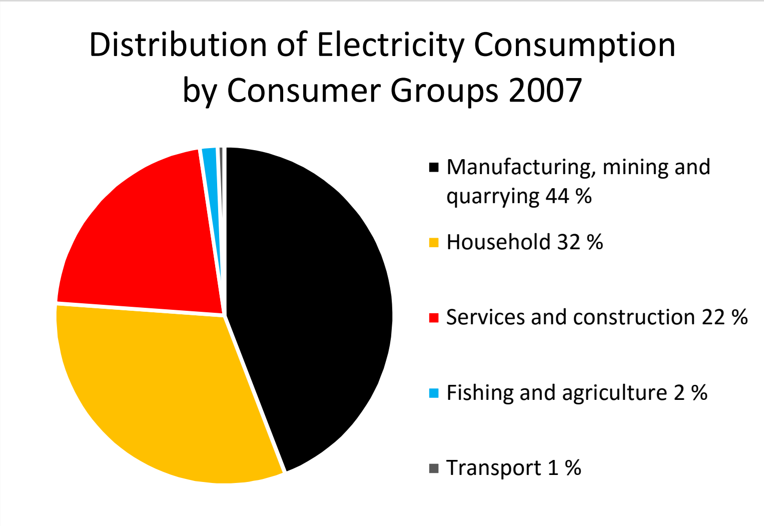

Figure 14: (Ssb 2015, table 05216)

Figure 14 shows the distribution of electricity consumption by consumer groups. The time series goes back to 1990 and does not show any changes in the distribution of any significance. The increase of popularity of electric and hybrid cars and busses in the more recent years makes it reasonable to believe that the share consumed by transport has increased by some extent.

Annual and daily variations in production and consumption

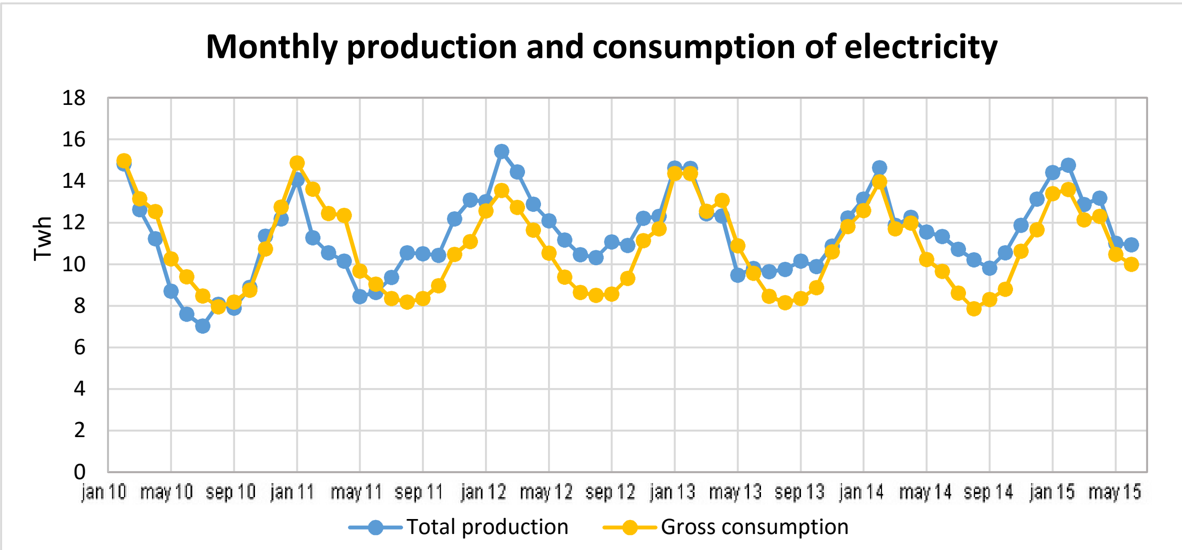

Figure 15: (ssb 2015, table 05224)

Figure 15 shows that both the production and the consumption of electricity is highest in the winter months peaking in January. Some of the annual variation is caused by that the cold winter months require more power to heating. In the summer not much power is used on cooling. Also parts of the industry is either shut down or the capacity is reduced in the summer due to vacation. The relation between domestic production and consumption is strong. When consumption is high the production is adjusted so the need for importing electric power is minimalized. This domestic dependency could be reduced if a bigger market for electricity is established.

Figure 16 shows the daily variations in two random days in 2015. Usually the consumption peaks around 4 pm as many people are cooking dinner.

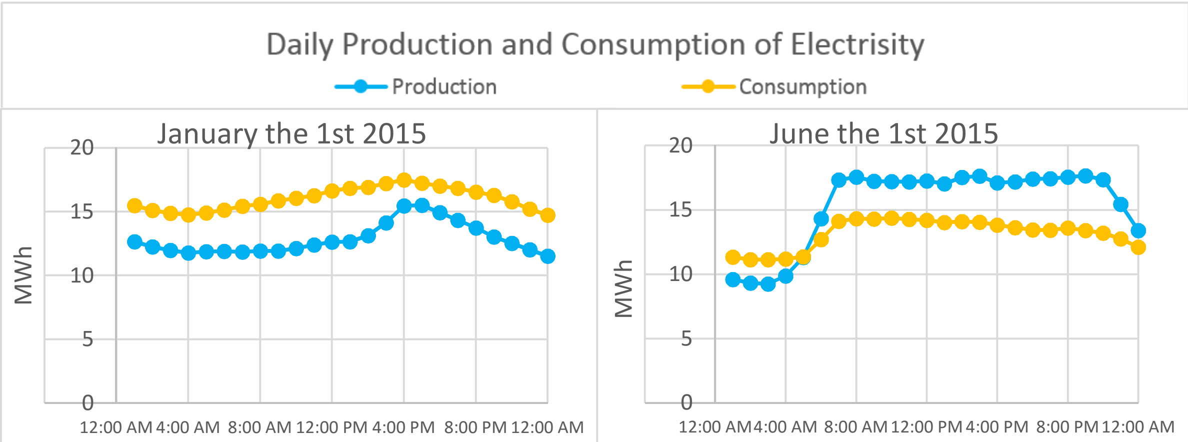

Figure 16: Statsnett 2015

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4. Electrical market (prices)

The electrical power marked can be divided into two layers of markets, the wholesale market and the end-user market. The price of the electric power naturally changes with the overall demand and supply, but is also dependent on the consumer group and the type of contract. The price of electricity has varied a lot in Norway, especially in the past ten years, and it is difficult to see a general trend.

In the first quarter of 2015 the electricity price excl. taxes on the wholesale market was 24.1 øre/kWh (Ssb, table 09363). This is the same as 0.201 DKK/kWh, 3.99 ISK/kWh and 0.0270 EUR/kWh by the exchange rate of July 23, 2015.

In general the price on the end-user market is higher than on the wholesale marked. Since 2012 the price difference for the different consumer groups in the end-user marked has been relatively small. However, the average grid rent is still very dependent on the consumer group and therefore so is the total price for power.

End-users do not just pay for electricity by itself to receive the power. In addition several other components of the service is charged such as a grid tariff, electricity tax, value added tax and a couple of fees. For household the electricity price only makes up about one-third of the total power bill for households. In the first quarter of 2015 the total price for electricity in households in Norway was 86.4 øre/kWh (Ssb, table 09387). This is the same as 0.720 DKK/kWh, 14.3 ISK/kWh and 0.0958 EUR/kWh by the exchange rate of July 23, 2015.

Structure of the power market

The electrical power marked can be divided into two layers of markets. The top layer consists of a wholesale market where large bulks of power are bought and sold. The traders are power producers and suppliers. Also large-scale consumers attend. The market in the layer below the wholesale market is called the end-user market. Here the energy supplier resells energy to households, industry and medium sized consumers, such as chain stores and hotels. The price of the electric power naturally changes with the overall demand and supply, but is also dependent on the consumer group and the type of contract. Large-scale companies that buys large bulks of power over a longer period usually pay less than the average household consumer per kWh. (Norwegian Ministry of Petroleum and Energy, p. 52)

Figure 17 provides the general overview of how the power marked Norway is a part of operates. NASDAQ WMX Group is an American corporation that owns and operates many of the stock markets in West-Europe. NORDPOOL Spot operates the largest market of electricity in Europe. Among other countries it operates in all the Nordic countries except (for) Iceland. Statnett is a Norwegian state owned company responsible for the power grid in Norway.

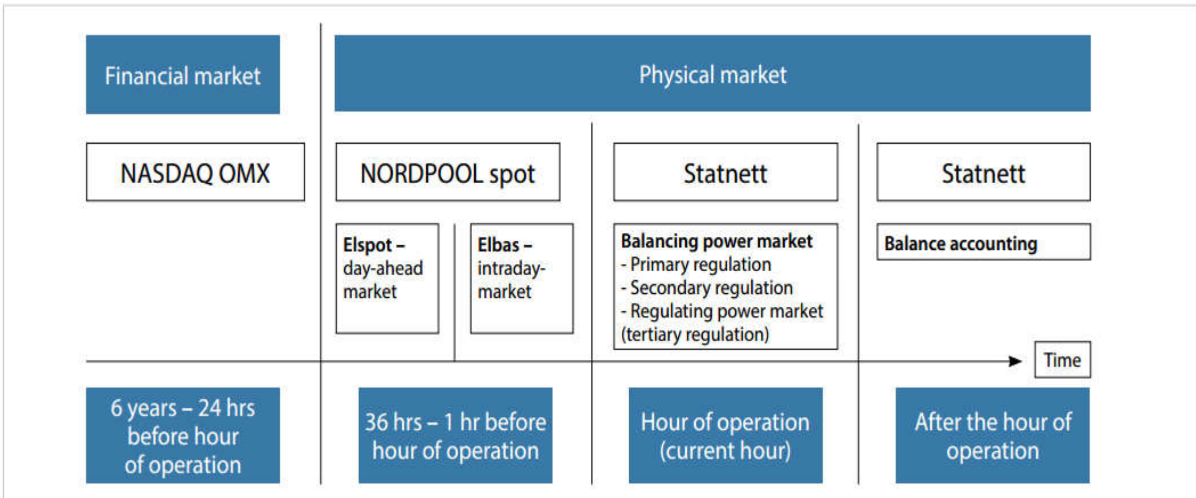

Figure 17: Organization of the electrisity trading market

As figure 27 illustrates, there are three submarkets in the physical power market. Here traders can bid and the prices within that submarket are determined. The three submarkets are:

- Elspot – "day-ahead market"
- Elbas – "continuous intraday market"
- Balancing market – "regulating power market"

(Norwegian Ministry of Petroleum and Energy, p. 54)

Price formation

The most decisive factor when it comes to how the prices are formed in Norway is the overall generation and consumption in the Nordic counties. Also the developments in markets outside the Nordic region can influence the price.

The foundation for production of electricity in Norway is hydro which is very dependent on the very unpredictable and highly fluctuating precipitation levels and the inflow to the reservoirs. The big dependency on hydro is deceive for the fluctuations in the power price. When the reservoirs of the hydro power plants are full, the price usually declines. Almost empty or empty reservoirs will result in high prices for electric power. Cold periods in the winter leads to a higher consumption of energy and the prices usually goes up. Consumption and therefore also the power prices are also dependent on the European economy. (Norwegian Ministry of Petroleum and Energy, p. 55)

Price differences between areas

Some places there are insufficient grid capacity and big bulks of power cannot be imported/exported. These bottlenecks in the grid make it necessary to divide the bidding area into smaller regions on each side of the bottleneck. Currently Norway is divided into five bidding areas (Norwegian Ministry of Petroleum and Energy, p. 55). The power situation differs between the bidding areas and cause variations in power price from region to region. Area prices are higher in areas with a shortage of power compared to the areas with a surplus. The difference in the power price provides a foundation when deciding where it would be most profitable to build power plants or power demanding industry. (Norwegian Ministry of Petroleum and Energy, p. 55)

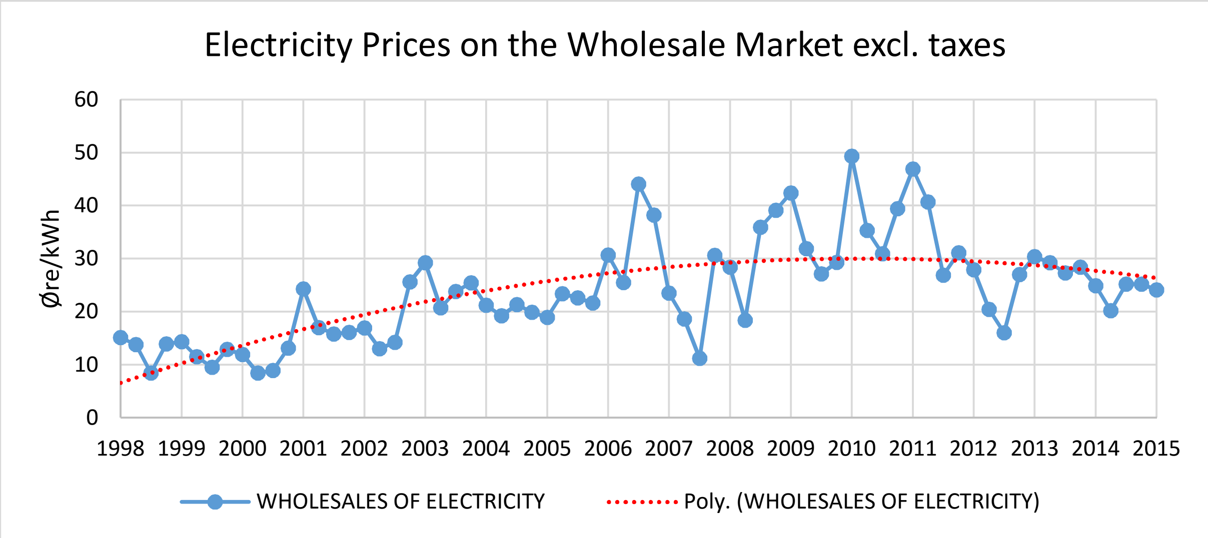

Figure 18: *(Ssb, table 04725 and 09363)*

Price differences between years and seasons

The electricity prices are different depending on the type of contract. On the wholesale market there are many different types of contracts and the figure above shows the average price. The electricity prices on the end-user market can differ quite much to the prices on the wholesale market. However, Figure 18 can illustrate the overall development in the electricity prices.

Annual

Figure 18 shows that the electricity price on the wholesale market has varied quite much in the past 17 years. The quarterly lowest registered price in the period is 8.4 øre/kWh measures in the summertime both in 1998 and in 2000. The highest price occurred winter 2010 with 49.3 øre/kWh, almost six times the price as in 1998 and 2000. In the first quarter of 2015 the electricity price excl. taxes on the wholesale market was 24.1 øre/kWh. This is the same as 0.201 DKK/kWh, 3.99 ISK/kWh and 0.0270 EUR/kWh by the exchange rate of July 23, 2015.

The red-dotted line is the best quadratic fit. The polynomial says something about the development in the period, but it cannot really say much of how the development is going to be in the future.

Seasonal

The demand of electric power is higher during the cold winter months compared to the rest of the year in Norway. So is also the production. Therefore the higher consumption of electricity in the winter does not necessarily lead to higher prices. The relation may change from year to year depending on many factors e.g. the degree of filling in the hydro reservoirs. Figure 18 shows that in the periods 1998 – 2004 and 2007 – 2015 the prices has been highest in the winter months and usually the annual peak is in the first quarter of the year. The period 2004 – 2007 does not show the same clear trend and the variation appears more random. In that period the quarterly highest price occurred in the summer either in the second or the third quarter of the year.

Price differences between consumer groups

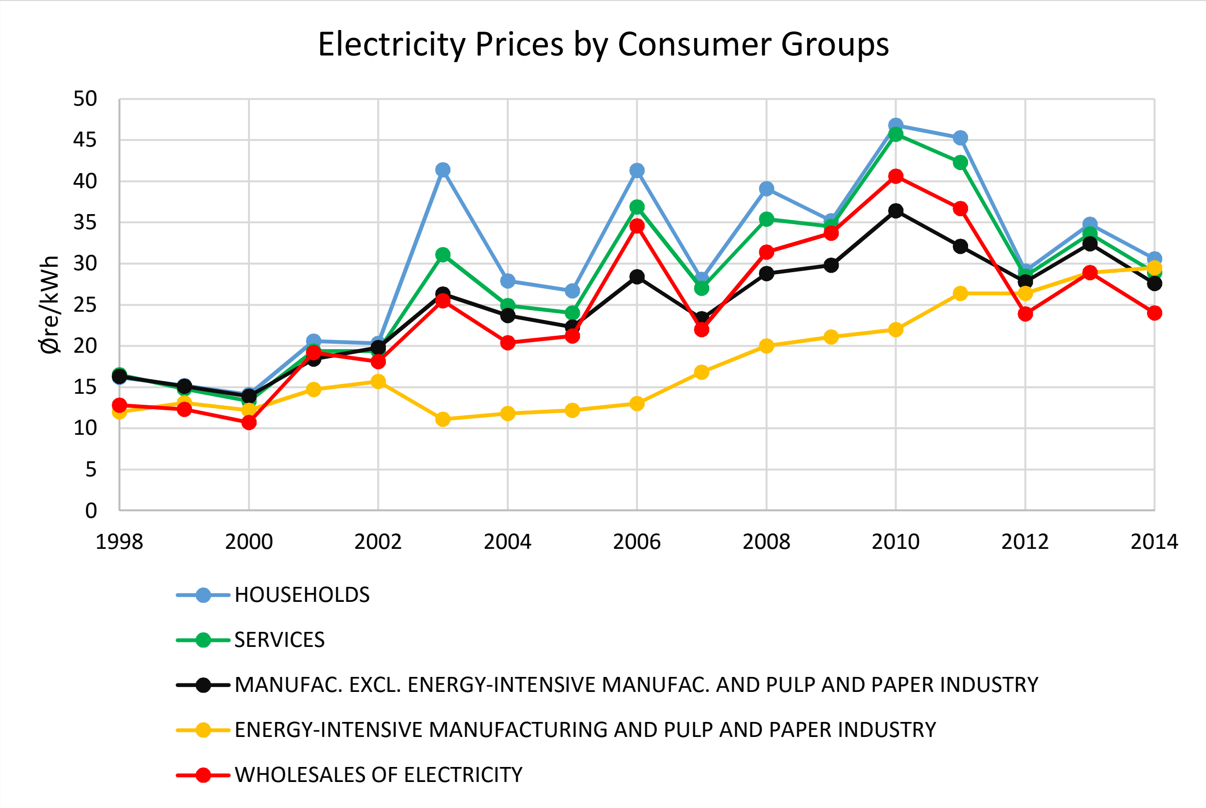

Figure 19: *(Ssb, table 08925, 08926, 09365 and 09366)*

The electricity prices are different depending on the consumer group. Figure 19 shows the average price excl. taxes on the end-user marked for different consumer groups and also the average price on the wholesale marked is added as a reference. In general the price on the end-user market is higher than on the wholesale marked. The power price for “Energy-intensive manufacturing and pulp and paper industry” (EIMPPI) is in most of the period even lower than the wholesale price. Also it does not seem to be affected so much to the overall fluctuations in the price. Some of the reason for the stable and low price for EIMPPI is that some of the companies are flexible regarding when to use the power and is consuming less when the overall demand in the market is high.

In the period the price “households” has been paying has maintained the highest. In 2003 it was almost four times as much as the average price for EIMPPI. “Services” usually has had the second highest price followed by “Manufacturing excl. EIMPPI”. Since 2012 the price difference for the different consumer groups in the end-user marked has been relatively small compared to the rest of the period displayed in Figure 19.

Additional costs for end-users

End-users are the traders who purchase power for their own consumption. In Norway they are free to choose their own power supplier and the type of contract. Large-scale consumers, e.g. large industrial companies, might buy their power in bulks directly on the wholesale market while smaller consumers purchase power from a power supplier.

End-users do not just pay for electricity by itself to receive the power. In addition several other components of the service is charged. The total electricity bill for end-user consists of:

- Power price - the raw material of electricity
- Grid tariff - connection to and use of the power grid
- Electricity tax
- Other charges
  - Value added tax (VAT)
  - Fee for the Energy Fund (Enova)
  - Fee for electricity certificates

(Norwegian Ministry of Petroleum and Energy, p. 56)

Grid rent for different consumer groups

Figure 19 shows that since 2012 the price difference for electricity for the different consumer groups in the end-user marked has been relatively small. In 2014 the price difference from the consumer group with the highest average price compared to the one with the lowest average price for electricity was only 3 øre/kWh.

Even though the electricity price may not be very different for the different consumer groups the total bill can. Figure 20 shows that the average grid rent is very dependent on the consumer group. In 2014 the grid rent for "Private household and agriculture" was over 12 times the price applied for "Power intensive manufacturing".

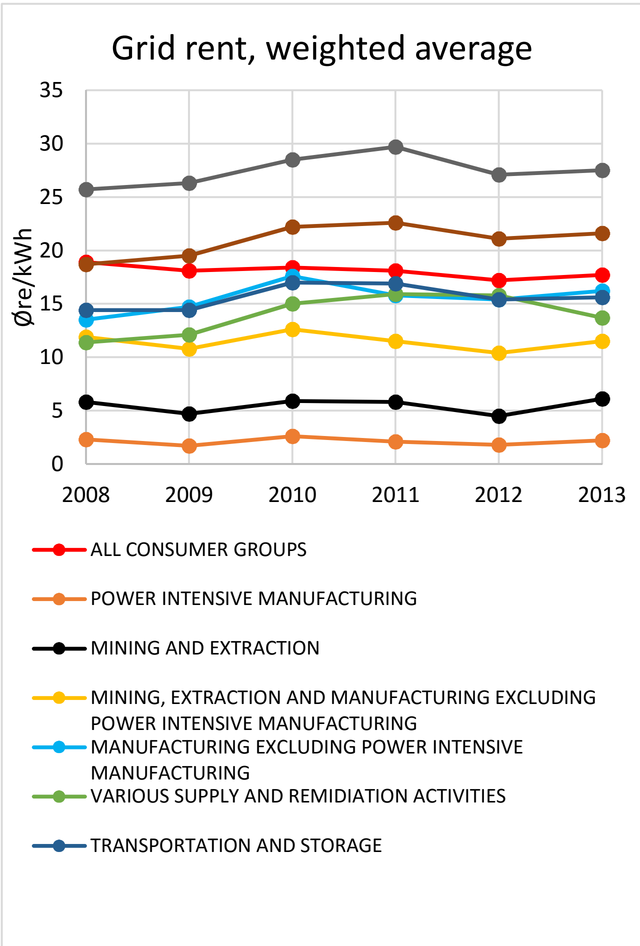

Figure 20: *(Ssb, table 08358)*

Contract types

There are different benefits with the different types of contracts regarding the risk and reliability. The most profitable and suitable type of contract will differ from companies and is depending on e.g. how flexible the company is with the consumption and also the size of the bill. However, as Figure 21 shows, contracts tied to a spot price was by far the most popular in the first quarter of 2015. About 30 % of households had variable price contracts.

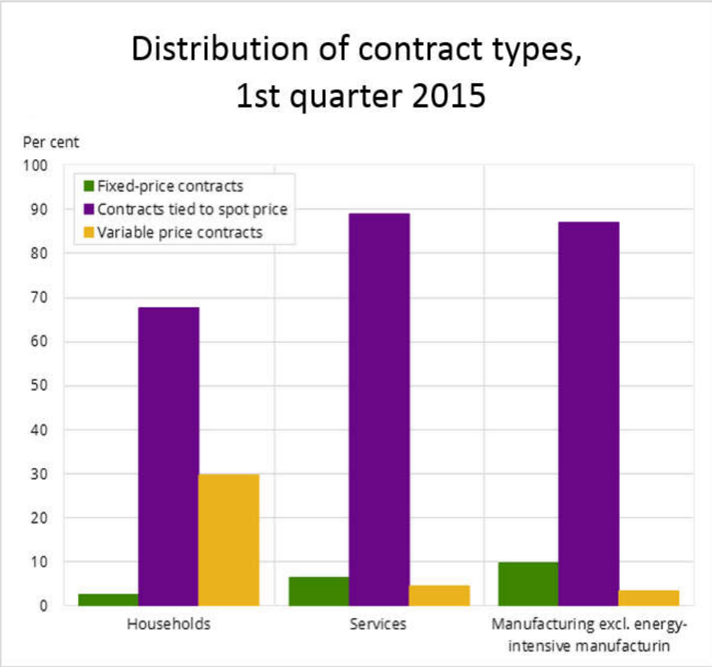

Figure 21: *(Ssb, table 09364)*

Households

Figure 22 reveals that the electricity price only makes up about one-third of the total bill for households. In the first quarter of 2015 the total price for electricity in households in Norway was 86.4 øre/kWh. This is the same as 0.720 DKK/kWh, 14.3 ISK/kWh and 0.0958 EUR/kWh by the exchange rate of July 23, 2015.

Contracts tied to spot price are the most commonly used for households in Norway. In those types of contacts the grid rent, VAT and the tax on consumption of electricity will maintain the same per kWh, but the price for the electricity itself will vary with the spot price.

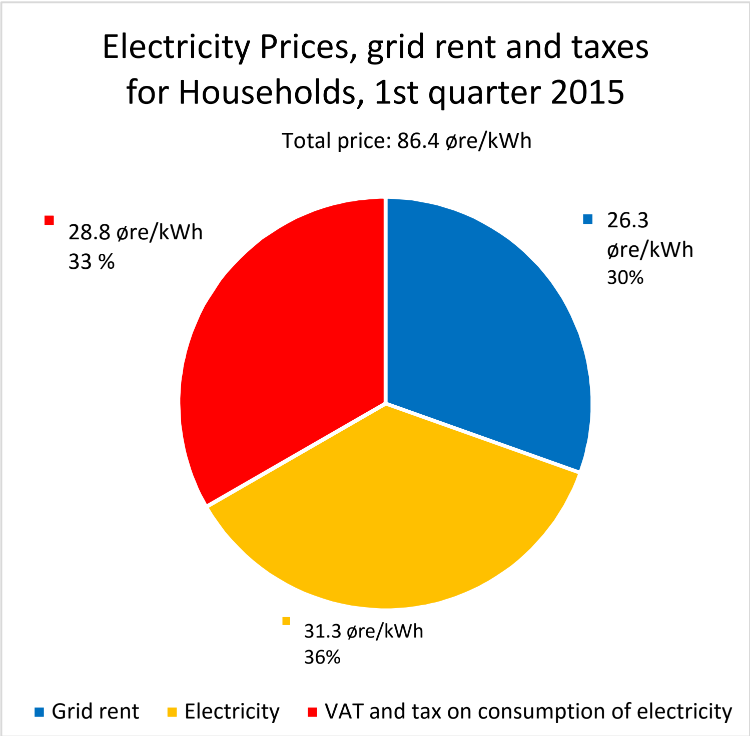

Figure 22: ***(Ssb, table 09387)***

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5. Potentials

The hydropower potential is estimated to be 213 TWh annually. 61 % of it is already developed, 24 % is protected leaving a potential increase of about 15 % (30.7 TWh). (Norwegian Ministry of Petroleum and Energy 2014, p.27)

Norway generally has good wind resources. In 2014 the produced electricity from onshore wind power plants was 2.2 TWh and is responsible for 1.5 % of the total production of electricity in Norway (NVE 2015 (source 3), p.4).

In a research published in 2009 by NVE the total domestic exploitable wind potential was first presented. Most of the potential lies in the northernmost counties and is very dependent of what mean wind speed it is decided to be sufficient profitable. If all the locations with an average wind speed 8 m/s or more are utilized the annual potential is 419 TWh. Setting the requirement down to 7 m/s or more increases the potential to 1243 TWh and dropping it further to 6 m/s gives the potential of 1847 TWh. (NVE 2009 (source 2), p.17)

NVE did a similar research in 2005 and found that the wind power potential which can be developed at a cost varying between 27-40 øre/kWh was found to be 250 TWh. This is the same as 0.223-0.330 DKK/kWh, 4.42-6.55 ISK/kWh and 0.0299-0.0442 EUR/kWh by the exchange rate of July 29, 2015. (NVE 200 (source 1), p.5)

Currently geothermal energy is only being used for heating/cooling purposes in Norway and according to the different sources used in this report large scale production of electricity is not to be expected in the near future. NGE estimates the technical potential for energy savings by using geothermal energy and heat pumps to be about 37 TWh annually (Fornybar.no 2015).

Even though the potential of solar power in Norway is quite much less than in countries lying closer to the equator the annual radiation is still about 1700 times the annual consumption

(NVE 2015 (source 5)). The practical potential of solar cells is estimated to be 4.4 TWh per year by the year 2020 (KanEnergi and SINTEF 2011, p. 65). In this estimate big solar power plants that deliver power to the grid are not included as they are not expected to be able to compete in the Norwegian energy marked by 2020. If the development continues the power from solar cells will sometime in the future be competing with power from other sources, and the potential will (then) be very much higher, almost unlimited. (KanEnergi and SINTEF 2011, p. 51, 65 and 66).

The ocean is an enormous source of energy. Norway has a long coast line and big properties in the sea making the potential of renewable energy from the sea gigantic. The potential of wave power is estimated to be 600 TWh annually and about 12 – 30 TWh is considered to be possible and realistic to develop (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007). The potential of tidal power is estimated to be about 1.2 TWh with a maximum power output of 337 MW. (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 11).The offshore wind potential in Norway is huge. It is estimated to about 14,000 TWh(SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p.20). How much electricity it is possible to produce of it is essentially not limited by the available energy, but by the power market and other practical relations.

Hydropower

Hydropower is already a well-utilized source of energy in Norway and is responsible for most of the electricity production in the country. The hydropower potential is the total energy in the Norwegian river system that is technically and economically feasible to generate electricity. In the start of 2014 the total hydropower potential was estimated to be 213 TWh per year. The distribution of how the potential is exploited is shown in Figure 23. The yellow share on the pie chart is the mean annual developed production capacity and is about 61 % of the total potential. The red share present the share of the potential that cannot be utilized. This energy cannot be utilized because it is either located in protected river systems or in areas where license applications have been rejected.

The blue and the green shades represent the total potential for growth in the production capacity. Together they add up to 30.7 TWh/year which corresponds to 14.4 % of the total potential. Power plants with a total potential of 7.7 TWh/year was in the start of 2014 waiting to be approved. 3.6 TWh/year was already approved and 1.5 TWh/year was under development. 13.1 TWh/year lies in smaller rivers where small power plants are needed to harness the energy Upgrades and expansions on already existing and operating hydropower plants have a potential of 4.8 TWh/year.

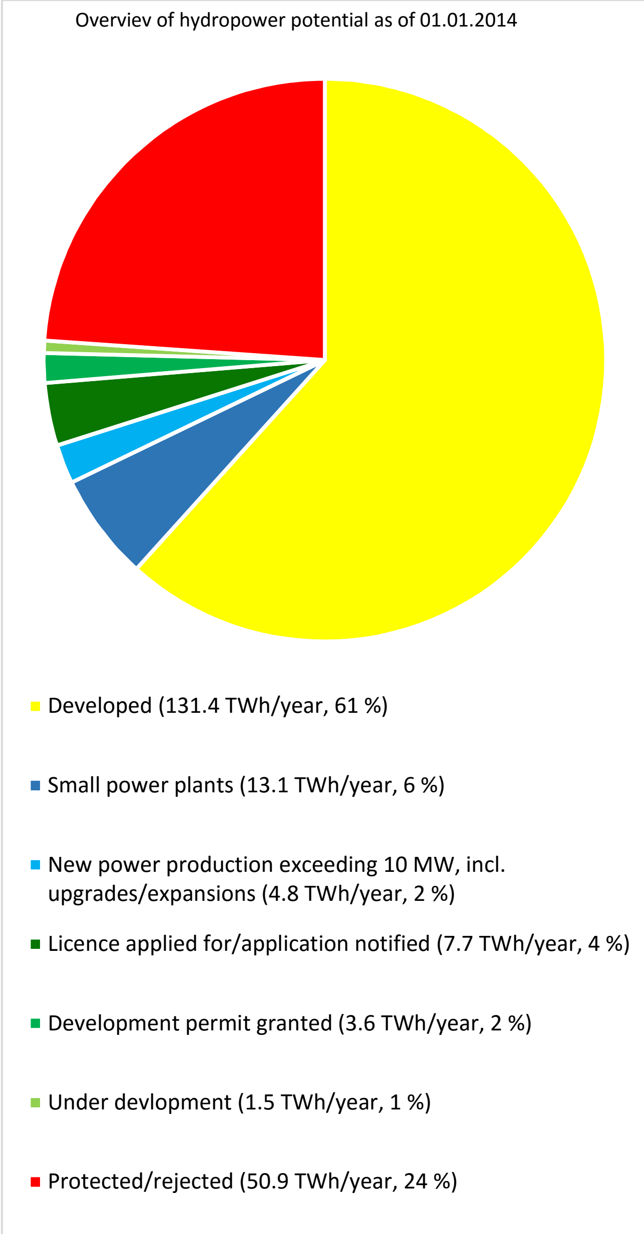

Figure 23: (Norwegian Ministry of Petroleum and Energy 2014, p.27)

Onshore wind

Norway generally has good wind resources, as shown in Figure 24. Most of the resources are in the sea, but there is still a lot of wind to harness onshore by the long coastline to the Norwegian Sea, especially in the northernmost part of the country. Start-up costs for onshore wind parks are still high, but not as high as offshore parks as they e.g. are less accessible to the power grid. In 2014 the total installed capacity of all the onshore wind power plants was 856 MW (NVE 2015 (source 3), p.4). The same year they produced 2.2 TWh and is responsible for 1.5 % of the total production of electricity in Norway (NVE 2015 (source 3), p.4). In the coast the average annual wind speed 50 meters above ground is usually between 7 to 9 m/s (Norwegian Ministry of Petroleum and Energy 2014, p.28). An average annual wind speed of more than 6.5 m/s (Norwegian Ministry of Petroleum and Energy 2014, p.28) is considered to be sufficient for establishing wind farms.

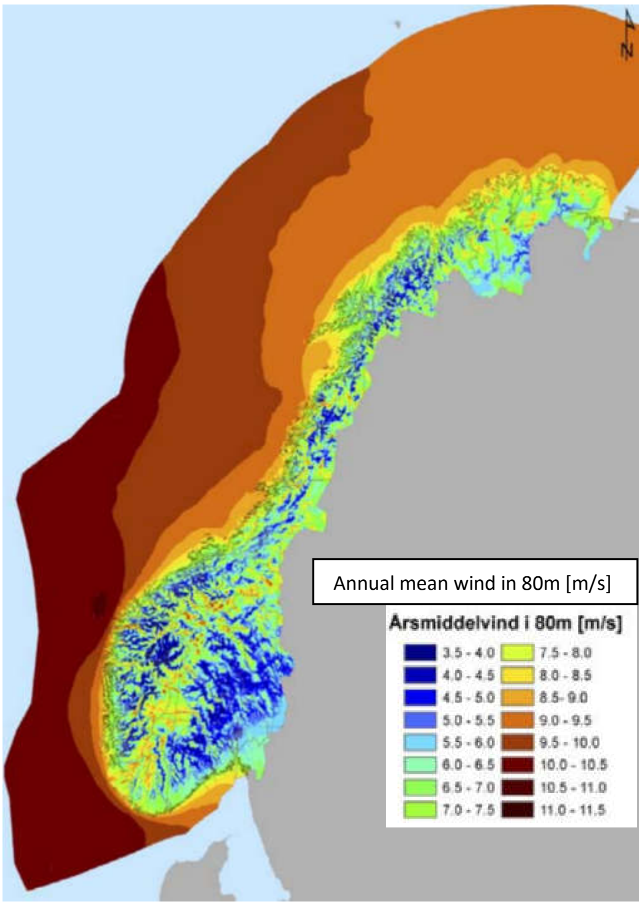

Figure 24: (NVE 2009 (source 2), p.1)

The potential of onshore wind in Norway can be calculated in many ways depending on what areas to include considering constraints like settlements, environment, average wind speed and price range. NVE is the Norwegian Water Resources and Energy Directorate, a government agency that does a lot of research related to the energy situation in Norway including making an inventory of the onshore wind potential.

In a research published in 2009 by NVE the total domestic exploitable wind potential was first presented. In this study it is not made any assessment of how much of these resources that actually can be developed in practice. The numbers are presented Table 1 and are based on an assumption of a development density of 8 MW/km^2.

County	U > 6 m/s [TWh]	U > 7 m/s [TWh]	U > 8 m/s [TWh]
Østfold	0.4	0	0
Akershus	0.2	0	0
Oslo	0	0	0
Hedmark	72.9	41.3	10.8
Oppland	101	55.2	19.1
Buskerud	49.1	35.4	13.3
Vestfold	0.1	<0.1	0
Telemark	32.9	23.9	9.2
Aust-Agder	9.8	6.8	1.6
Vest-Agder	32.6	29.4	11.1
Rogaland	55.1	46.8	23.7
Hordaland	81.3	50.3	10.4
Sogn og Fjordane	120	84.0	41.2
Møre og Romsdal	86.9	57.4	17.5
Sør-Trøndelag	97.8	74.1	27.7
Nord-Trøndelag	116	82.7	28.3
Nordland	289	197	66.6
Troms	202	109	18.4
Finnmark	500	349	120
The whole country	**1847**	**1243**	**419**

Table 1: NVE 2009 (source 2), p.17)

Most of the potential lies in the northernmost counties listed in the bottom of the table. In order to build big/many wind power plants here the capacity of the grid in the area needs to be improved.

As the table shows the potential is very dependent on what exploitable region of the annual mean wind, U, is being developed and utilized.

NVE did a similar research in 2005. In that research the simulation capacity was not as big as the one a few years later published in 2009 and only 12.5 % of the total domestic area was included. The included areas were coastal areas and other areas with favorable weather conditions. Unlike the research in 2009 this study considered the formal development restrictions and the economic criteria and gave a more practical potential. The wind power potential which can be developed at a cost varying between 27-40 øre/kWh was found to be 250 TWh. This is the same as 0.223-0.330 DKK/kWh, 4.42-6.55 ISK/kWh and 0.0299-0.0442 EUR/kWh by the exchange rate of July 29, 2015.

The practical potential found in 2005 would probably be more like the numbers from the study published in 2009 if more areas had been included. Regardless, the study shows that the wind power potential in Norway that is achievable within reasonable production costs, is at least hundred times the 2.2 TWh that was being utilized in 2014.

Geothermal

Geothermal energy is thermal energy generated and stored in the Earth. Geothermal energy can be divided into “deep geothermal energy” and “ground heat” separated by different depth and existing techniques for exploitation. Currently geothermal energy is only being used for heating/cooling purposes in Norway and according to the different sources used in this report large scale production of electricity is not to be expected in the near future. “Norwegian Geological Survey” (NGE) is a government agency responsible for mapping and research of the geology in Norway. NGE estimates the technical potential for energy savings by using geothermal energy and heat pumps to be about 37 TWh annually (Fornybar.no 2015).

Ground heat

By using ground-sourced heat pumps, heat energy from low-temperature areas in the bedrock and groundwater can be exploited. Usually wells are drilled down to about 100 to 180 meters where the temperature is stable throughout the year and can be used for heating purposes (NVE 2015 (source 4)). Ground-sourced heat pumps are the only utilization of geothermal energy as of 2011(Fornybar.no 2015).

In theory can ground heat be used to cover all of Norway’s need for heating and cooling buildings directly. In practice is the potential restricted by high start-up costs. If the cost limit is set to 70 øre/kWh (equivalent the price of electric heating) the potential is 45 TWh (Fornybar.no 2015). 70 øre/kWh is the same as 0.580 DKK/kWh, 11.42 ISK/kWh and 0.0777 EUR/kWh by the exchange rate of July 30, 2015. Today it is approximately 26 000 heating systems in Norway that combined produce 3.5 TWh for heating/cooling purposes and not to produce electricity (NVE 2015 (source 4)).

Deep Geothermal Energy

Deep geothermal energy lies deeper than the heat harnessed by ground- sourced heat pumps and require different and more expensive techniques to be utilized. In Norway it is necessary to drill relatively deep to reach a desirable temperature. The drilling costs increases rapidly as the wells go deeper. To achieve a temperature of more than 100 °C it is in Norway needed to drill down to about 4,500 to 6,000 meters (Norconsult AS 2012). According to Norconsult AS, deep geothermal energy can in the future cover up to 40% of the heating market in Norway, but in the near future, the potential is very limited to the costs.

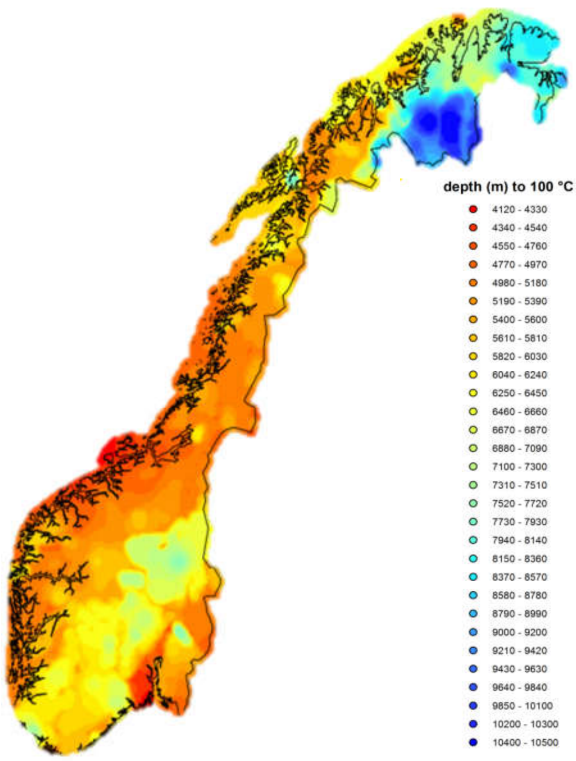

Figure 25: Map of depth to find 100°C temperatures

Solar

Solar is by many predicted to be the energy source of tomorrow. Even though the potential in Norway is quite much less than in countries lying closer to the equator the annual radiation is still about 1700 times the annual consumption (NVE 2015 (source 5)). Solar radiation can directly be utilized by either solar thermal collectors, mainly used for heating, and solar cells for production of electricity.

Due to the location far north the solar radiation varies greatly with the seasons in Norway. At the same time it can be very different from the south to the north. Figure 27 on the right shows the daily mean radiation on a horizontal surface in January and in July. The annual radiation on a horizontal surface variesfrom about 700 kWh/m^2 in the north to about 1100 kWh/m^2 in the south (KanEnergi and SINTEF 2011, p. 44). By tilting solar collectors and photovoltaic modules to thebest gradient depending onthe latitude the radiation will be somewhat stronger.

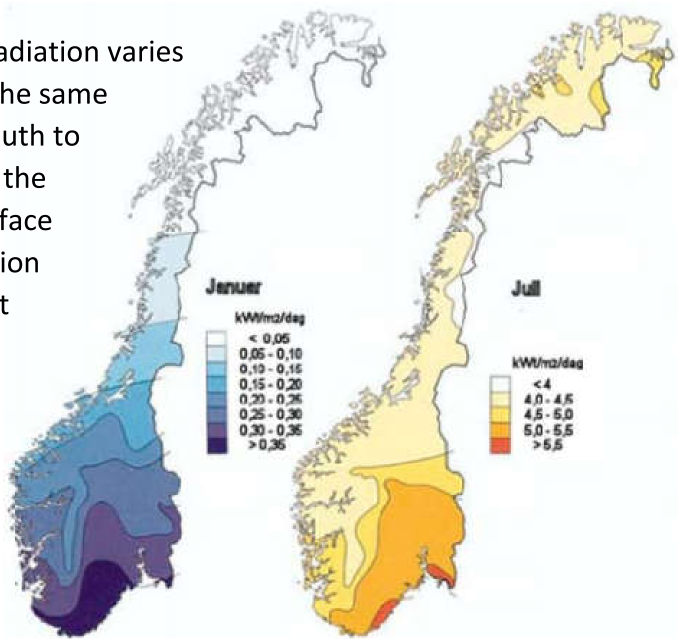

Figure 27: (KanEnergi and SINTEF 2011, p. 44)

Figure 26 displays simulation of how much the radiation is changing throughout a year based on climate data. Five places that can be considered as weather representatives for each region was picked: Oslo (southeast), Kristiansand (south), Bergen (west), Trondheim (middle) and Tromsø (north). (Multiconsult 2013 p. 7).

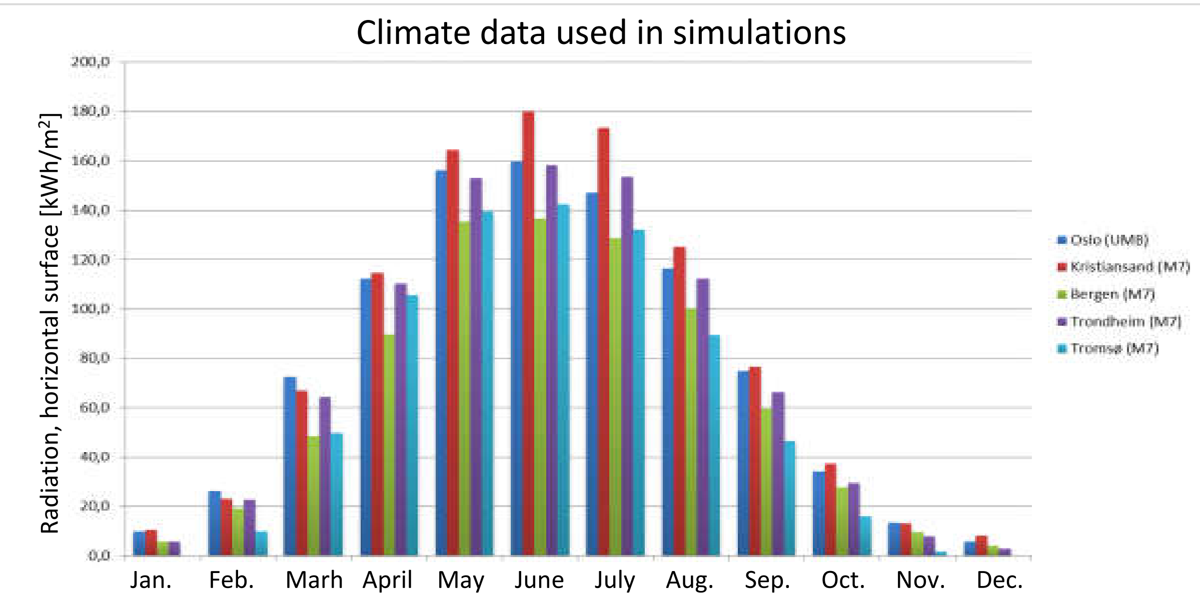

Figure 26: (Multiconsult 2013, p. 8)

Solar thermal collectors

Solar thermal collectors collects heat by absorbing the sunlight. This heat can later be converted to electrical energy by heating a fluid to drive a turbine. Using solar energy directly to heating in Norway is considered not to be desirable as the radiation is very small when the demand for heating is high during the winter (KanEnergi and SINTEF 2011, p. 44).

A typical solar collecting system for heating homes is estimated to produce/store heat to a price of about 70 – 120 øre/kWh$_{(thermal)}$ (KanEnergi and SINTEF 2011, p. 65). This is the same as 0.583 – 1.000 DKK/kWh, 11.49 – 19.69 ISK/kWh and 0.0781 – 0.1339 EUR/kWh by the exchange rate of July 30, 2015.

The practical potential of solar thermal collectors for heating homes and other buildings by 2020 is estimated to be 1.6 TWh$_{(thermal)}$ per year(KanEnergi and SINTEF 2011, p. 65). The potential is reached if solar collectors are installed on all the new and renovated buildings by 2020. An estimate of what is actually realistic to expect is a production between 53 and 66 GWh$_{(thermal)}$ per year by 2020(KanEnergi and SINTEF 2011, p. 65).

Solar cells

Solar cells, or photovoltaic cells (PV), converts the radiation energy in the sun lights directly into electricity by the photovoltaic effect. The potential of producing electricity from solar cells is very high, even in Norway, but high costs stands in the way of the development. The most resent overview of the installed capacity found is from 2011. The overview estimates the installed capacity of solar cells in Norway to be about 8MW, which of only 7 % was connected to the power grid (KanEnergi and SINTEF 2011, p. 51).

The practical potential of solar cells is estimated to be 4.4 TWh per year by the year 2020 (KanEnergi and SINTEF 2011, p. 65). The potential is reached if solar cells are installed on roofs and facades on all the new and renovated buildings by 2020. In this estimate big solar power plants that deliver power to the grid are not included as they are not expected to be able to compete in the Norwegian energy marked by 2020. In the past decade the costs of solar cells have decreased tremendously while the efficiency is constantly being improved. If the development continues the power from solar cells will sometime in the future be competing with power from other sources, even in Norway, and the potential will be very much higher, almost unlimited. (KanEnergi and SINTEF 2011, p. 51, 65 and 66).

Offshore renewable energy

The ocean is an enormous source of energy that is powered by the sun, geothermal sources, the earth's rotation and gravitation. Hydrothermal processes drive the energy transport in the ocean and the Norwegian Sea and the North Sea annually gets a lot of energy from the coast outside North America in the form of hot water that is transported by the Gulf Stream. Norway has a long coast line and big properties in these two seas as well as Skagerrak and the potential of renewable energy is gigantic. Regarding offshore renewable energy is this report focusing on wave, tidal and wind, but it could also be conceivable to produce electricity from the salinity gradient.

Wave

In a study ordered by Enova SF, a Norwegian government enterprise responsible for environmental friendly production of electricity, published in from 2007, the potential of wave power in Norway was estimated to be 600 TWh annually (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007). About 12 – 30 TWh was considered to be possible and realistic to develop. (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007)

The waves are generated by the wind, which is powered by the pressure gradients in the air. The energy transfer occurs in the top layer of the sea and to utilize it devises that transfers the mechanical energy into electricity need to be installed here. Near the coast can refraction and reflection phenomena cause the energy to focus in certain geographic areas. These areas make suitable locations for power plants. The power in the waves changes a lot throughout the year. Even in the best areas the potential power in the summer is less than 15 KW/m, in the same areas it increases up to 125 kWh/m in the winter (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 9). Figure 28 shows the annual mean wave power density per meter along the coast.

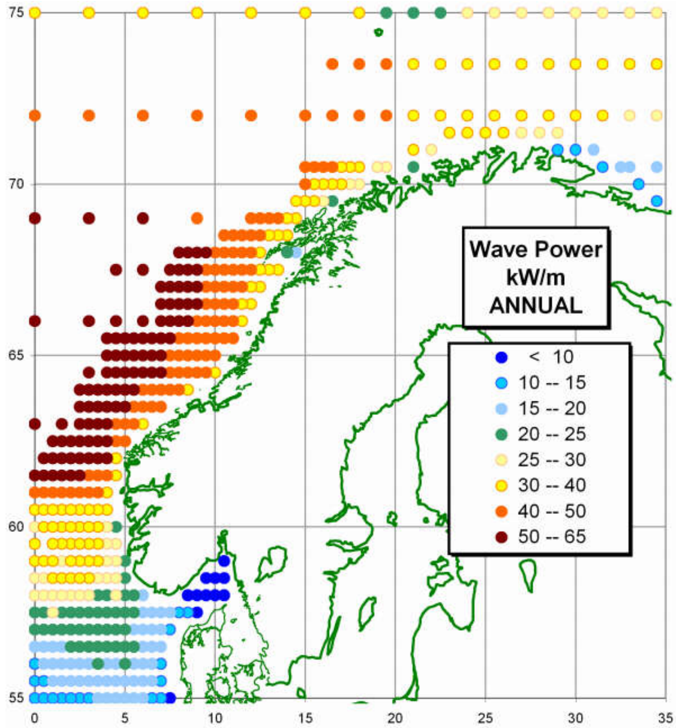

Figure 28: (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 8)

However, the development of wave power plants is in conflict with other preexisting industries in the region like the fish industry and the oil industry. Another challenge that faces wave power is whether it will be profitable in the near future. Many different solutions has been designed and developed, but they are yet to be commercialized enough to get the prices down.

Tidal

Table 2 shows is the potential of tidal power estimated to be about 1.2 TWh annually in Norway with a maximum power output of 337 MW. The table only includes fjords, straits and other suitable locations north of Bodø, a city in the middle of Norway. There are fewer fjords and strait from Bodø and southwards to Trøndelag and the ones in the region are orientated in a way that the tides do not give rise to strong currents. Further south the tidal variations decreases and no locations are considered to be suitable for generating electricity. The tidal variations in the different parts of Norway are illustrated in Figure 29. LAT stands for "Lowest astronomical tide" and correspondingly HAT means "Highest astonomical tide"

Only locations with water flow of 3 knots (about 1.5 m/s) or more are included as this is considered to be the minimum velocity needed to be profitable as the energy increases with the velocity cubed. The numbers in the table are based on the assumption that about half of the cross section of the flow can be utilized by different technologies giving a total efficiency of about 40 %. Some of the locations included in the potential cannot fully be utilized for different reasons. One reason is that some of the locations are currently partly protected. Another reason is that big power plants would interfere with the shipping industry in some locations. Because of these reasons is the practical potential of tidal power in Norway somewhat less than 1.2 TWh annually. (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 10 and p. 11)

Fjord/strait/location	***Power [MW]***	***Energy [GWh]***
Saltstraumen	9	30
Sundtstraumen	1	30
Tysfjorden	0	0
Moskenstraumen	216	758
Nappstraumen	5	18
Gimsøystraumen	4	15
Moholmen	1	5
Raftsundet	2	6
Strauman/Øksfjorden	0	0
Risøysundet/-renna	4	15
Ballstadstraumen	1	3
Sandtorgstraumen	2	5
Ramsundet	2	8
Rystraumen	10	36
Kvalsundet i Troms	5	17
Skagerøysundet	4	14
Kågsundet	6	22
Utenfor Sørøya	4	14
Kvalsundet i Finnmark	14	48
Straumsfjorden	3	12
Vargesundet/Straumen	21	72
Måsøysundet	9	32
Magerøysundet	10	34
Utenfor Nordkinnhalvøya	3	9
Total Norway	**337**	**1178**

Table 2: SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 11)

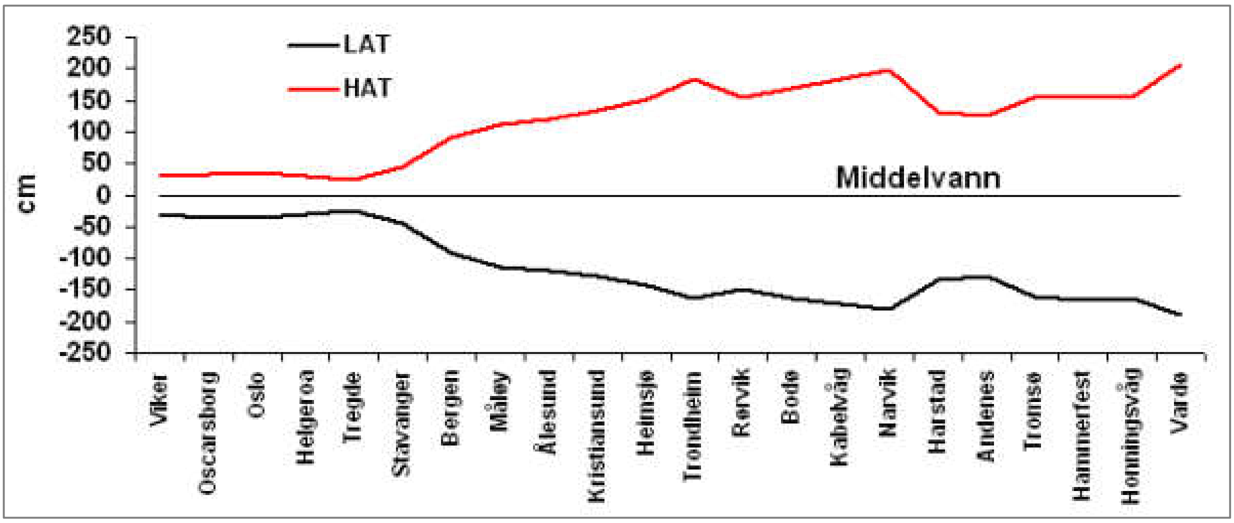

Figure 29: (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 10)

Wind

The offshore wind potential in Norway is huge. Table 3 shows that the total estimated potential is about 14,000 TWh. The potential is calculated using the efficiency of already existing windmills and measurements and simulations of the weather throughout the year. How much electricity it is possible to produce of it is essentially not limited by the available energy, but by the power market and other practical relations. Those limitations are e.g whether the seafloor makes an acceptable foundation, distance to the power grid and conflict of interest with other industry. (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 14 -20)

Area	***Water depth***	***Energy [TWh]***
South of Lat. 61°N	0 – 30 m	6.8
	30 – 60 m	334
	60 – 300 m	2320
	Total	2660
Lat. 61°N to Lat. 67.5°N	0 – 30 m	100
	30 – 60 m	51
	60 – 300 m	3740
	Total	3890
North of Lat. 67.5°N	0 – 30 m	17.6
	30 – 60 m	486
	60 – 300 m	6910
	Total	7420
Sum	0 – 30 m	125
	30 – 60 m	871
	60 – 300 m	12970
	Total	**13970**

Table 3: (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 20)

Most of the available energy is far away from the coast and the power grid, but the potential energy closer than 20 km to the shore is still a lot, about 200 TWh annually (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 20). Windmills that are fixed to the seabed can be installed on locations where the sea is less than 60 meters deep. On locations where the sea is from 60 to 300 meters deep floating structures have to be used. Most of the available energy is found in these areas, but the technology to utilize it on a large-scale is not quite ready yet. Locations where the sea is deeper than 300 meters are considered to be unlikely to utilize as the price for anchoring the turbines are too high. (SWECO Grøner, ECON, and Kjeller Vindteknikk 2007, p. 16)

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6. Timescale and licensing process

The licensing process in Norway is thorough and detailed. The process involves governmental bodies, stakeholders and public interests. In each step of the process public consultation is a major part. Decisions on licenses for new major power lines longer than 20 Kilometers carrying a voltage of 300 kV or more are now made by the King in Council. The NVE is still responsible for normal licensing procedures, but not for making a decision on whether to grant a license. Instead, they consider applications in a normal way, but will not make decisions as the authority of first instance. Instead, the NVE submits its recommendation to the Ministry. The Ministry holds a public consultation on the recommendation for consultation, and prepares the matter for the King in Council, who makes a decision on licensing. Such decisions cannot be appealed.

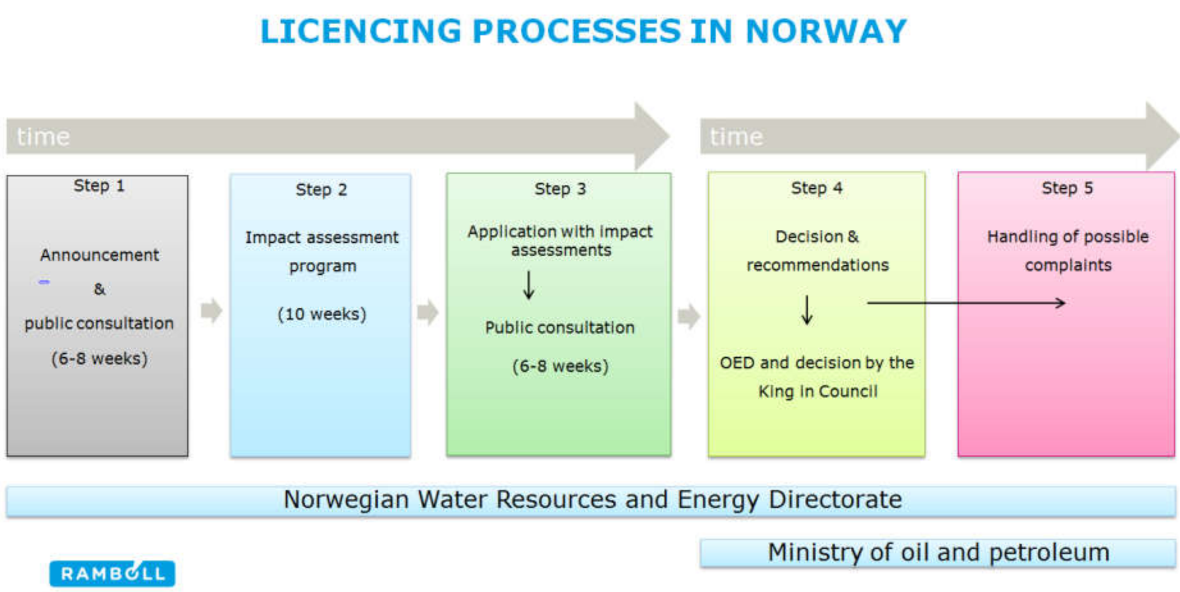


Figure 30 show the authority process for licensing

Several factors have impact on the time spent on license processing, for example the conflict level and complexity of each project. Energy projects are most likely to affect commerce and industry, local communities, the environment and other user interests. The licensing authority is responsible for ensuring that a project has been thoroughly assessed and described before a decision is made, and must during the application procedure consider the need for additional studies of various topics and supplementary statements on issues raised during the process. For new interconnectors it is crucial that the projects are socioeconomic profitable and contributes to safety and stability.

7. CO_2 emission

The Norwegian parliament on 25th of March 2015 approved a plan that will see the country take on a target to reduce carbon emissions at least 40% below 1990 levels, pending a bilateral agreement with the EU, and implement a national climate law.

The decision means Norway will go through with its plan to pledge a minimum cut of 40% from 1990 levels in its INDC, which will be submitted to the UN before the end of the month, but make the target dependent on reaching a deal with the EU next year on bilateral cooperation. “Within the emissions trading sectors Norway will contribute to achieving a 43 percent cut in emissions compared to 2005 within the EU Emissions Trading System,” the bill said.

The country’s power and heavy industrial sectors are already linked to the EU ETS, but Norway’s bilateral negotiation also foresees Norway linking regulation under remaining non-ETS sectors such as transport, agriculture and buildings. “The target will likely be to cut emissions in the sectors outside the EU ETS with 40 percent by 2030 compared to the 2005 level,” said Stig Schjolset, an Oslo-based analyst with Thomson Reuters Point Carbon.

“Norway will buy a substantial, but not yet defined, amount of CERs to comply with the 2020 target under the Kyoto Protocol, while it will have access to flexible mechanisms at EU level to ensure compliance with the 2030 target,” he said.

Figure 31 shows the annual carbon dioxide emission to air in Norway by source. From 1990 to 2014 it increased by over 25% and has maintained quite stable since 2009. The share of the emission from oil and gas extraction has increased the most in the period. Also the emission associated from the energy supply has amplified since 2008. In 2014 the total emission from all the sources was over 44 megatons carbon dioxide.

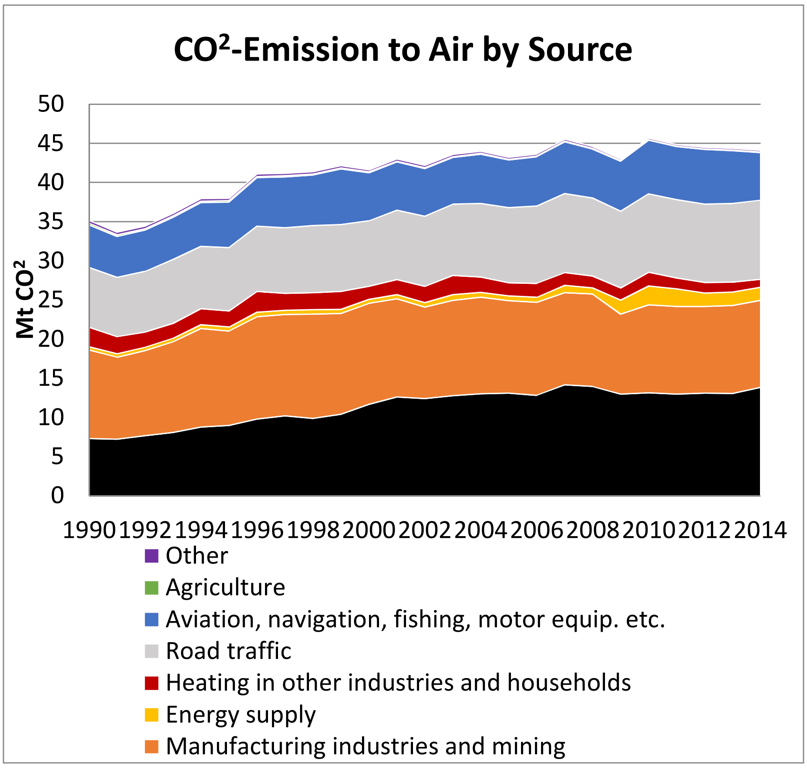


Figure 31: (Ssb 2015, table 08940)

Emissions of other greenhouse gasses

Other greenhouse gases (GHG) are also emitted throughout the year. The different gasses have very different characteristics and CO^2 is therefore used as a reference gas. The amount of any GHG is converted to the mass of CO^2 that would cause the same level of radiative forcing.

Figure 32 shows that carbon dioxide was responsible for most (82 %) of the radiative forcing from any GHG in Norway 2014. In CO^2-equivalent the total emission added up to 55.8 Mt CO^2 and methane was the second biggest contributor accountable for about 10%. The total emission has not changed much the past decades, but the distribution has. HFK has increased from no registered, or negligible, emissions in 1990 and was in 2014 responsible for 2 % of the radiative forcing. On the other hand have PFK and SF6 emissions decreased significantly in the period.

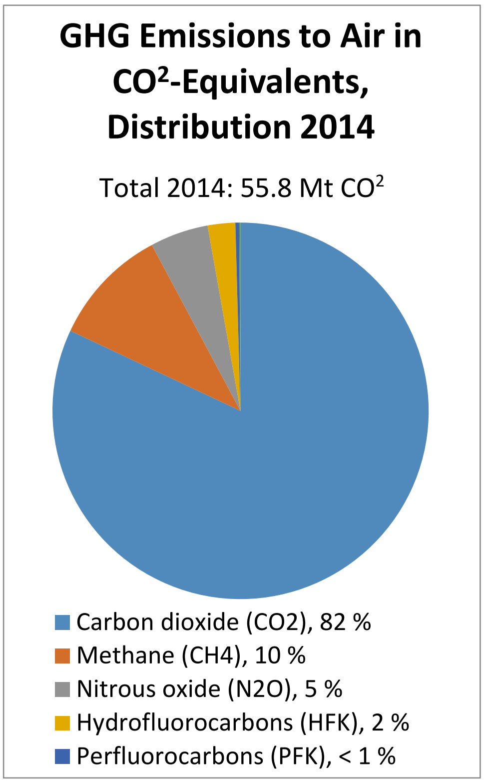


Figure 32: (Ssb 2015, table 08940)

The Pie chart in Figure 33 shows the distribution of GHG emissions to air by industry.

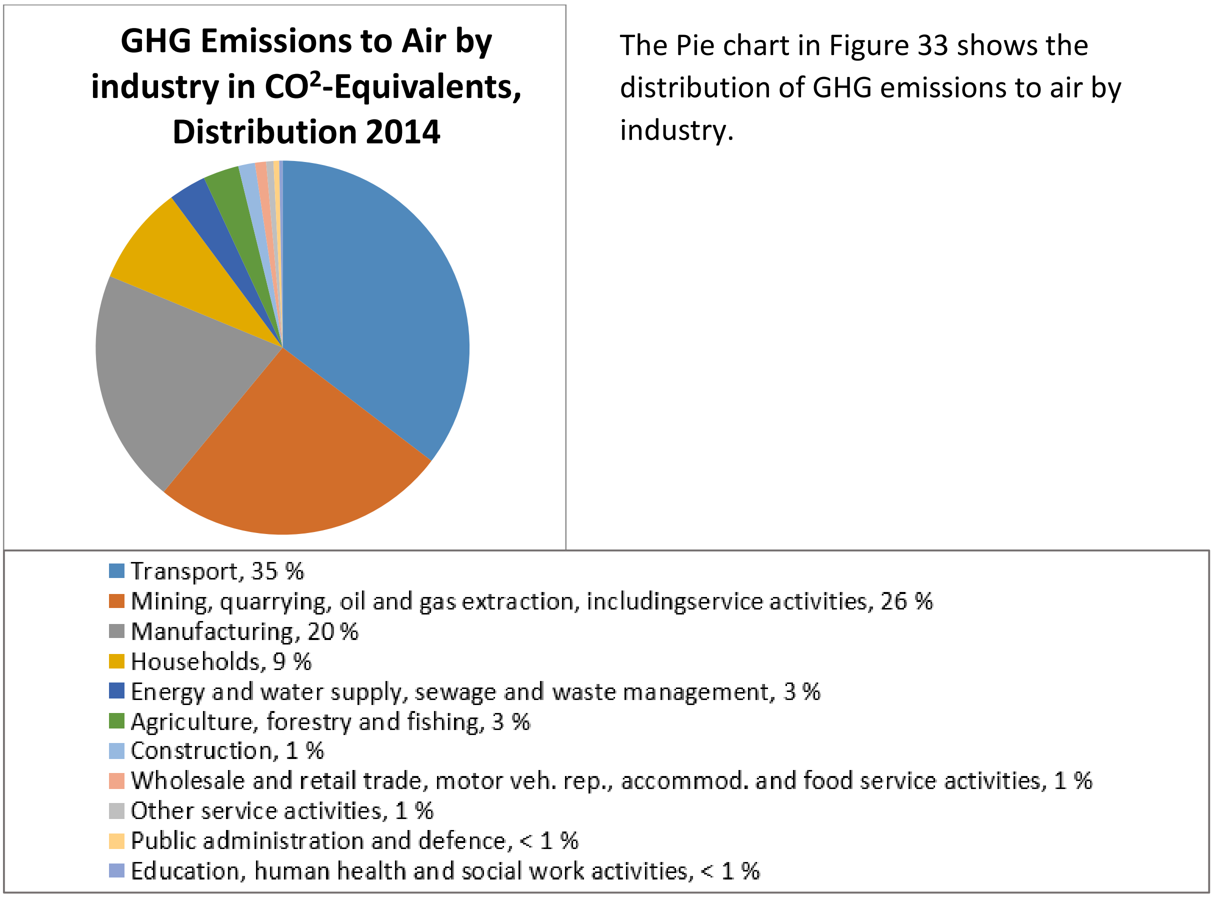


Figure 33: (Ssb 2015, table 09288)

8. Legal perspectives

The Storting (Norwegian parliament) determines the political framework for energy and water resources management in Norway. The Government has the executive authority, and exercises this through various ministries. Figure 44 show the state organization for energy activities. Various Ministries are involved with the Ministry of Petroleum and Energy with the Ministry of Petroleum and Energy has the overall responsibility for managing the energy and water resources in Norway. The Ministry's job is to ensure that this management is carried out according to the guidelines provided by the Storting and the Government. The Ministry's Energy and Water Resources Department has ownership responsibility for the state-owned enterprises Enova SF and Statnett SF. Interconnectors to countries outside of the Nordic region require a license for facilitation of power exchange - a so-called foreign trade license. The Norwegian Ministry of Petroleum and Energy processes the application.

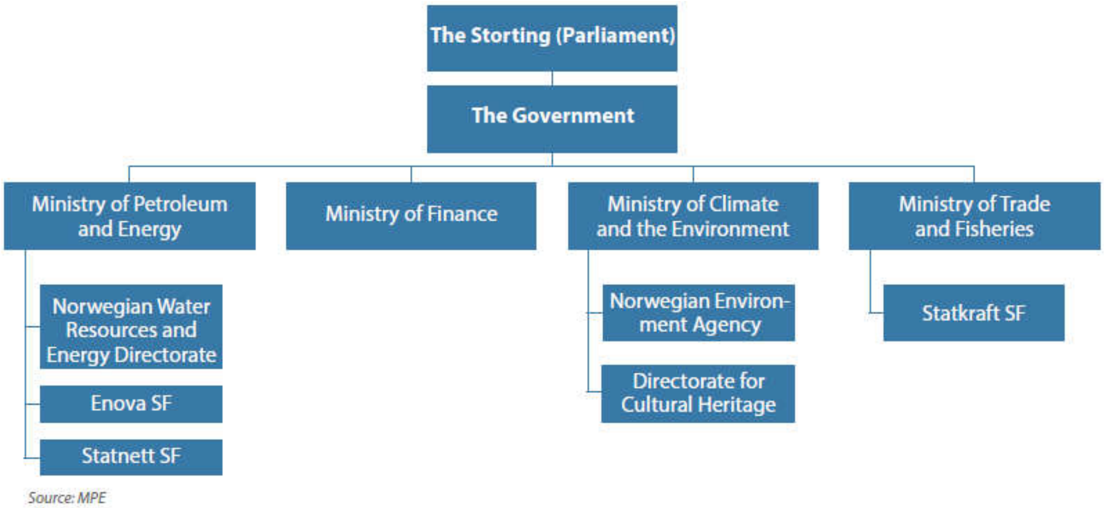


Figure 34 shows Norway state organization of energy and water resources activities

Norwegian Water Resources and Energy Directorate The NVE, which reports to the Ministry of Petroleum and Energy, is responsible for managing domestic energy resources, and is also the national regulatory authority for the electricity sector. The NVE is also responsible for managing Norway's water resources and for central government functions as regards flood and avalanche/landslide risk reduction. The NVE is involved in research and development and international development cooperation, and is the national hydrology expert body.

Enova is a state-owned enterprise that manages the assets in the Energy Fund. Enova's objective is to promote a shift to more environmentally friendly consumption and production, as well as development of energy and climate technology.

Statnett is the state-owned enterprise responsible for building and operating the central grid. The enterprise is the transmission system operator (TSO) for the central grid and owns more than 90 per cent of it. Statnett is responsible for both short- and long-term system coordination, responsibility for ensuring the instantaneous power balance, and facilitating satisfactory quality of supply throughout the country.

One of the objectives of Norway's legislation is to ensure that these different interests are heard and considered, and that the various measures are subject to government control and conditions that safeguard these interests. The legislation is also intended to ensure effective management of our resources. Security of energy supply and a well-functioning power market are key considerations here.

Comprehensive legislation applies to the energy sector and to water resource management. The most important legislation governing these areas is:

- Water Resources Act,
- the Watercourse Regulation Act,
- the Industrial Licensing Act,
- the Electricity Certificate Act,
- the Offshore Energy Act and the Energy Act,

There are also a number of other statutes that are significant for energy and water resources. With the exception of the natural gas legislation, these statutes are administrated by authorities other than the Ministry of Petroleum and Energy and the NVE.

- Planning and Building Act (Ministry of Local Government and Modernization)
- Nature Diversity Act (Ministry of Climate and Environment)
- Expropriation Act (Ministry of Justice and Public Security)
- Competition Act (Ministry of Government Administration, Reform and Church Affairs)
- Natural Gas Act (Ministry of Petroleum and Energy)
- Consumer Purchases Act (Ministry of Justice and Public Security)
- Pollution Control Act (Ministry of Climate and Environment)
- Neighboring Properties Act (Ministry of Justice and Public Security)
- Cultural Heritage Act (Ministry of Climate and Environment)
- Outdoor Recreation Act (Ministry of Climate and Environment)
- Reindeer Husbandry Act (Ministry of Agriculture and Food)
- Public Administration Act (Ministry of Justice and Public Security)

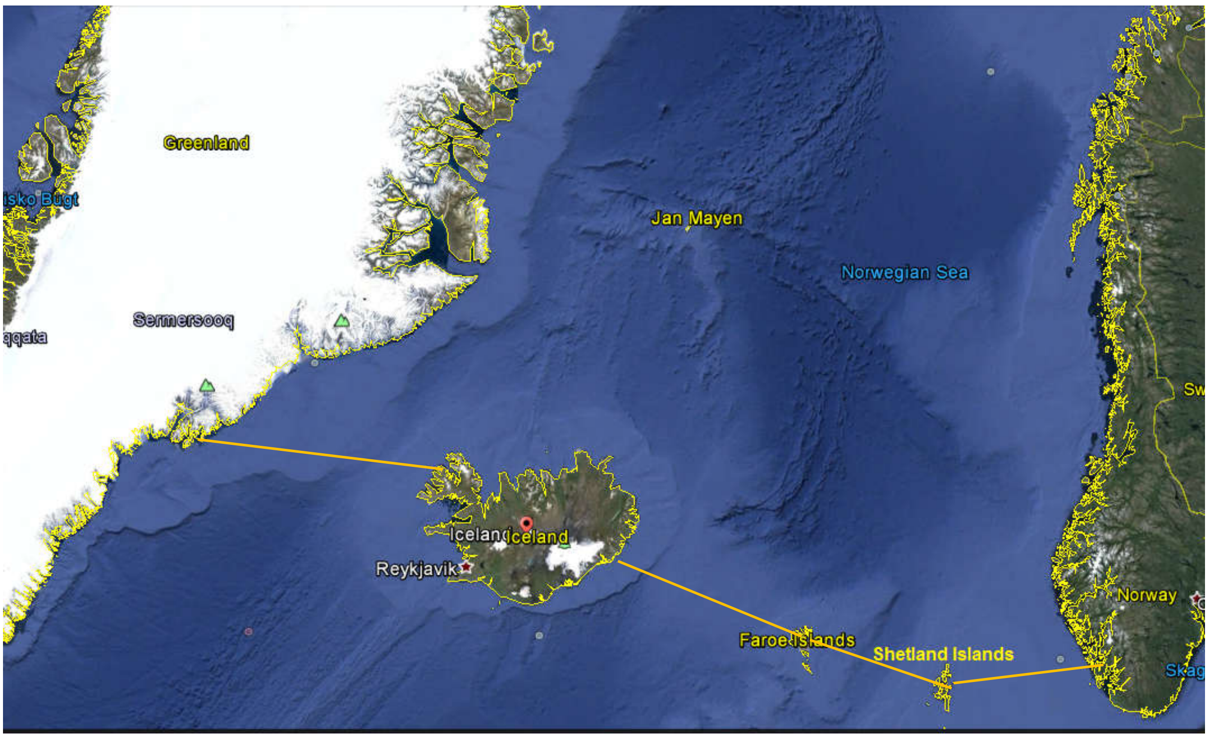
Energy policy is an important area for the EU, and a number of directives and regulations in this field have been incorporated into Norwegian regulations and legislations.

Shetland Islands Council

Appendix E

North Atlantic Energy Network

Shetland



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Introduction

The Shetland Islands are located at the latitude 60 degrees north and longitude 1 degree west; the same latitude as Bergen, Oslo and the Southern tip of Greenland. The capital, Lerwick is about 360 km west of Bergen and 365 km SE of Torshavn. The North of Scotland, Duncansby Head, is about 200km from Lerwick and the main shipping port of Aberdeen, 340km.

Shetland is an Archipelago of 100 islands, 15 of which are inhabited. The islands, including Fair Isle, stretch north to south about 160 km and have an area of 1,468 square kilometres, with a long indented coastline of 2,702km.

The waters of the Atlantic and North Sea surrounding Shetland are warmed by the North Atlantic Drift, an extension of the Gulf Stream. The islands have a maritime climate, with a max average daily mean of 14.4 degrees Centigrade in August and an average minimum of 1.1 degrees Centigrade in February. It doesn't get particularly cold in Shetland during the winter but the islands are in line for many of the fierce Atlantic storms and weather systems that track through. The sea around Shetland is rich in nutrients, the phytoplankton and zooplankton provide the bases of a food chain that support commercial fish stocks and over 1 million breeding pairs of seabirds, as well as a large variety of marine mammals.

Shetland's commercial fishery has been the mainstay of the Shetland economy for several centuries. The modern fishery is a highly mechanised and energy intensive industry. Fish catching and processing of pelagic and whitefish; along with aquaculture, salmon farming and mussel farming contribute over £300 million to the Island's economy.

For the last 40 years Shetland has proven to be a strategic location, in the heart of the UK oil and gas industry with its close proximity to the North Sea and West of Shetland Oil and Gas fields. The Sullom Voe Oil Terminal and the soon to be commissioned Total Gas plant are important infrastructure in the UK sector, handling oil and gas production. The Ninian & Brent pipelines land at the Sullom Voe Terminal with an oil pipeline from the West of Shetland Clare field and Lagan Toremore gas pipeline, as well as the Magnus EOR pipeline.

Oil and gas contributes approximately £70m to the local economy through local businesses and services supporting the sector on Shetland. The operation of the terminal and also the transport of personnel to offshore installations are significant sources of employment in Shetland. Sullom Voe Terminal, since production started in 1978, has seen circa 8 billion barrels flow through it and has been a major contributor to the UK exchequer.

Agriculture and tourism, although smaller industry sectors are important contributors to the Shetland economy, particularly in rural areas; Shetland also has a vibrant creative industries sector including knitwear and music that bring World-wide recognition to the islands. Being an island group remote from the Scottish Mainland, there is a large public service sector to meet the needs of the community. Shetland has a low unemployment rate of about 1%.

Shetland – Economic Output Value 2011 = £1.091 billion

Industry Sector	£ millions
Fisheries & Aquaculture	310
Oil Terminal	46
Oil Supply Services	25
Marine Engineering	11
Tourism	17
Agriculture	18
Textiles	4
Construction	89
Other Manufacturing	11
Ports & Harbours	23
Retail & Distribution	68
Public Services	205
Other Services	120

Harnessing the potential of Shetland's abundant renewable energy resource will reduce Shetland's reliance on imported fossil fuels, reduce carbon emissions and has the potential to establish a new industry sector. The Burradale wind farm has pioneered commercial renewable energy on Shetland and proven the exceptional wind regime; two Vestas V52 and three V47 wind turbines have produced electricity consistently at over a 50% capacity factor each year since their blades started turning in 2001.

Conclusions

The submission of Scottish Hydro Electric Transmission's (SHE-T) needs case for developing a 600 MW transmission cable between Shetland and the UK national grid, is expected to be submitted to the UK electricity regulator Ofgem in 2016. The innovative, 284 km, single circuit, HVDC sub-sea cable, would allow for the Viking Energy island onshore wind farm on Shetland to be constructed and generate ca. 400MW of electricity. The interconnector project has been driven by the wind farm development and will only be built if Viking Energy Partnership secures a contract to supply its low carbon electricity to the UK electricity market; under the Contract For Difference (CFD) bidding process now expected in late 2016.

The Shetland to UK interconnector project has been in process for over a decade and is the main focus for harnessing Shetland's exceptional wind resource. The North Atlantic Energy Network has highlighted the potential for Iceland and Faroe to export renewable energy to electricity markets in the UK, Norway and connect to the wider European grid. Cable routes from Iceland to the UK are currently being investigated and Faroe also has an interest in securing a supply of renewable energy from Iceland.

Shetland could become a strategic location for grid connection with the commissioning of a HVDC connection to the UK National Grid. Any cable from Iceland would most likely require additional capacity but an interconnector between Faroe and Shetland could provide electricity supply to Faroe and an export route for Faroese renewable generation into the UK; utilising head room in the

Shetland to UK cable. The renewable energy developer Element Power is working on a proposal for an interconnector between Shetland and Norway. The 'Maali' interconnector project is at an early investigative stage but is included in the EU Ten Year Network Development Plan 2016. A transmission link between Shetland and Norway would make Shetland a more attractive landfall for an Icelandic or Faroese cable that would in turn strengthen the case for the 'Maali' link.

A scenario with additional interconnectors provides a more secure transmission network, improving the security of supply to Shetland consumers. The 'Maali' link from Shetland to Norway would allow the flow of electricity to Norway north from the UK grid and East from Shetland; an alternative to electricity always having to flow south into the UK grid and reducing the occurrence of bottle necks in the transmission network, that require wind generation in the north of Scotland to be constrained off the grid. A renewable energy mix of hydro, geothermal and wind; from Iceland, Faroe and Norway, could provide a very good balance to UK renewable generation. With a diverse energy mix and wide geographical spread of wind resource, the energy of weather systems can be harnessed as they travel across the regions. This can provide a much more consistent supply of renewable energy to the UK and reduce the requirement for back up generation from fossil fuels.

The North Atlantic Energy Network has explored the potential of connecting up some of the best renewable energy sources in the Arctic, Nordic and northern European regions to the large energy markets of the UK and European continent. The project has allowed informative exchange of knowledge between the participating regions and organisations. Shetland's immediate focus is on a new energy solution for the islands; the Shetland to UK interconnector and Shetland generation projects but realises the potential and scale of developments within the NAEN regions could include Shetland in a wider transmission network. Shetland values the continued co-operation with NAEN project partners and wishes to be kept informed of future developments.

Transmission system and production

Electrical energy production

Shetland's Energy Mix 2015

Shetland's electricity is supplied predominantly from fossil fuels in the form of fuel oil generation, gas fired generation, with a contribution from windpower and micro renewables.

Shetland has a population of 23,240. Around half of the islands population live within 10 miles of Lerwick and the main power station. As there is no mains gas supply a large number of consumers rely on electricity for heating, hot water and cooking. The average household electricity consumption in Shetland is 10,348 kWh pa, twice the Scottish average.

Overview of Electricity Generation in Shetland

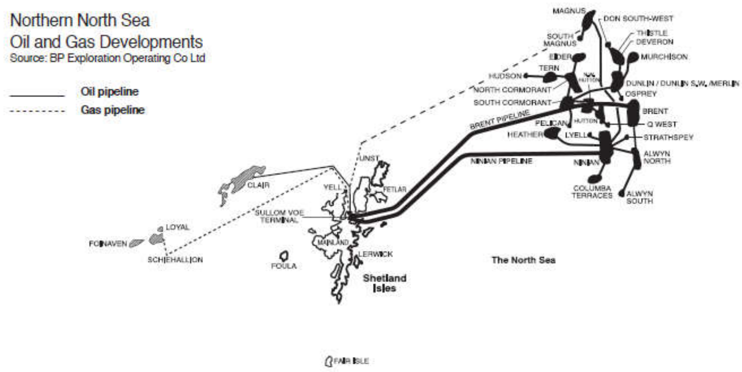
Units of electricity generated in 2013 were 214,185,500 kW hrs
Maximum Demand in 2014 of 45.5MW
Minimum Demand in 2014 of 11MW
The electricity network has 1,650km of overhead lines and underground cables operating at 33kilovolts and below. There are 13 subsea cables joining up smaller islands.

Lerwick Power Station and a map of the Shetland distribution grid.

Generation Capacity

Lerwick Power Station (67MW) – Medium and Heavy Fuel Oil meeting around 52% of Shetland demand over the course of a year. All but one of the engines in the plant is over 25 years and half the plant has now been in service for over 35 years. This plant is planned for replacement as it can no longer meet permitted EU emissions levels.

Sullom Voe Terminal Power Station (15MW)
The Sullom Voe station is a 100MW gas fired power station which was developed in the 1970s solely to meet the oil terminal's full electricity demand. 15MW of this is put into the Shetland grid. The contract with Sullom Voe Power Station is up for renewal; there is no guarantee that the plant will continue to supply power to the Shetland grid.



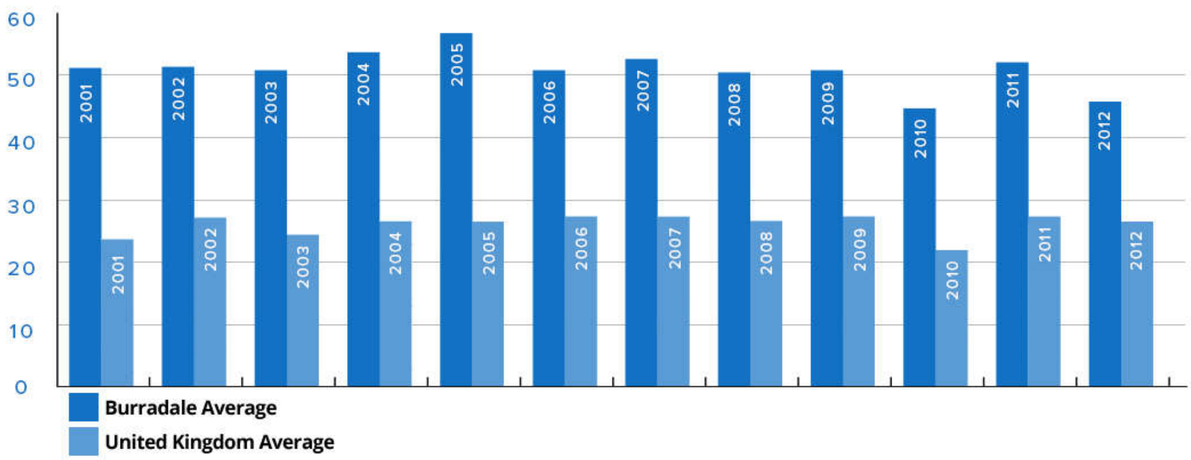
The map above shows the proximity of Shetland to the North Sea oil and gas fields and the developments west of Shetland. The supply of offshore facilities with electricity from onshore generation has been under investigation in the Norwegian oil and gas sector. With a robust grid infrastructure in the North Atlantic, there may be scope to investigate the electrification of oil and gas installations in the UK sector from shetland or passing subsea infrastructure.

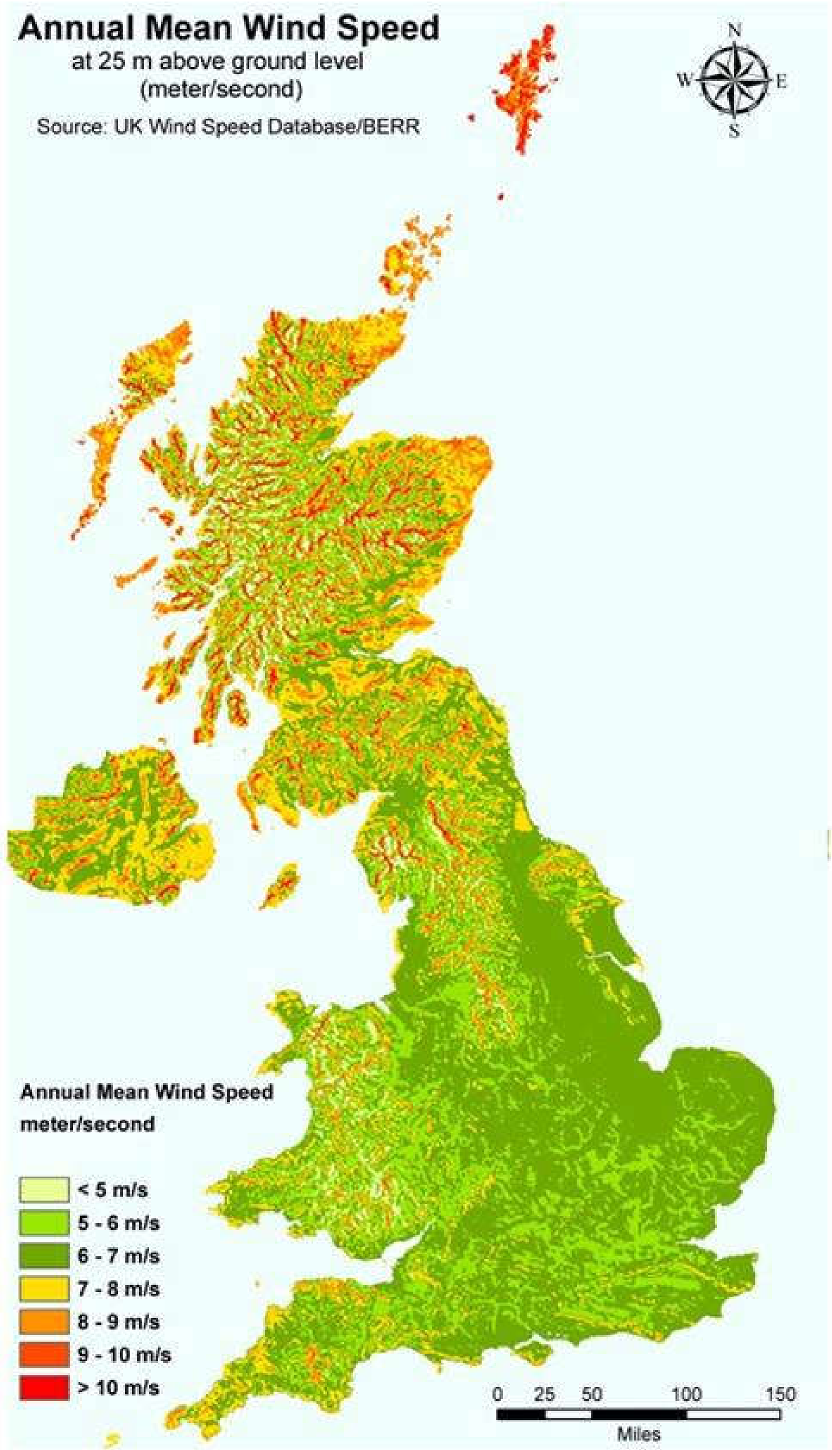
Burradale Windfarm

Burradale windfarm

Burradale Wind Farm (3.68MW) was commissioned in the year 2000 and consists of five Vestas wind turbines. The windfarm has an average load factor of 52% since it began production. A 900kW and a 3MW Enercon wind turbine have recently connected to the grid close to Lerwick; bringing the total installed wind capacity, along with micro renewables up to approximately 8.9 MW

This bar chart compares the capacity factor of the Burradale wind farm and the average capacity factor for UK wind farms. It can be clearly seen how much more wind energy there is in Shetland.





The electricity production from wind turbines located in Shetland is significantly higher than the UK average capacity factor. This map shows annual mean wind speed for the UK, Shetland stands out in red. Many of the hills having an average wind speed above 10m/s.

Heating

Above: The incinerator plant in Lerwick that generates the majority of heat to its 400 customers on the Lerwick district heating scheme.

The district heating scheme in Lerwick has a capacity of around 10 MW of heat. The heat source is from incineration of municipal waste and some oil and biomass. Biomass is also used in some rural villages to heat larger public buildings. Biomas accounts for around 1.5 MW of heat capacity. This biomass capacity is expected to increase over the next few years as a number of large buildings such as leisure centres with swimming pools are replacing oil fired boilers with biomass. The biomass is from a mix of waste wood, imported pellets and also timber that is shipped in, dried and chipped. Many households use oil fired boilers and some solid fuel, coal and peat for heating.

There is potential to use windpower in combination with a large thermal store to reduce the requirement to meet peak demands at the Lerwick district heating scheme with the use of oil boilers. Shetland Heat Energy and Power, operators of the district heating scheme are also investigating the potential of a seawater heat pump as another heat source.

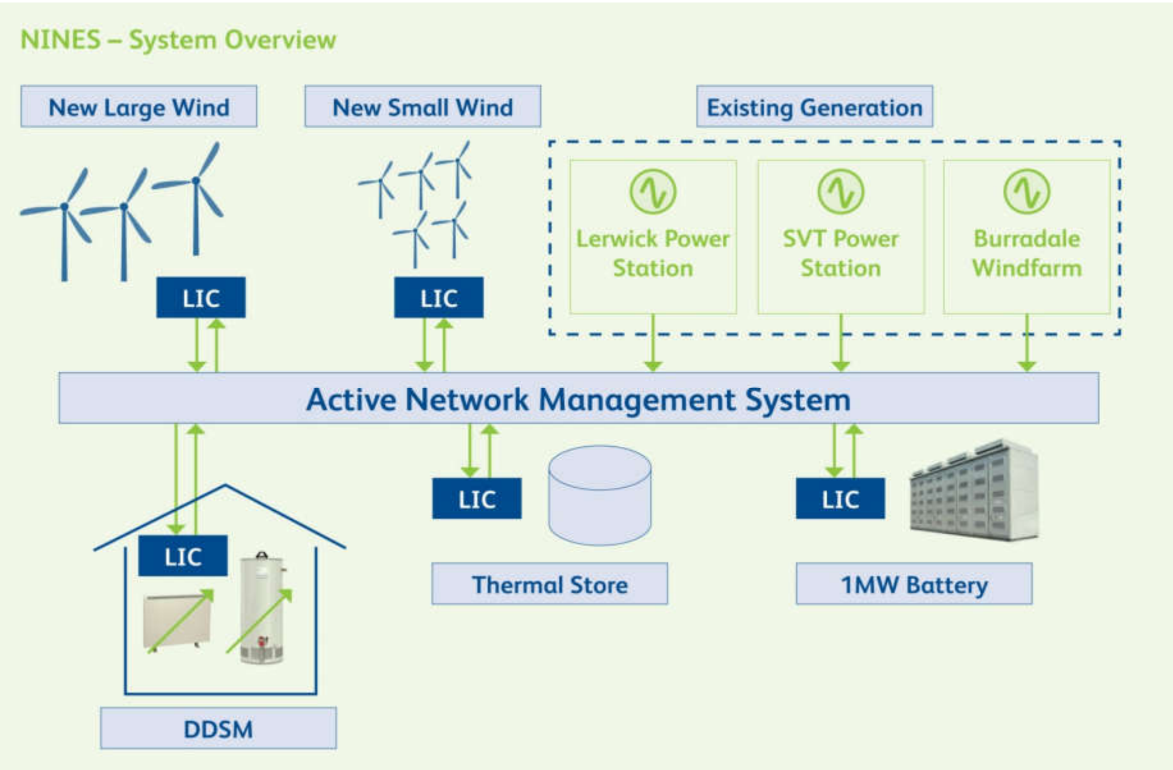
Northern Isles New Energy Solutions (NINES)
This project was developed by Scottish Hydro Electric Power Distribution to look at reducing maximum demand in Shetland; increasing renewable generation output; reducing the reliance of fossil fuels and reducing the size and cost of a replacement energy solution for Shetland.

The system uses active network management servers to control storage via a 1MW battery; and via domestic demand side management for 234 homes connected via the NINES trial and linked to renewables generation output.

A New Energy Solution for Shetland

Various consultations on a new energy solution for Shetland have been undertaken over the last few years. As far back as 1997 replacement options for the Lerwick Power Station were being discussed; that included as an option, a sub-sea interconnector to the UK Mainland and the National Grid. The decisions are still to be made in regard to the replacement for the Lerwick Power Station, with some generating plant over 35 years old. The Lerwick power station is also in breach of permitted EU emissions levels under the combustable plant directive and is another reason that a new plant is required. The cost of the Electricity supply to Shetland customers is subsidised across the consumers of the North East of Scotland to around the sum of circa £30 million per annum and a new energy solution should look at how this figure can be reduced. When this is taken into account over the cost of an interconnector it has a net present value figure of around £250 million.

The proposed replacement power station was to be generating by 2017 and a plan was presented that incorporated the NINES project and a new modular 90MW dual fuel power station. This proposal was rejected by the UK electricity regulator Ofgem and they wanted Scottish and Southern Energy Power Distribution to carry out a competitive process to seek solutions from the market to ensure the most cost effective and efficient solution could be found. The outcome of this bidding process is expected to be completed by the end of 2015, with an outcome to be announced in March/ April 2016. We are aware of one potential bidder to a future energy solution for Shetland that would incorporate a sub-sea interconnector to the Scottish Mainland in their plan (This is seperate from the proposed interconnector for the Viking Energy windfarm project) . The details of this will only be clear after the tendering process. The cable option would allow more renewable energy production to contribute to the energy mix on Shetland. A new energy solution for Shetland is estimated to be in place no sooner than 2019 or 2020.



Scottish and Southern Energy diagram showing and overview of the NINES system.

Sub-Sea Interconnector

To add to this scenario of a new energy solution for Shetland, SHE-T (Scottish Hydro Electric Transmission) has been developing the needs case for a 600 MW cable between Shetland and the UK. This process has been driven by the Viking Energy windfarm development which has planning permission consented for 103 turbines on the Shetland Mainland. SHE-T have developed and tendered an innovative, single circuit, 284 km sub-sea cable as the most cost-effective solution. It would connect Shetland to the National Grid and be able to import power to supply Shetland electricity customers as well as export wind power. A backup arrangement would have to be in place in case of a cable break. SHE-T's needs case for the connection will be considered by the UK electricity regulator Ofgem before it can proceed.

The subsea interconnector would make landfall in Weisdale Voe in Shetland, close to the proposed Viking Energy wind farm site and Sinclair's Bay on the north coast of the Scottish Mainland. The DC convertor station will be located in the Kergord Valley in Shetland. Once it makes landfall on Scotland it will join into a proposed hub for connecting renewable energy from the Northern Isles and Caithness before heading down the Caithness to Moray 1200MW capacity subsea cable to the Buchan coast and onwards. Caithness to Moray has been approved by Ofgem and is now under construction (estimated completion, late 2018)

Proposed route of interconnector from Shetland to Scottish Mainland.

The interconnector and onshore hub at Sinclair's Bay would allow the UK to access a major source of efficient zero carbon energy. It would also reduce the subsidy that is required to keep consumers electricity costs in Shetland on a level with consumers in the North of Scotland. The Viking Energy project would be the largest UK community-owned windfarm, with 45% of the project owned by Shetland Charitable Trust.

Renewable Energy Developments on Shetland

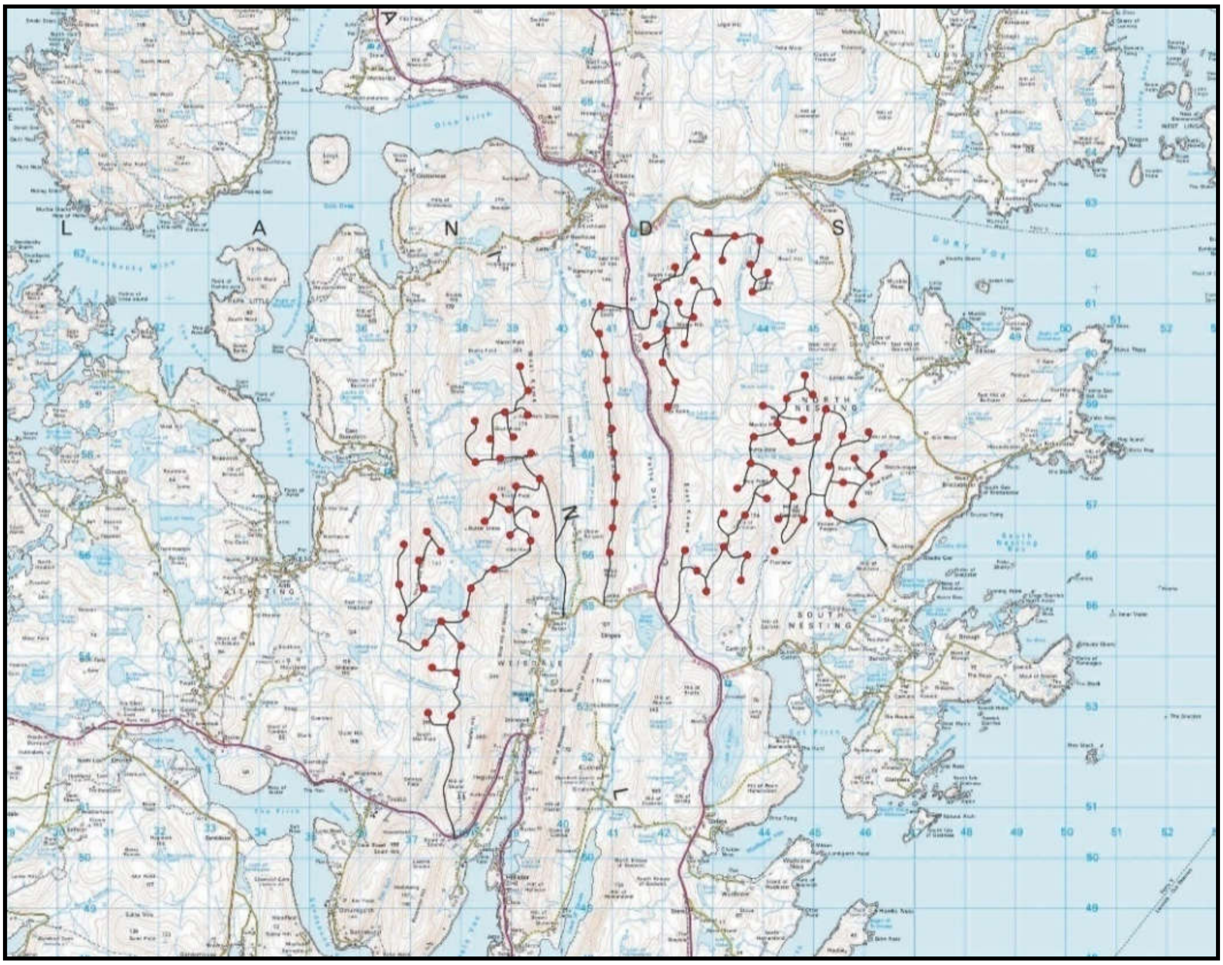
There are a number of renewable energy developments being worked on in Shetland. At an advanced stage, there is about 10 MW of generation looking to connect to Shetland's existing distribution grid as part of the NINES project. Most of these projects will have a non-firm connection agreement so they can be turned off the grid at periods of low demand. Some of these projects are looking at the use of heat, thermal stores and other solutions to make use of the power rather than having to turn off generation and losing all the energy, these alternative uses of the power are at a fairly early stage of development. There is also a proposed 500kW tidal turbine array planned for Bluemull Sound, the project has a grid connection under NINES. This tidal turbine technology has been developed by Scottish Company, Nova Innovation Ltd. They have had a 30kW, grid connected device deployed in Bluemull Sound, Shetland and conducted sea trials on its performance. Nova Innovation are currently deploying the first 100kW, second generation turbine, that will be used in the 500 kW array.

Large scale renewable energy projects will all require an interconnector to the UK National Grid or connect to a location that can take the power.

Viking Energy

Viking Energy has planning consent for up to 457 MW of wind generation and a contracted grid export capacity of 412 MW. The proposed interconnector is for a 600 MW single circuit HVDC link. Based on wind power in Shetland of up to 600 MW, around 2.3 TW hrs would be delivered down the cable. The cable is a separate contracted process with the transmission owner SHE-T currently designing a connection for 600 MW. A date for landfall is 2020 and connection for 2021. The needs case for the connection that looks at the technical and economic case has to be approved by Ofgem, this is a two stage process. The submission of the initial needs case is expected to be made in 2016; if approved, the interconnector project would move into Ofgem's assessment stage; this sets a budget with an agreed spend and return by SHETL on the project, with a decision expected in early 2017. The Viking Energy Windfarm would pay an annual use of system charge for transmission over the interconnector. It is planned for Viking to bid into the Contract for Difference(CFD) process; if successful they will secure a contract to sell power into the UK energy market. The CFD contract requires Viking Energy to meet a commitment to have the windfarm operational in line with that of the connection dates of the cable. Viking Energy expect to enter the bidding process in late 2016 with wind generation from islands competing with offshore wind for CFDs. The Viking project would aim to be at financial close in early 2017 based on current CFD contract timescales. Work is now underway with the procurement process, including early discussions with turbine manufactures and civil engineering contractors.

Photomontage of what the Viking windfarm would look like in Da Lang Kames, Shetland.



Proposed layout of the Viking Energy windfarm.

The development of renewable energy in Shetland aims to diversify the Shetland economy and generate income to the community. The Viking energy project estimates an annual income to the Shetland economy of £37 million per annum. The wind farm will produce enough electricity to supply around 4% of Scotland's electricity demand.

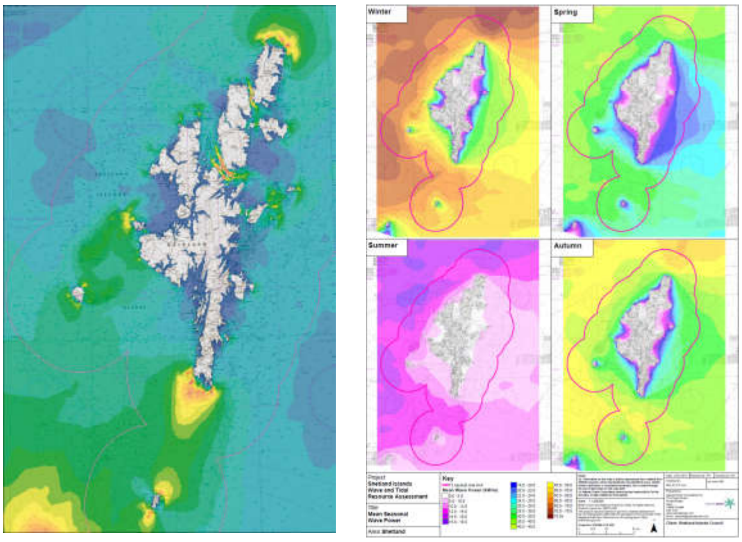
The Viking project is ca 400 MW which means there would be spare capacity or 'headroom' on the interconnector for other generation. There are 2 further wind energy projects planned on Shetland that are looking to secure space on the interconnector cable. None of these projects have formally signed up for capacity on the cable as yet but are scoping for planning and have done some public consultation as well as environmental studies. The project owned by Peel Wind Farms (Yell) Ltd is a 70MW project in South East Yell. Peel Wind is running a second round of consultation with the local community, having revised their site layout based on local feedback on their initial plan. The other project is a consortium of 18 Shetland businesses with a project called 'Energy Isles' looking at 150-200MW of wind power in North Yell. Both projects would require to connect to the HVDC convertor station in Kergord. This connection would involve a short subsea crossing from Yell to the Shetland Mainland and some overland cabling.

Beyond these projects there is significant additional interest but it is difficult to come up with a figure of how much more onshore wind is likely to be granted permission, given potential planning and environmental constraints.

Wave and Tidal Energy

Winter Storm, Stenness, north west Shetland.

At the current rate of advancement in generation technology and the construction of necessary grid infrastructure; the development of the wave and tidal industry in Scotland is thought to be at least 10-15 years away from seeing large scale commercial projects.



Maps showing Shetland's tidal and wave resources.

In Shetland, initial approaches have been made by wave and tidal developers to look at smaller semi-commercial/ demonstration projects. This has been limited by constraints on the Shetland grid. Resource assessment mapping and modelling has been undertaken for wave and tides around Shetland and this data incorporated into the Shetland Marine Spatial Plan. Also initial planning guidance has been issued on Marine Renewables. With so much of Shetland's economy relying on the use of the waters around Shetland for fishing and aquaculture, as well as other marine traffic, it was felt important to look at potential marine renewable energy developments in context with other marine uses and location of facilities around Shetland. This approach is aimed at saving developers time in searching out suitable sites for developing their projects as well as providing all relevant contacts to be able to consult with other marine users.

Nova Innovation's 30kW tidal stream turbine deployed in 2014 and the base of the first 100kW machine now being deployed in September 2015.

Another marine energy concept has been investigated by the private sector, is a bridge between the islands of Unst and Yell which could allow for the development of some tidal stream generation. This project could be in the region of 40MW. For this project to go ahead it would most likely depend on a level of generation capacity in Yell and Unst large enough to justify the cost of connection back to the Shetland Mainland and Interconnector convertor station.

There is a huge potential for marine renewables in Shetland waters but at the moment the technology is not there for large scale commercial developments and they will require access to the grid. Shetland Companies already benefitting from the sector are Delta Marine Ltd who are involved in servicing the offshore wind sector and specialise in wave and tidal installations. They have worked in many countries and have also gained considerable experience in Orkney at the European Marine Energy Centre where a number of wave and tidal devices have been deployed and undergone trials. In the photo above, Delta Marine can be seen with one of their multipurpose work vessels working with the Nova Innovation tidal device. Shetland Composites is another Shetland business that has gained work from the wave and tidal sector, recently they have made blades for tidal prototypes, the Nova Innovation devices being deployed and components for wave and tidal test tank facilities. Shetland Composites also refurbished the blades of the Vestas wind turbines at Burradale Windfarm. After 10 years of production the blades were in need of an overhaul, retipping and resurfacing was carried out locally and paint systems applied. The refurbishment shows that these skills are already available in Shetland.

Electrical market (prices)

In the case of the Viking Energy project it is bidding into the UK market under a CFD contract in competition with offshore wind generation. When it comes to the trading of electricity between different markets such as Iceland and Faroe, into the UK they would have to agree a mechanism to allow the export of power into the UK market. This is an area that would require further examination as to how any renewable projects build their business case.

Benefits (interests)

Interconnectors from Iceland, Faroe and Norway

In terms of Shetland interconnectors, the focus has been on the 600MW interconnector to the UK National Grid. The interconnector is scaled to match what the level of generation that is likely to be developed on Shetland with a high level of certainty and not leave a 'stranded' asset.

A cable from Faroe, Iceland or Norway would strengthen the security of supply to Shetland customers compared with the single circuit planned to the UK National Grid, reducing the use of fossil fuel back up. It would allow for the use of a clean cost effective hydro and geothermal sources of renewable generation as opposed to the fuel oil to back up locally generated windpower in the event of down time on the connection to the National Grid. It would also provide security of connection for the renewable wind generated electricity being exported from Shetland.

Another possibility is that a connection to any source of hydro generation, geothermal or additional wind, from a location experiencing different weather patterns, could ensure that the UK to Shetland interconnector is fully utilised and would further improve the economics of the connection to the UK National Grid. At times of high wind production on Shetland or other connected areas it can be used to save on hydro resource. The project being investigated by Element Power called Maali is proposing an interconnector between Shetland and Norway. The landfall in Norway being somewhere north of Bergen.   The Maali project is based on the 600 MW link going ahead between Shetland and Scotland. The aim is to provide a more robust grid network between countries and allow windpower in Scotland to be exported at times it is constrained off the UK grid; possibly conserving Norwegian hydro power. At times of low wind energy, the cable would enable the import of hydro electricity from Norway. The Maali project is part of the EU Ten Year Network Development Plan 2016.

The scale of the export planned from Iceland in the longer term to the UK may be far beyond what can be used on Shetland and the proposed interconnector network of 600MW.   However the initial 600MW proposed cable may be large enough to take some of the readily available hydro and geothermal power that does not require further planning and development in Iceland. A route from Iceland through Faroe and connecting to the UK National Grid in Shetland would provide to some extent the same benefits in Faroe as previously described for Shetland. The planned interconnector from Shetland to the UK will certainly reduce the amount of subsidy required to keep electricity bills in Shetland at a comparable level to consumers on the Scottish Mainland. The additional link to Faroe and Iceland would increase the security of supply on Shetland and export links.

It is also possible that demand for a second circuit could be triggered between Shetland and the UK National Grid if additional generation were to connect from Iceland, Faroe and Norway. If marine renewables were to be developed around Shetland on any significant scale in the future it is likely to require a second circuit. Links to other generation sources such as Hydro, Geothermal and additional wind from Faroe, Iceland or Norway could help build a case for a second Shetland to UK circuit and a marine renewables sector.

There would be significant economic benefits for Shetland in the development of a wind, wave and tidal sector with a local supply chain of businesses and port facilities servicing the industry. Any interconnector project would bring with it significant capital works and this will be of benefit to the Shetland economy.

Potentials

In terms of renewable energy development the interconnector planned between Shetland and the UK National Grid is rated at 600 MW and there is consented ca. 400MW of onshore wind power to be connected. With other renewable energy projects in the early stages of planning it is expected that there is capacity in the cable to meet these onshore wind and tidal projects. In a timescale we are looking at 5 – 15 years from now. As marine renewable technology becomes commercial there is great potential for wave power development in Shetland waters with a world class resource. From discussions with wave developers that were investigating the potential for development in Shetland waters, for the next 5 years to 10 years they were looking at small arrays of devices up to 10 MW. In order to take advantage of the best wave climate and move the generating devices further offshore, they envisioned that a wave farm of several hundred MW would be required to justify the cabling and infrastructure costs. Another potential source of generation would be offshore wind, this also depends on the technology. Floating offshore wind turbines look like they may be suited to the deeper waters around Shetland. A floating wind turbine project is planned for the north east of Scotland, part of Statoil's Hywind project. This will see five of the 6MW floating turbines operating in more than 100m of water about 12 miles off of Peterhead. The marine sector is probably at least 15 years away from large scale commercial projects, these projects will probably be looking for additional interconnector infrastructure.

Timescale for each energy sources

Large Scale onshore wind - 6 to 15 years

Small scale wave and tidal - 6 to 15 years

Large scale wave, tidal and offshore wind - 15 to 20 years

Additional cost

- Reinforcement of transmission system – Interconnector from Shetland to UK National Grid is estimated at ca £700m
- Building new power plants – Viking Energy wind farm capital cost is estimated ca £700m; additional 200MW of wind/ renewable generation ca £350m

Backup issues – Cost of a new power station or standby generation plant/ additional supply via grid connection would cost ca £100 - £200m

CO_2 emissions

The Shetland Energy Source Analysis conducted by the PURE Energy Centre in 2008 showed that energy use had increased from 1990 to 2008 by 58%; corresponding with an increase of CO2 emissions of 57%. It estimated an increase from 1,000 to 1,550 GWh of energy use; in CO2 terms that is 323,000 tonnes up to 507,000 tonnes of CO2. These levels are high per capita due to the relatively energy intensive industry on the island and the small population.

The study noted CO2 levels had shown a decrease in vehicle transport. Despite a 42% increase in vehicles the level of CO2 had decreased with more efficient vehicles and more diesel cars with improved fuel economy.

Reductions in CO2 emissions could be made through increasing renewable on the electrical network with the use of intelligent load management. Improved energy efficiency would reduce heating and electrical demand, save consumers money on their bills and reduce the use of fuel oil. The use of a clean energy tariff to encourage energy use when renewable energy was available could also be effective in reducing the burning of fuel oil. The use of renewable heat would also contribute to carbon savings and reducing the reliance on fuel oil.

A 600MW interconnector would transmit 2,365,200MWh of wind generated electricity per annum. Based on the UK's Department of Energy and Climate Change carbon saving factor for wind power 0.43kg/ MW hr, this would save an estimated 1,017,036 tonnes of carbon per year.

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