IceScot

Submarine Power Cable
from Iceland to Scotland

Reykjavik Iceland 25th of March 2011

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Photo on front page from Eldvorp Iceland: Student, Professor, Geothermal Borehole and a car, Atlantic Ocean looming behind the mist.

Photo by: Skuli Johannsson Annad veldi ehf

Contents

1. Summary

In this report main emphasis will be on discussion of the proposed submarine power cable IceScot from Iceland to Scotland without landfall in the Faroe Islands. The cable is assumed to have a transmission capability of 600 MW and main technical assumptions are further described in table 4.1.

To put IceScot into context it is deemed necessary to get familiarized with cost of different types of electrical power production as shown in table 1.1.

Table 1.1
Characteristics of various energy types for electrical power production

	Type	Installed Capacity	Utiliza tion	Energy Production	Production Cost	Notes
		(MW)	hours/y	GWh/y	USD/MWh	
1	Geothermal in Iceland and for European market	5	8000	36	39,84	Icelandic experience
2	Hydro in Iceland for European market	55	7313	402	39,66	Icelandic experience
3	Nuclear in Europe	25	8000	200	55,38	Manufacturer Info
4	Coal in Europe	650	7446	4840	93,77	Ref [07] and A2.4
5	Natural gas in Europe	540	7621	4115	92,32	Ref [07] and A2.5
6	OIL in Europe	85	8000	680	110,85	Ref [07] and A2.6
7	Wind Onshore Site in Europe	100	2628	263	98,18	Ref [07] and A2.7
8	Wind Offshore Site in Europe	400	3504	1402	173,87	Ref [07] and A2.8

Detailed calculations of production costs are presented in appendices A2.1 - A2.10. Some points are worth mentioning at this stage:

- Basic fuel costs are: Oil 110 USD/barrel, Natural Gas 8,5 USD/mmBTU and Coal 76 USD/ton.
- Carbon taxes are based on 12USD/tonCO_2. Current carbon taxes in European Countries are in different stages of development
- Prices are valid for last quarter 2010 through first quarter 2011.
- Necessary increased production due to 8% estimated transmission losses are included in Icelandic Geothermal and Hydro.
- Costs of future dismantling of facilities are included.
- Waste management costs are included in nuclear costs.
- Currency rates are 1,36 for USD/EURO and 115 ISK/USD
- Wind Power production prices on table 1.1 do not take into account local subsidies through ‘feed in tariff’ prices in Europe. These are politically and locally stimulated uplifted prices for renewable energy projects in the homeland.

The Production Costs of all types and especially types 3-6 will vary according to price fluctuations of oil and energy at world markets and are also sensitive to political decisions on CO_2 environmental taxation also called Carbon Tax

The Production Cost in table 1.1 (Levelized Cost) represents the minimum dollar cost per megawatt-hour that must be charged over time in order to pay for the total cost of power production.

The relative low Production Cost of available power production alternatives from renewable energy resources reveals the overwhelming attractiveness of Geothermal and Hydro in Iceland.

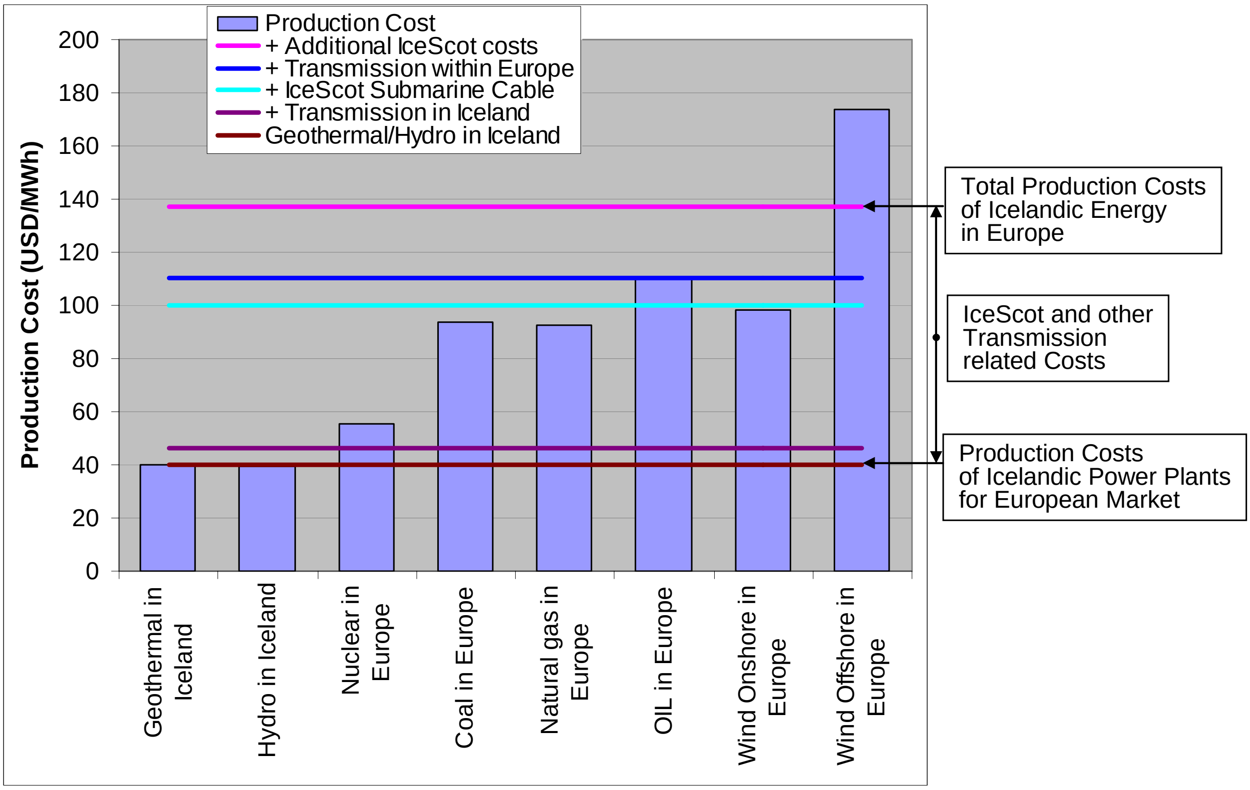
Table 1.2 shows the estimated price of outfeed (delivered) power from the IceScot cable in Europe.

Table 1.2. Production Cost of IceScot outfeed power in Europe

	Cost Item	USD/MWh
A	Production Cost of Geothermal/Hydro in Iceland according to table 1 (Average)	39,75
B	Transmission infrastructure costs in Iceland	6,81
C	Basic Transmission cost of the IceScot Submarine Cable	53,64
D	Transmission from Scotland to European market (Estimated)	10,00
E	Total Production Cost for outfeed power in European Market	110,20
F	Additional risk related cost of IceScot (see A2.10)	26,86
G	Total Production Cost for outfeed power in European Market	137,05
	<u>Competition</u>	
H	Nuclear, Coal, Natural Gas or OIL near European Market	55,38 – 110,85
I	Wind Power (incl. 10 USD/MWh for Transmission)	108,18 – 183,87

Tables 1.1 and 1.2 can be presented in a graph as in Figure 1.1

Figure 1.1 Cost of IceScot electrical energy at European Markets



This kind of calculation reveals that the Icelandic power through IceScot is not competitive at the European market. The economic indications must be more attractive to justify commencement of large scale development of the IceScot submarine power cable.

As seen in chapter 4, commissioning of the IceScot cable is assumed in the year of 2027. In the period of 2022-2027, several Hydro and/or Geothermal power plants must be built in Iceland to be available with 5-600 MW of generating capacity for the cable in 2027. Other possibility would be to end the contracting period for existing aluminum factory before 2027 to free capacity in existing power plants for the cable. Anyway the start of cash flow from cable utilization is only expected in 2027 and later.

The first important phase in IceScot would be a Marine Survey (Bathometry) of sea bottom to find the best cable route for cable design and the design of cable installation procedure from Iceland to Scotland including buying (renting) appropriate ship to that purpose. Profitability of the cable link would critically depend on the survey.

One of the most important issues of IceScot is availability. Probabilistic estimation of damages and repair period estimation is discussed in chapter 5, where the results are not favorable for the cable. This would be an important subject for further feasibility studies but the costs in tables 1.1 and 1.2 do not take into account extra operational costs of cable repair, which could be huge.

It would be of paramount importance if and which investor would be willing to take the risk of financing the IceScot cable. It is not recommended that the Icelandic Pension Funds would step in as major investors in this project. The risk is simply too great to enter.

Further desktop studies would be needed to find a more satisfied economic outlook for the IceScot project before committing to initiate a costly development phase.

Figure 1.1 reveals that nuclear power is the main competition of IceScot cable power from Iceland. In this report no reference is made of the recent Fukushima nuclear disaster in Japan, even though it seems to be clear that it will have huge impact on energy policy in the coming years.

2. Introduction

Since the early 1970's several studies have been made in Iceland on connecting the country and Continental Europe with submarine electrical cable(s) to export electrical power produced by hydro and geothermal renewable energy in Iceland. Former analysis were based on exporting base energy but recently ideas on using the cable only for exchange of surplus energy have emerged.

Figure 2.1 shows cable pathways in question. There are 3 sections:

1. **IceScot** 1070 km between South-East Iceland and Peterhead in Scotland. This section is the main subject of this report.
2. **ScotNed** 690 km between Peterhead Scotland and Eemshaven in the Netherlands. Only shown for comparison purposes but this cable section would be necessary in case of limited transmission capacity down through UK.
3. **NorNed** 580 km between Feda Norway and Eemshaven in the Netherlands. NorNed submarine was put into service in mid 2008 and is the longest of its kind in the world today.

Figure 2.1. Submarine Power Cables routes

Figure 2.1 shows the cross section of the ocean floor along the path revealing the ocean depth at each place. In case of the existing NorNed the depth reaches 410 m near the Norwegian coast but IceScot goes down to 1200 m depth in the submarine valley between Faroe Islands and Scotland.

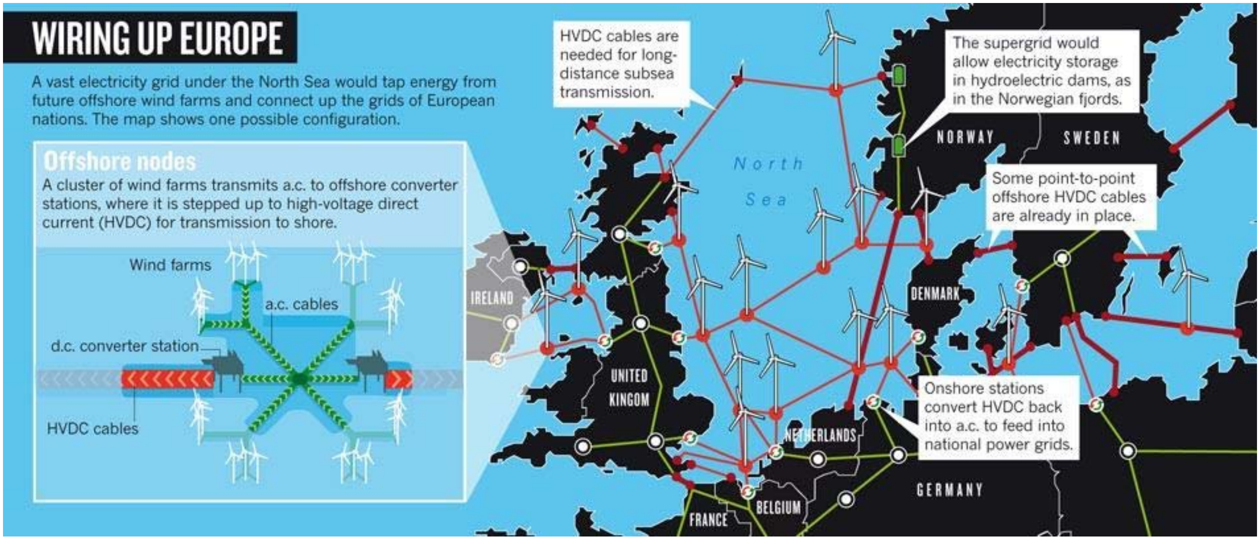
The ScotNed and NorNed pathways are only shown for comparison purposes.

The IceScot submarine cable would be the first of its kind to be laid in an outer ocean, in this case the Atlantic Ocean.

The reason for taking IceNed submarine all the way to the Netherlands would be limited transmission capacity from Scotland through England to be connected the electricity grid of Continental Europe.

Figure 2.2 shows recent advances in proposition of undersea electricity 'supergrid' of the North Sea [02]. Main purpose of the supergrid would be to bring wind-generated electricity from the North Sea to Europe. We assume the possibility that the IceScot submarine cable would be able to connect to the supergrid in North Scotland, but of course it must be analyzed further.

Figure 2.2, North Sea Proposed Supergrid



WIRING UP EUROPE

A vast electricity grid under the North Sea would tap energy from future offshore wind farms and connect up the grids of European nations. The map shows one possible configuration.

Offshore nodes

A cluster of wind farms transmits a.c. to offshore converter stations, where it is stepped up to high-voltage direct current (HVDC) for transmission to shore.

HVDC cables are needed for long-distance subsea transmission.

The supergrid would allow electricity storage in hydroelectric dams, as in the Norwegian fjords.

Some point-to-point offshore HVDC cables are already in place.

Onshore stations convert HVDC back into a.c. to feed into national power grids.

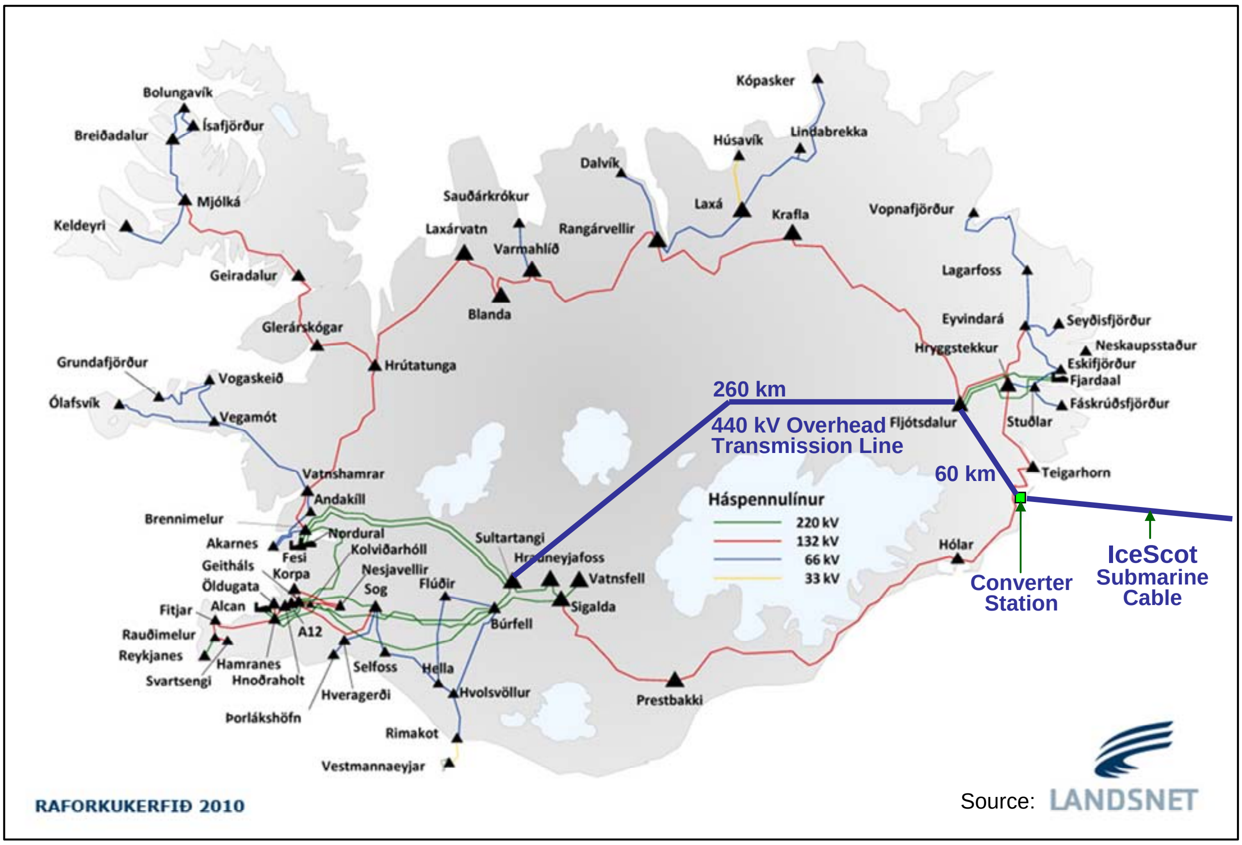
In view of this recent information, we assume hereafter only the IceScot alternative.

In The current staus of the UK transmission system is shown in Appendix 3.

3. Transmission in Iceland and IceScot

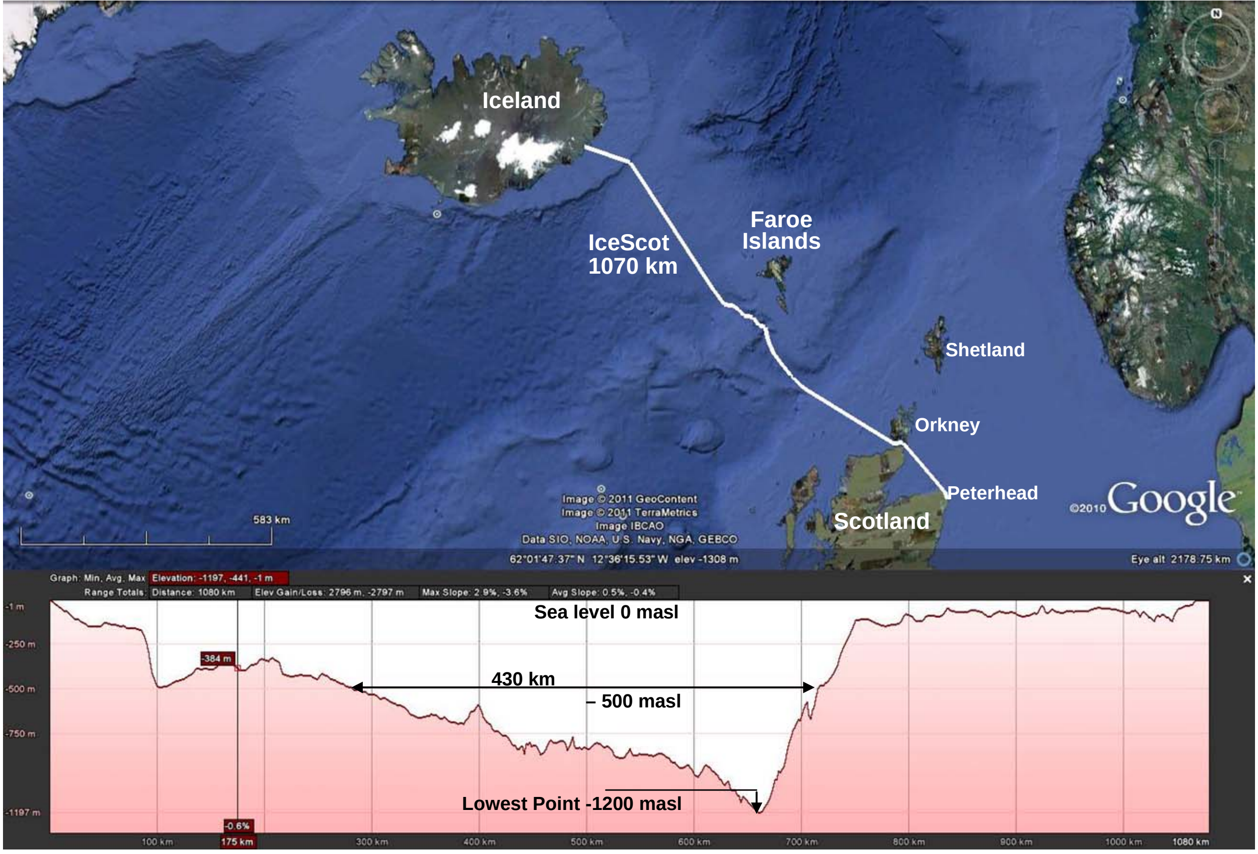
In Figure 3.1 the submarine cable is assumed to leave Iceland just south of the Teigarhorn Substation on the South-Eastern Coast.

Figure 3.1 Proposed transmission projects in Iceland in connection with IceScot



Source: LANDSNET

Figure 3.2 IceScot submarine cable



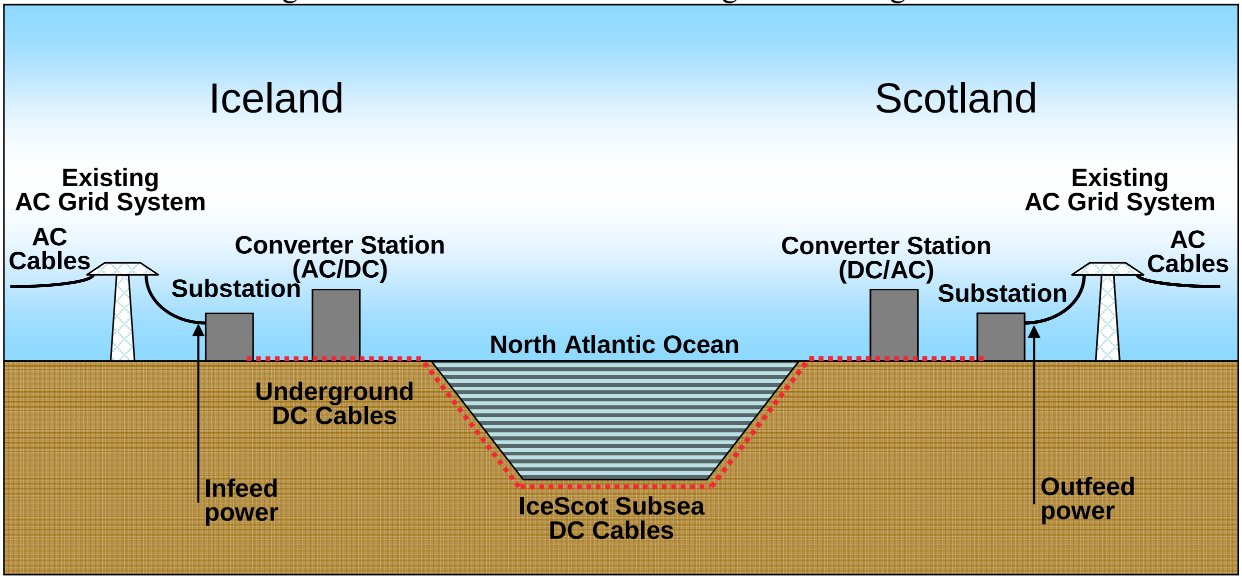
Regarding infrastructure in Iceland, a 260 km 440 kV highland transmission line is assumed as shown in figure 3.1. The project allows for transmission of electrical power from the Thjorsa Area to East-Iceland. An additional 60 km 440 kV transmission line from Fljotsdalur Power Plant to the converter station south of Teigarhorn is also shown in figure 3.1. It is quite unclear at this moment if application for such projects would be accepted. Fierce criticism could be expected from environmentalists.

Assuming specific capital cost of the 260+60=320 km Sultartangi-Fljotsdalur-Teigarhorn transmission line as l,1 MUSD/km, the total cost is estimated as 1,1 * 320 = 352 MUSD. Corresponding energy cost with 600 MW transmission would be 6,81 USD/MWh as explained in appendix A2.9.

Figure 3.2 shows suggested route for IceScot with related depth profile. This alternative is approximate so it will be used without further consideration of a landfall in the Faroe Islands. As seen in the picture the largest depth is 1200 m. The cable would be under 500 m depth for 430 km.

Schematic of the general agreement of the IceScot submarine Cable and associated structures is shown in figure 3.3.

Figure 3.3 Schematic of the IceScot general arrangement



Cable laying on 500-1200 m depth is not considered a problem in itself. The challenge is the weight of the cable and the necessary armoring, and consequently the capacity in MW that are feasible. On this kind of depths there are no activities that can harm the cable, so a low probability of cable faults could be expected.

Cost estimation of IceScot is shown in the next chapter.

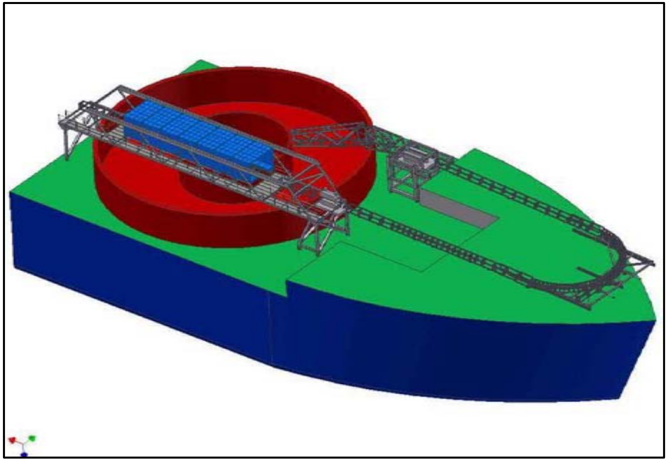
4. NorNed and IceScot

Table 4.1 shows some description of the NorNed submarine power cable and estimated characteristics for the planned IceScot cable and also for an eventual IceFar cable.

Table 4.1 Technical and Financial data

	Items	NorNed (Actual)	IceScot (Estimated)	IceFar (Estimated)
1	Member countries	Norway (Feda) - Holland (Eemshaven)	Iceland – Scotland	Iceland – Faroes
2	Commissioning	2008	?	?
3	Operating Voltage	450 kV DC	Same	Same
4	Length	580 km	1070 km	550 km
5	Maximum depth	410 m, just off the coast of Norway	1000-1100 m, between the Faroe Islands and Scotland	500 m
6	Transmission capacity	700 MW	600 MW ?	100 MW
7	Transmission losses	5%	8%	5%
8	Investment, incl development and converter stations	900 MUSD	2100 MUSD	400 MUSD
9	Specific Cost	1,55 MUSD/km	1,96 MUSD/km	0,72 MUSD/km
10	Development period	10 years	10 years	5 years
11	Project Period	3 years	5 years	2 years
12	Total Period	13 years	15 years	7 years
13	Earliest Year of Commissioning	Year 2008	Year 2027	Year 2019

Figure 4.1 Schematic of a Cable Lying Vessel [11]



The estimated costs of IceScot and IceFar are extremely approximate and a separate study would be needed. IceFar with transmission capacity of 100 MW is considerably thinner than IceScot with capacity of 600 MW.

Cost estimates in table 4.1 do not assume reserve cable to be activated in case of cable failure or damage. NorNed 2, a new cable parallel to the existing NorNed cable, is already under preparation. Needless to say, another IceScot 2 cable parallel to a first one would increase cable costs tremendously.

Schematic of a typical Cable Lying Vessel is shown in figure 4.1.

The process of submarine cable lying procedures is illustrated in [06] and this book is probably the best reference literature on the market to-day and especially draws experience from the recent NorNed submarine power project.

Cable laying procedures are discussed in the book [06]:

> *A sufficiently detailed marine survey is one of the most important activities during the planning and preparation of a submarine power cable project. The survey can deliver critical input data for the choice of the best cable route, the cable design, and the design of the cable installation procedure. These parameters do not only have an important impact on cost and schedule. A comprehensive survey can also make a substantial difference for the future cable link availability and repair costs. The profitability of the cable link can critically depend on the survey.*
>
> *Based on the survey data of the submarine area between the landing points, the best possible cable route can be suggested in order to avoid submarine obstacles and hazards, such as:*
>
> - *Existing cables and pipelines*
> - *Fishing and trawling*
> - *Shipping lanes, harbour entries, anchorages*
> - *Dumping and dredging*
> - *Seabed contamination*
> - *Oil and gas fields*
> - *Military activities*
> - *Ammunition dumping grounds*
> - *Ship wrecks and other submarine junk, abandoned cables*
> - *Areas of sand or gravel extraction.*
>
> *Troublesome areas should be avoided, since every major obstacle to a smooth laying operation can generate large costs. Avoiding these areas can be an important piece in the protection concept for the cable project.*
>
> *The best cable route is also depending on the knowledge of the seafloor condi¬tions and properties. In particular, the following data are necessary to know:*
>
> - *Bathymetry, i.e. the water depth along the entire cable route*
> - *Seafloor structure, existence of boulder fields, outcrops, crevices, canyons, steep slopes, rocky irregular sea floor*
> - *Areas with risk for free spans of the cable*
> - *Seafloor morphology, i.e. the structure of the soil beneath the seafloor*
> - *Geophysical data such as grain size, hardness, thermal conductivity*
> - *Sediment movements.*

5. Cable protection and Repair

An excellent description on cable protection is taking from [01]:

> “*An unburied NorNed cable is exposed to a very high risk of cable failures (60 failures per year). The main risk element is trawl fishing. Buried cables are theoretically protected against this hazard; however, there is still a risk for cable damage due to ship traffic (mainly anchoring). Taking possible limited untrenched sections and cable exposure due to sand migration into account, the probability of cable failure is assessed to be 0.1 failures per year.*
>
> *Trenching to 0.5 - 1.0 m depth by use of post-lay water jetting is the recommended protection method along most of the route. In the morphologically unstable Dutch nearshore area pre-lay dredging is considered necessary in addition to post-lay trenching to obtain the required burial depth (max. 5 m). In some sections offshore and nearshore Norway where trenching proves non-feasible due to the seabed conditions, the required protection shall be obtained by rock dumping. A flexible protection philosophy taking local seabed conditions and risk into account will be applied to get cost efficient cable protection.*
>
> *The cable protection work will be performed as a post-lay operation, thus the cable will not be protected immediately after laying. However, the trenching spread shall follow as close to the laying vessel as possible, and shall cater for cable protection within a few days after laying. In the period when the cable is not buried, guard vessels will be patrolling the route to prevent fishing vessels from trawling across the cable.*”

Typical failure rates for subsea cables of 0.1 failures per 100 km per year leads to the conclusion that for a 1070 km IceScot cable one failure per year is to be expected. With a mean time to repair of 2 months for conventional submarine power cables of the world to-day with depth of up to 400 m (NorNed) we could expect a longer repair periods at least 3-4 months for IceScot with depths of up to 1200 m, but this could obviously vary with local conditions. These are not favorable failure statistics for IceScot in operation without a spare cable. [12]

Submarine cable systems have an expected lifetime of 30-40 years.

Figure 5.1 Rock Dumping vessel

For rock dumping at greater depth more control of the falling rocks could be achieved with discharge through a flexible fallpipe, see figure 5.1. [06] [11]

We would assume that all experiences from NorNed would be applied for IceScot regarding power cable production, contracting work etc.

In figure 5.2 two cases of damaged cable are illustrated to emphasize the complexity of repair jobs and impact of increased depth on sea bottom space requirements which in turn would have effect on extent of the costly marine survey.

Figure 5.2 Cable repair cases (Inspired by discussion in [05])

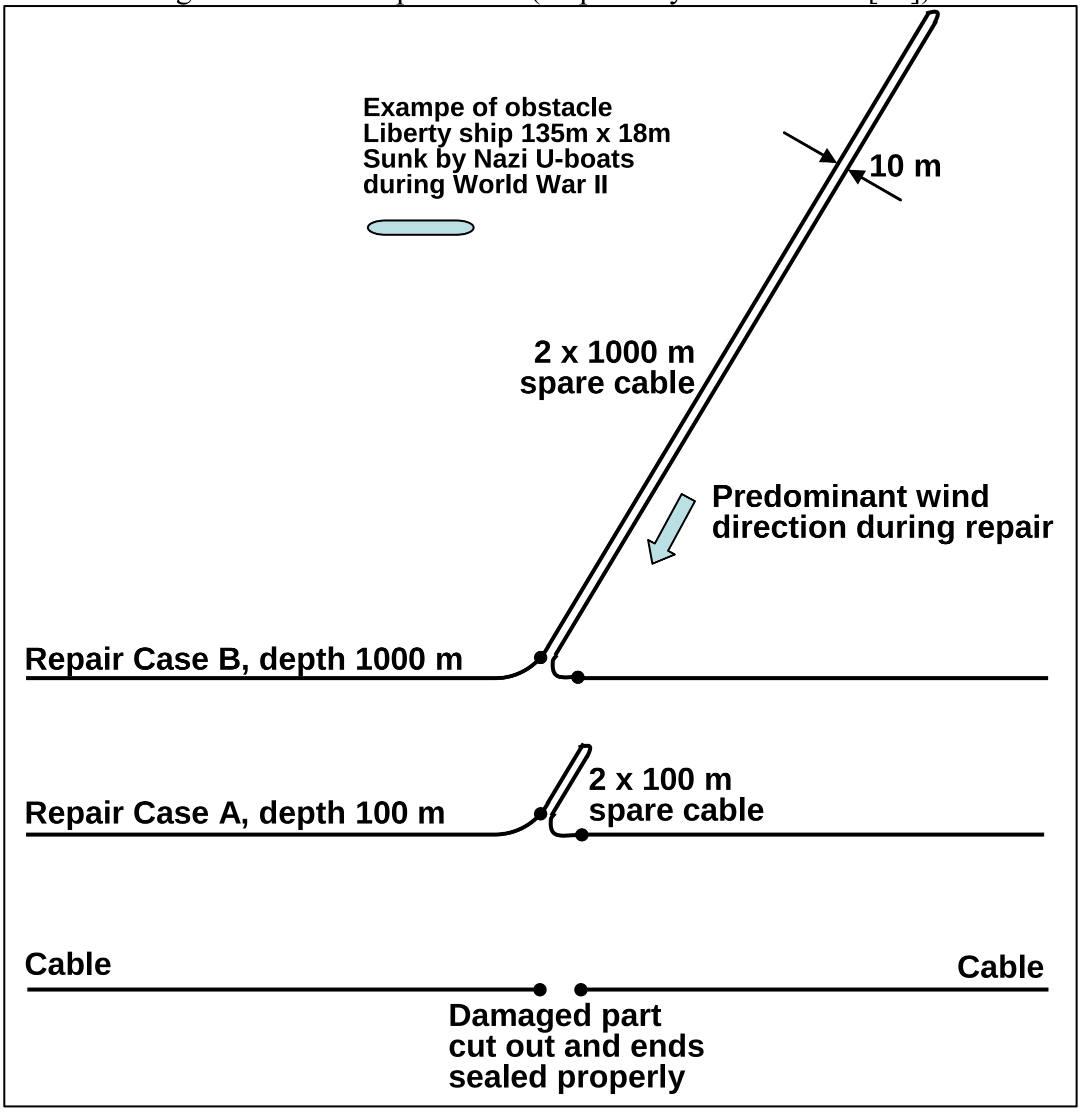


Figure 5.3 Liberty Ship

Ship wrecks and other submarine junk should be avoided. For illustration a Liberty ship wreck is shown in figure 5.2, see also figure 5.3 (from Wikipedia). The Battle of the Atlantic was the longest continuous military campaign of World War II running from 1939 to the defeat of Germany in 1945. During the battle 3,500 merchant ships and 175 warships were sunk for the loss of 783 U-boats [10]. Some of these ship wrecks are expected to be placed in the pathway of the IceScot cable.

It could be an idea to contact war museum authorities in Europe and USA for co-operation on collecting of war related artifacts during cable preparation and laying operation.

Manned submarine vessels to repair damaged cables on the seafloor have been considered. Attempts hitherto have not been successful [05], but the extraordinary case of IceScot could present an opportunity to take a fresh look at it again.

The effect of ocean waves on repair jobs in the middle of the North-Atlantic Ocean is of course of paramount importance. Waves will be discussed in brief in chapter 7.

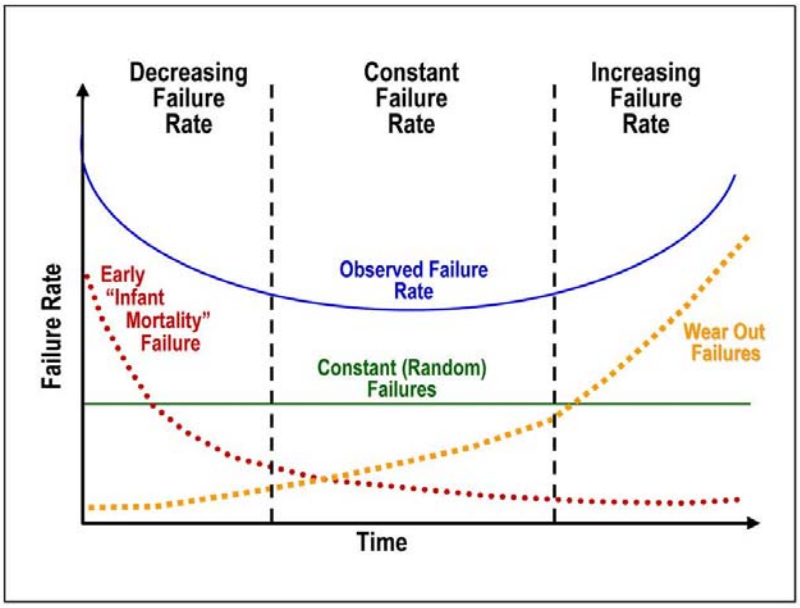
6. Operation and Feasibility of NorNed

Operational History NorNed is interesting, but the main events are shown in Table 6.1.

Table 6.1. Operational History of NorNed 2008-2010

Event	Description	Completed	Duration
06.05.2008	Commissioning		2 years 7 month 22 days
27.07.2008	Early failures	30.07.2008	3 days
15.05.2009	Failure at Eemshaven in Holland	16.05.2009	1 day
06.08.2009	Failure at Feda substation in Statnett	10.08.2009	4 days
29.01.2010	Failure of the cable 70 km from the Netherlands	20.04.2010	3 months
18.05.2010	Failure at Eemshaven substation in the Netherlands	18.05.2010	5 hours
03.06.2010	Preparation for application NorNed 2		
06.09.2010	Preventive maintenance	10.09.2010	4 days 12 hours
21.12.2010	Preventive maintenance	22.12.2010	1 day 16 hours

Figure 6.1. The bathtub curve



The failure rate is more than anticipated as described before in cable protection. It is to be expected that failure rate will take the form of the "bathtub curve" as shown in Figure 6.1 and that NorNed is still in the "Infant Mortality" failure period.

According to table 6.1 NorNed uptime has been 89% but design assumptions expected 97,3%. The failure 29.01.2010 with duration of 3 months seems to have the effect that owners of NorNed have already started preparations for a second parallel cable NorNed 2 to increase uptime connection. The second cable would probably cost 800-900 MUSD at same currency level. It is easy to imagine that in the future similar measures would be necessary for IceScot.

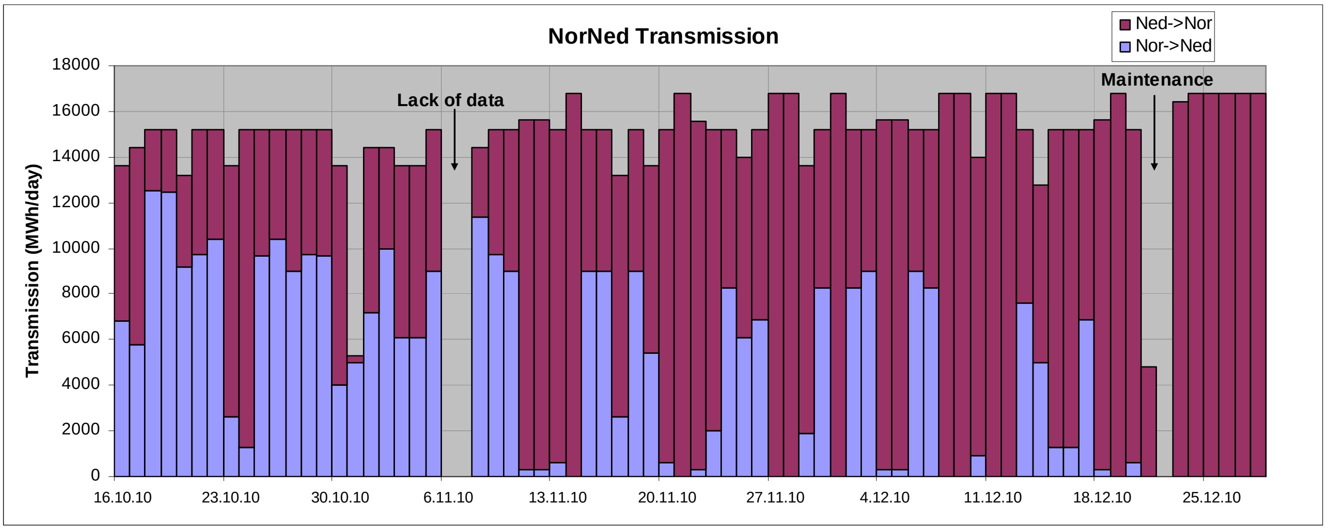
Repair of NorNed is only possible when standing wave height does not exceed 3 meters. The repair in February to April 2010 was delayed considerably because of this but in addition it took some time to localize the failure. Conditions in the middle of the Atlantic Ocean between Iceland and the Faroe Islands will probably mean that it will not be easy to find a period of weather for repair work. Specially designed two people submarines, which can withstand the pressure of great depth, wilt eventually be used for repairs. Different technique means different requirement of weather conditions.

Figures 3 show the energy transmission for NorNed submarine for the periods 16th of Oct to 5th of Nov and 8th of Nov to 28th of Dec 2010, totaling 72 days.

In the first part of the period transmission is more from Norway to Netherlands but after 11th of Nov the main flow of transmission is the other way around showing the Norwegians careful reservoir long term management considerations. This is exactly how the operation was assumed to be from the start.

The transmission charge is a tradable commodity at the NordPool power market and the charge was 6,47 USD/MWh for the Nor->Ned transmission, payable by the Dutch and 21,04 USD/MWh for the Ned->Nor transmission payable by the Norwegians. Overall charge is **16,57 USD/MWh**.

Figure 6.2. NorNed actual transmission



Source: NordPool

It should be noted that it takes one hour to reverse the power flow in the NorNed cable. Probably the flow direction would very seldom for IceScot to be reversed as the flow will be predominantly from Iceland to Scotland. Variations in flow would only involve different transmission flow always in the same direction.

According to news reports from Norway and the Netherlands owners of NorNed are somewhat happy with the financial return of the submarine cable and substantial cash flow has been generated by electricity transmission which during the period shown in figure 6.2 was on average 14.766 MWh/day, 4.533 MWh from Norway to the Netherlands and 10.232 MWh the other way around. This is equivalent to about 5.390 GWh/year, and is of the same order of magnitude as total power production of the 690 MW Karahnjukar power station in Iceland.

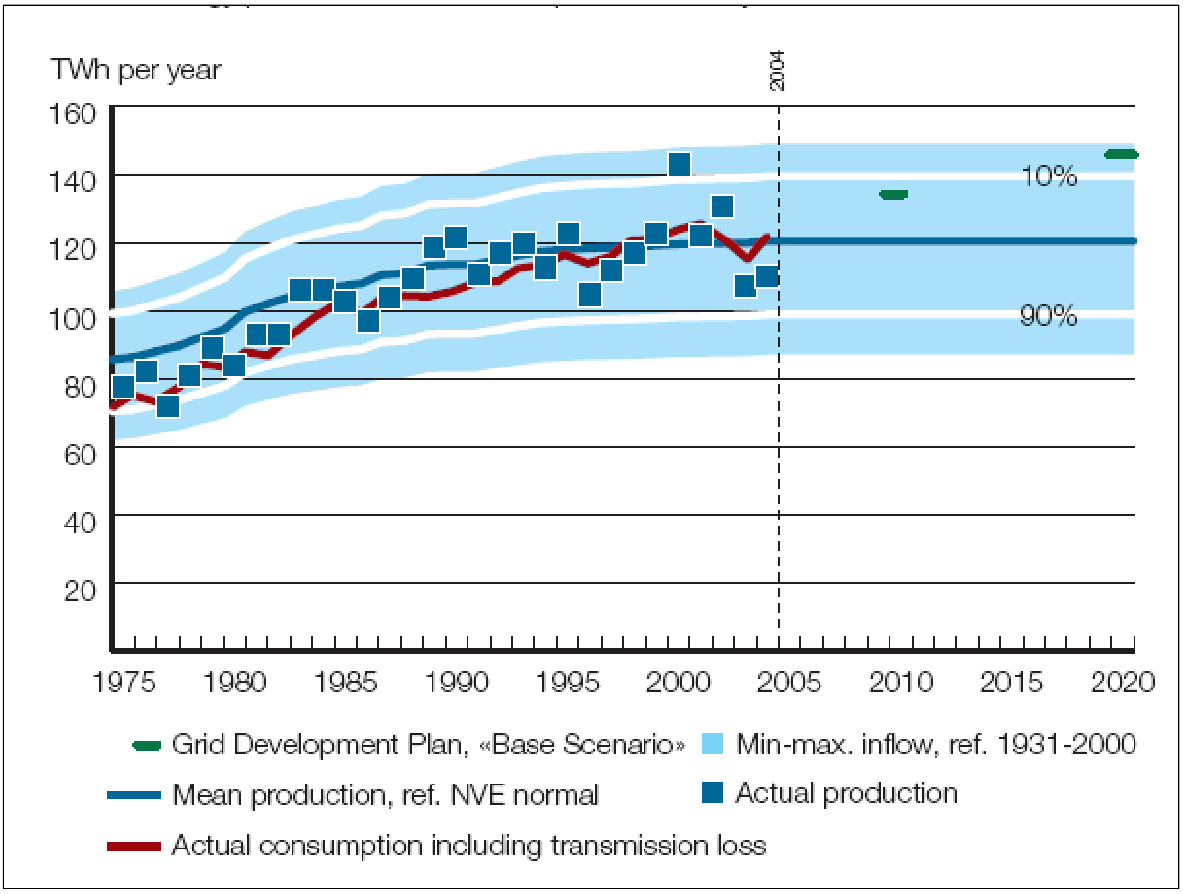
According to figure 6.2, variability of water supply in Norway within 10% - 90% confidence interval is about 40.000 GWh/year of Total Power Production Capability of 120.000

GWh/year. Assuming NorNed transmission capability of 5000 GWh/year this amounts to 12,5% of the variability.

Assuming the same circumstances for the Icelandic Power System with Power production capability of 17.000 GWh/year, the variability would be 5.600 GWh/year, so by the same utilization as in Norway then IceNed transmission would be 700 GWh/year.

Now it is known that installed hydro power in the Norwegian power system is relatively higher and more abundant than in the Icelandic Power System. We therefore estimate the available excess energy for the IceScot submarine power cable in the Icelandic Power system to be **500 GWh/year**, equivalent to capacity of ca 70 MW.

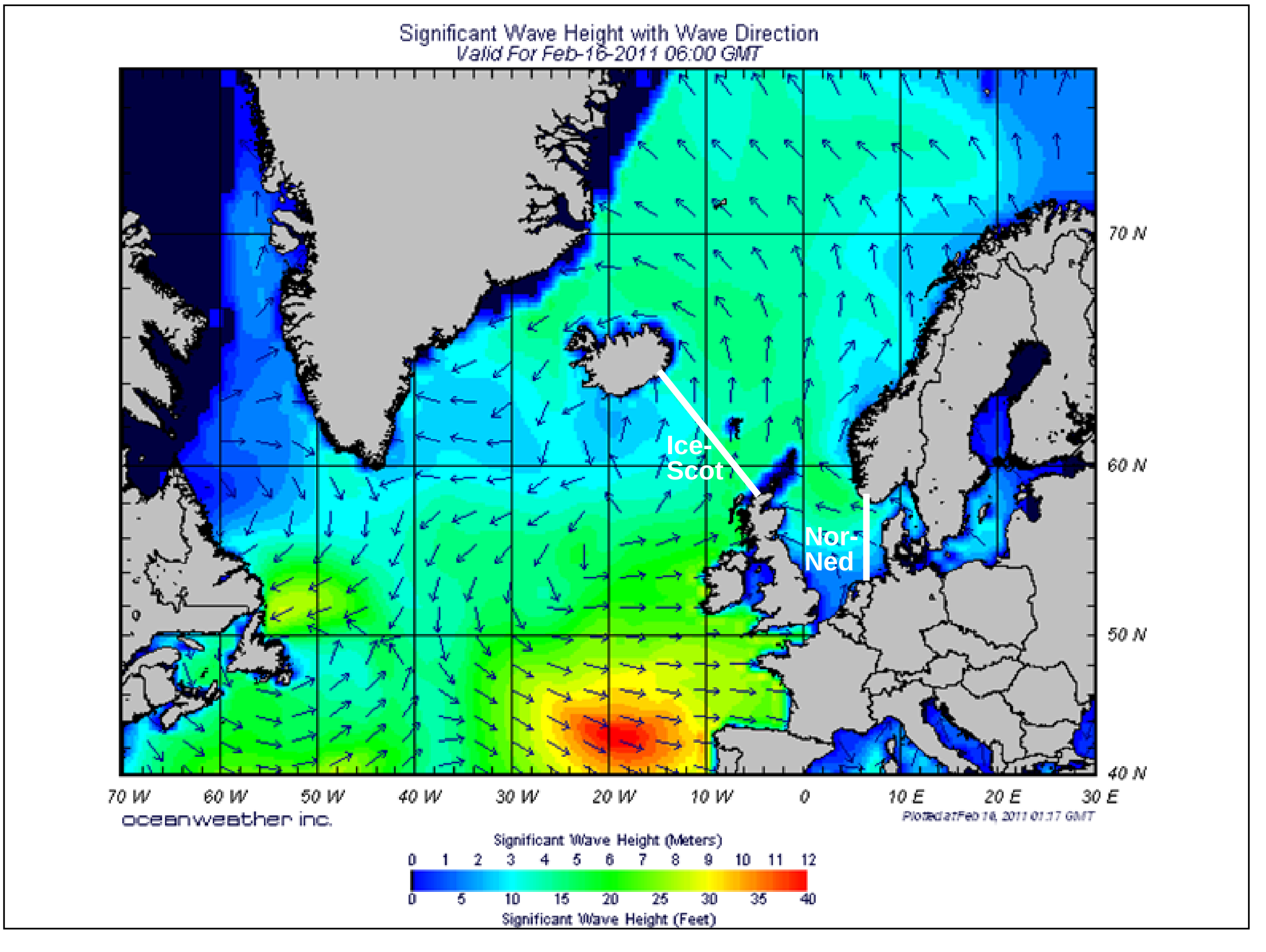
Figure 6.2. Energy Production and Consumption in Norway [09].



7. Operation of and Feasibility of IceScot

Wind driven ocean waves have much effect on repair of submarine cables both cost- and time wise. Figure 7.1 shows a snapshot on Feb-16-2011 of ocean wave heights in the North-Atlantic where Ice Scot will traverse between Iceland and Scotland and ocean wave heights are between 3 and 6 meters. In the North Sea at the location of NorNed the wave heights are significantly lower or between 0 and 3 meters. This is only a snapshot and further studies are needed on impact of ocean waves on the IceScot cable, both during initial cable laying and subsequent operation and maintenance. See chapters 4 and 5 for further discussions on the subject.

Figure 7.1. Wave height in the North Atlantic

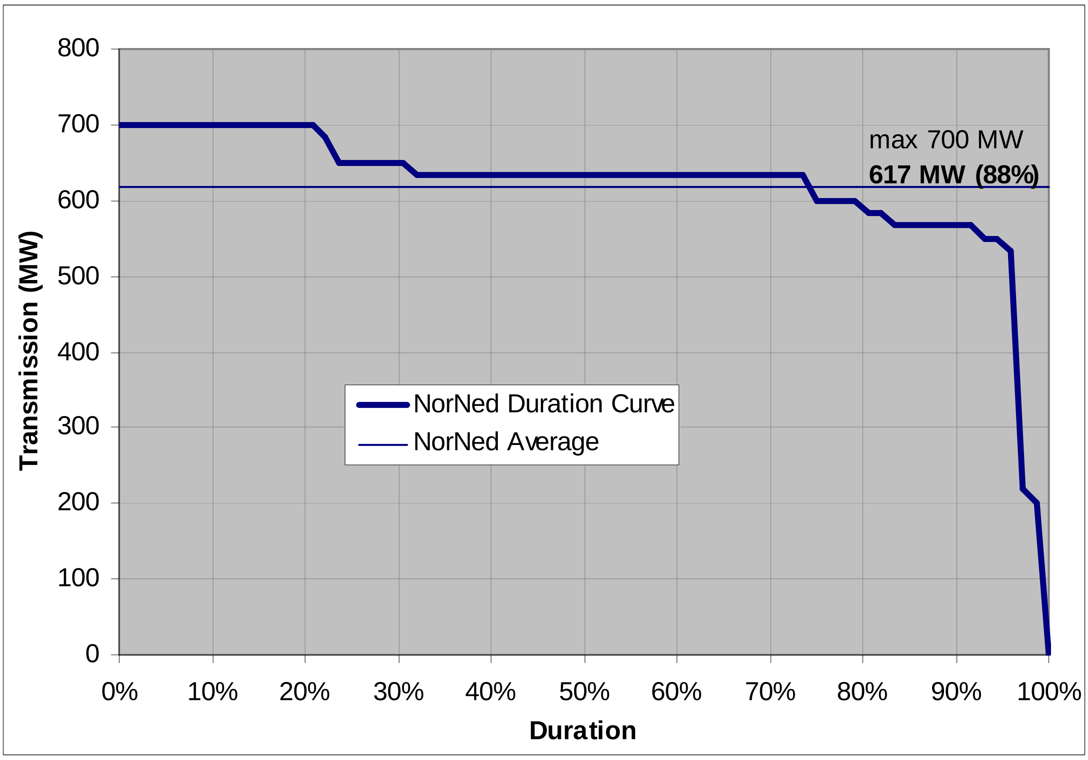


Study of waves is crucial for successful laying and operation of a submarine power cable. Waves on the surface of the ocean are primarily generated by winds blowing over the water surface. Wave height in the North Atlantic Ocean is often larger than in marginal seas as the Baltic Sea or the Mediterranean. Waves are composed of fresh wind waves, swells from far away and freak waves (also called ‘monster waves’ or ‘rouge waves’). Significant wave height is defined as the average wave height of the highest third of all waves. [06]

Cable Laying Vessels react to a given wave spectrum and the vessel response very much depends on wave characteristics. It defines the forces on the ship during cable laying and repair and also defines the forces the cable must withstand and the armoring needed to obtain the necessary cable strength.

According to Figure 7.2, utilization of NorNed has been 88%. This utilization takes account of preventive maintenance. Transmission of IceScot must be of similar magnitude to achieve economic effectiveness of NorNed. This can only be done by building new power stations in Iceland as needed for that purpose.

Figure 7.2. NorNed Transmission



Given energy price of 16,57 USD/kWh for NorNed transmission in chapter 6 and utilization of the IceScot cable would be similar to NorNed, then cost of transmission would be:

$$IceS\cot TransmissionCost = 16{,}57 \cdot \frac{2100 MUSD}{900 MUSD} \cdot \frac{700 MW}{600 MW} = 45 \cdot USD / MWh$$

To this value we would need to add extra cost related to project risks. Further studies shall have to be performed for that purpose.

This value of 45 USD/MWh is only a reference value but elsewhere in the report we calculate the base IceScot transmission cost as 53,65 USD/MWh.

8. The Faroe Islands

As shown in the following discussion on the electrical power situation the Faroese have not been showing much interest of receiving power from Iceland by submarine power cable. In this report we will therefore not consider a landfall in the Faroe Islands but some discussion on the electrical power situation in the Faroe Islands could be interesting.

8.1 The 2007 study

In 2007 a preliminary study on “Preliminary assessments of potential to lay the power cable from Iceland to Faroe Islands” was made in the Faroe Islands in 2007 [03]:

> *“Price trends of oil and general awareness of greenhouse gas emissions, has again breathed life into the idea of exploring the possibility of importing electricity through submarine cable from Iceland to the Faroe Islands, as one among other options to replace large parts of the oil-based energy with renewable energy sources.”*

The 2007 study was to identify if the IceFar was technically and legally possible and it is.

In a report a cable with transmission capability of 100 MW costing ca 350 MUSD was considered, see table 8.1.

Table 8.1
Cost of delivered electrical power in the Faroe Islands
from a submarine cable from Iceland

Delivered energy (GWh/year)	Cost of outfeed Power in the F.I (USD/MWh)
350	160
500	125
700	100

Costs of outfeed power in the Faroe Islands are approximate as they have not beed adjusted to currency changes from 2007 to 2010. Currency rate of 5,57 DDK/USD was used to convert results tos USD.

According to the study competitive costs from other energy sources in the Faroes are:

Wind Energy	70 USD/MWh
Oil based el production	110 USD/MWh

New estimates of production costs for Wind and Oil based energy are in Appendix A2.

8.2 The Sep 2010 energy conference

28.-29. Sep 2010 in Torshavn the capital of the Faroe Islands a conference on was arranged by a working group of the Nordic Council of Ministers on ‘Sparsely Populated Areas’. The energy situation of the islands was in focus.

The driving force in development of the energy system in the Faroe Islands is the political objective that CO_2 emission should be reduced by 20% in 2010 compared to 2005. Two paths are there to go:

- Reduce energy demand, by better insulation of houses etc
- Reduce use of fossil fuel for electricity production, by replacing diesel oil production by green energy etc.

The Faroese seem to be determined to solve their energy situation by windmill electrical energy production accompanied by pumped water storage. The pumped storage system would produce needed electrical energy in times of too little wind and also provide much needed kinetic energy to stabilize the power system.

Residential heating would be solved by remotely controlled in-house electrical heat storage. Geothermal heat pumps are not gaining the momentum that was expected in 2007.

A submarine electrical power cable from Iceland was only briefly mentioned at the conference and it is also to be noted that the IceFar cable has hardly been mentioned locally since the 2007 study.

It is interesting to note that Russian nuclear technology for solution of the Faroe Islands energy situation has been seriously discussed. The nuclear alternative was briefly mentioned at the conference.

Neighboring countries of Iceland and the Faroe Islands, where nuclear energy is used for generating electricity include UK, Sweden and Finland. The fact that nuclear power has neither been mentioned in Norway nor in Iceland is that these countries still have access to abundant, unutilized and still economical hydro and geothermal renewable energy resources for electricity production. Unfortunately the Faroese do not.

Both IceFar and the nuclear alternative are ideas probably classified as unrealistic by the present Faroe energy administration. But both the alternatives could be valuable as brainstorming ideas, if only for discussion purposes

In appendix 2 the 25 MW Hyperion Power Module (HPM) is discussed. It would be interesting to see how it compares with Submarine Power Cable from Iceland, local Wind Mills and Pumped Hydro or the conventional Diesel Power Plant.

Appendix 1. Cable types in the NorNed submarine cable

For reference see [11].

Length 2 x 155 km
Weight: 37,5 kg/m

Length 270 km
Weight: 85 kg/m

Appendix 2. Cost Analysis

To determine the economic characteristics of different technologies of power production we use the concept of levelized costs.

Levelized costs represent the present value of the total cost of building and operating a generating plant over its financial life, converted to equal annual payments and amortized over expected annual generation from an assumed duty cycle, impact of general inflation removed. Levelized cost reflects overnight capital cost, fuel cost, fixed and variable O&M cost, financing costs, and an assumed utilization rate for each plant type. The availability of various incentives including resources taxes, CO_2 taxation and state or federal tax credits will also impact the calculation of levelized costs. [08]

In the following chapters Levelized costs are determined for:

- Geothermal Power
- Hydro Power
- Nuclear Power
- Coal Power Plants
- Natural Gas Power Plants

And related to this particular study:

- Transmission in Iceland
- IceScot Submarine Power Cable

A2.1 Geothermal Power

Table A2.1.1 Levelized Costs for Geothermal Power

5 MW KAPS Geothermal Power Plant in Iceland			21.03.2011 / SJ	
COST ESTIMATES	Value	Unit	Comments	
Feasibility Studies	2.000.000	USD		
KAPS 5 MW Unit	6.750.000	USD		
1 Borehole	2.500.000	USD		
Additional Infrastructure	2.250.000	USD		
Total Capital Costs	13.500.000	USD		
MW Specific Cost	3.000.000	USD/MW		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	30	years		
Installed Capacity	5	MW		
Parasite Power	-0,5	MW	-10%	of Installed Cap
Netto Production	4,5	MW		
Power Production Capability	36	GWh/á		
Utlization	8000	klst/ári		
CALCULATIONS & RESULTS				
Demolition at end of lifetime	202.500	USD	1,50%	of Capital Costs
Yearly Costs				
Capital Costs	983.322	USD/year	7,28%	of Capital Costs
Operation & Maintenance	270.000	USD/year	2,00%	of Capital Costs
Grid Input	37.220	USD/year	Landsnet Tariff	
Resources Tax in Iceland	37.440	USD/year	1,04	USD/MWh
Sum Production Cost	1.327.982	USD/year		
Production Specific Cost	36,89	USD/MWh	for Icelandic market	
Cost of Transmisson loss to Europe	2,95	USD/MWh	8%	Transmission loss
European Specific Cost	**39,84**	**USD/MWh**	for European market	

Geothermal is assumed single flash type.

Cost of 5 MW KAPS is from manufacturer and installation is included and borehole cost is based on Icelandic experience. Geothermal costs are highly site-specific mostly based on drilling success.

Included in additional infrastructure is including and not limited to land acquisition, geological, geophysical and geochemical feasibility studies, remote location issues, civil infrastructure, grid connection, financial costs, management, other owner’s costs.

A2.2 Hydro Power

Table A2.2.1 Levelized Costs for Hydro Power

55 MW Hydro Power Plant in Iceland				21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Comments	
HPP Hydro Power Plant 80 MW	185.625.000	$		
MW Specific Cost	3.375.000	$/MW		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	40	years		
Installed Capacity	55	MW		
Power Production Capability	402	GWh/year		
Utilization	7313	hours/year		
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	18.562.500	$	10,00%	of Capital Costs
Yearly Costs				
Capital Costs	12.456.865	$/year	6,71%	of Capital Costs
Operation & Maintenance	1.856.250	$/year	1,00%	of Capital Costs
Grid Input	37.220	USD/year	Landsnet Tariff	
Resources Tax in Iceland	418.304	USD/year	1,04	USD/MWh
Sum Production Cost	14.768.638	$/year		
Production Specific Cost (Iceland)	36,72	USD/MWh	Input to a Grid Substation	
Cost of Transmisson Loss to Europe	2,94	USD/MWh	8%	Transmission loss
Production Specific Cost (Europe)	**39,66**	**USD/MWh**	for European market	

This hydro power plant is assumed to represent a (non-existing) typical Hydro Power Plant in Iceland.

A2.3 Nuclear Power

Table A2.3.1 Levelized Costs for Nuclear Power

25 MW Hyperion Power Module				21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Lifetime	Unit
25 MW GenSet and Auxiliaries	30.000.000	USD	30	Years
Hyperion Module	50.000.000	USD	10	Years
Net Pres.value of 3 HPM Modules	93.509.975	USD	30	Years
Demolition Costs at end of lifetime	450.000	USD	1,50%	of Capital Costs
Initial MW Specific Cost	2.857.143	USD/MW		
ASSUMTIONS				
Interest rates	6%	yearly		
Installed Capacity	28	MW		
Parasite Power	-3	MW	ca -10%	of Installed Cap
Netto Production	25	MW		
Power Production Capability	200	GWh/year		
Utilization	8000	hours/year		
CALCULATIONS & RESULTS	Value	Unit		
Yearly Costs				
Annuity Payments of GenSet & Aux	2.185.159	USD/year	7,28%	of Genset Cost
Oper & Maint of GenSet & Aux	750.000	USD/year	2,50%	of Genset Cost
Annuity Payments of HPM Module	6.793.398	USD/year	13,59%	og HPM Cost
Oper & Maint of HPM Module	1.000.000	USD/year	2,00%	og HPM Cost
Grid Input Tariff	347.038	USD/year	13.882	USD/MW/year
Sum Production Cost	11.075.595	USD/year		
Production Specific Costs	**55,38**	**USD/MWh**	Input to a Grid Substation	

Nuclear energy currently provides about 17% of the world's electricity power production from 437 nuclear power plants.

Recent trends in development of nuclear power plants have been towards smaller unit sizes as has also been the case for geothermal[1]. For similar nuclear development see for example The Hyperion Power Module (HPM) which is in the category of power reactors known as Small & Modular nuclear power Reactors (SMRs). Reactor Power is 70 MW_t and electrical output 25 MW_e. Uranium enrichment is < 25% and the core is factory sealed with no in-field refueling and closed fuel cycle. At end of use (8-10 years) the fuel will be returned to the factory for fuel and waste disposition. These are very save and secure arrangements.

As for the 5 MW Geothermal KAPS Units the HPM is a Transportable Unit measuring approximately 1.5m wide x 2.5m tall, fits into a standard fuel transport container, transported via ship, rail, or truck, modular design for easy and safe transport.

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[1] Icelanders have taken initiative and the first 5 MW KAPS (KAldara Power System) geothermal power plant will be launched in Kenya in Mar 2011. Serial mass production of KAPS has already started when this is written in Feb 2010.

Each 25 MW_e module will cost 50 MUSD, amounting to 2 $MUSD/MW_e$. The 70 MW_t reactor also produces energy for residential house heating.

In [05] it is stated that Nuclear power is one of the best solutions to environmental public health problems, as well as a necessary and probably central part of any effort to reduce global warming and also that no other technology to produce energy steadily on a large scale has a better safety record than nuclear power.

A2.4 Coal Power

Table A2.4.1 Levelized Costs for Coal Power

650 MW APC Advanced Pulverized Coal				21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Comments	
MW Specific Cost (Overnight)	3.167.000	USD/MW		Overnight Cost
MW Financial costs	570.060	USD/MW	18%	5 years project time
Transmission Investment	92.000.000	USD	1,43	USD/MWh
APC Power Plant 650 MW	2.521.089.000	USD		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	30	years		
Installed Capacity	650	MW		
Power Production Capability	4840	GWh/year		
Utilization	7446	hours/year	85%	Capacity Factor
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	504.217.800	USD	20,00%	of Capital Costs
Yearly Costs				
Capital Costs	189.532.178	USD/year	7,52%	of Capital Costs
Fixed Operation & Maintenance	23.380.500	USD/year	35.970	USD/MW
Variable Operation & Maintenance	20.569.575	USD/year	4,25	USD/MWh
Fuel Costs	153.263.500	USD/year	31,67	USD/MWh
Grid Input	9.022.988	USD/year	13.882	USD/MW/year
CO_2 Tax	58.078.800	USD/year	12,00	USD/MWh
Sum Production Cost	453.847.541	USD/year		
Production Specific Cost	**93,77**	**USD/MWh**	Input to a Grid Substation	

Calculations are based on information from [07] and [08].

Fuel price assumption is 76 USD/ton.

A2.5 Natural Gas Power

Table A2.5.1 Levelized Costs for Natural Gas Power

540 MW Conventional NGCC Natural Gas Combined Cycle				21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Comments	
MW Specific Cost (Overnight)	978.000	USD/MW		Overnight Cost
MW Financial costs	117.360	USD/MW	12%	3 years project time
Transmission Investment	76.500.000	USD	1,40	USD/MWh
NGCC Power Plant 540 MW	667.994.400	USD		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	30	years		
Installed Capacity	540	MW		
Power Production Capability	4115	GWh/year		
Utilization	7621	hours/year	87%	Capacity Factor
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	133.598.880	USD	20,00%	of Capital Costs
Yearly Costs				
Capital Costs	50.218.946	USD/year	7,52%	of Capital Costs
Fixed Operation & Maintenance	8.083.800	USD/year	14.970	USD/MW
Variable Operation & Maintenance	14.115.987	USD/year	3,43	USD/MWh
Fuel Costs	272.854.202	USD/year	66,30	USD/MWh
Grid Input	7.496.021	USD/year	13.882	USD/MW/year
CO_2 Tax	27.161.957	USD/year	6,60	USD/MWh
Sum Production Cost	379.930.913	USD/year		
Production Specific Cost	**92,32**	**USD/MWh**	Input to a Grid Substation	

Calculations are based on information from [07] and [08].

Fuel price assumption is 8,5 USD/mmBTU.

A2.6 Oil based Power

Table A2.6.1 Levelized Costs for Oil based Power

85 MW Conventional CT Combustion Turbine				21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Comments	
MW Specific Cost (Overnight)	974.000	USD/MW		Overnight Cost
MW Financial costs	116.880	USD/MW	12%	3 years project time
Transmission Investment	76.500.000	USD	7,62	USD/MWh
NGCC Power Plant 540 MW	169.224.800	USD		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	40	years		
Installed Capacity	85	MW		
Power Production Capability	680	GWh/year		
Utilization	8000	hours/year		
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	33.844.960	USD	20,00%	of Capital Costs
Yearly Costs				
Capital Costs	11.465.631	USD/year	6,78%	of Capital Costs
Fixed Operation & Maintenance	593.300	USD/year	6.980	USD/MW
Variable Operation & Maintenance	9.996.000	USD/year	14,70	USD/MWh
Fuel Costs	45.238.253	USD/year	66,53	USD/MWh
Grid Input	1.179.929	USD/year	13.882	USD/MW/year
CO_2 Tax	6.907.064	USD/year	10,16	USD/MWh
Sum Production Cost	75.380.177	USD/year		
Production Specific Cost	**110,85**	**USD/MWh**	Input to a Grid Substation	

Fuel price assumption is 110 USD/barrel.

A2.7 Onshore Wind Power

Table A2.7.1 Levelized Costs for Onshore wind Power

67 x 1,5 MW = 100 MW Onshore Wind Farm				21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Comments	
MW Specific Cost	2.438.000	USD/MW		Overnight Cost
MW Financial costs	146.280	USD/MW	6%	1 year project time
Transmission Investment	11.500.000	USD	3,5	USD/MWh
Onshore Wind 100 MW Wind Farm	269.928.000	USD		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	25	years		
Installed Capacity	100	MW		
Power Production Capability	263	GWh/year		
Utilization	2628	hours/year	30%	Capacity Factor
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	26.992.800	USD	10,00%	of Capital Costs
Yearly Costs				
Capital Costs	21.607.572	USD/year	8,00%	of Capital Costs
Fixed Operation & Maintenance	2.807.000	USD/year	28.070	USD/MW
Variable Operation & Maintenance	0	USD/year	0,00	USD/MWh
Fuel Costs	0	USD/year	0,00	USD/MWh
Grid Input	1.388.152	USD/year	13.882	USD/MW/year
CO_2 Tax	0	USD/year	0,00	USD/MWh
Sum Production Cost	25.802.724	USD/year		
Production Specific Cost	**98,18**	**USD/MWh**	Input to a Grid Substation	

Calculations are based on information from [07] and [08].

A2.8 Offshore Wind Power

Table A2.8.1 Levelized Costs for Offshore Wind Power

80 x 5 MW = 400 MW Offshore Wind Farm			21.03.2011 / SJ	
COST ESTIMATES	Value	Unit	Comments	
MW Specific Cost	5.975.000	USD/MW		Overnight Cost
MW Financial costs	537.750	USD/MW	9%	2 years project time
Transmission Investment	103.304.000	USD	5,9	USD/MWh
Onshore Wind 400 MW Wind Farm	2.708.404.000	USD		
ASSUMTIONS				
Interest rates	6%	yearly		
Economic Lifetime	25	years		
Installed Capacity	400	MW		
Power Production Capability	1402	GWh/year		
Utilization	3504	hours/year	40%	Capacity Factor
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	270.840.400	USD	10,00%	of Capital Costs
Yearly Costs				
Capital Costs	216.806.088	USD/year	8,00%	of Capital Costs
Fixed Operation & Maintenance	21.332.000	USD/year	53.330	USD/MW
Variable Operation & Maintenance	0	USD/year	0,00	USD/MWh
Fuel Costs	0	USD/year	0,00	USD/MWh
Grid Input	5.552.608	USD/year	13.882	USD/MW/year
CO_2 Tax	0	USD/year	0,00	USD/MWh
Sum Production Cost	243.690.696	USD/year		
Production Specific Cost	**173,87**	**USD/MWh**	Input to a Grid Substation	

Calculations are based on information from [07] and [08].

A2.9 Transmission in Iceland

Table A2.9.1 Levelized Costs for Transmission in Iceland

320 km 440 kV transmission line in Iceland			21.03.2011 / SJ
COST ESTIMATES	Value	Unit	Comments
Ttransmission line specific cost	1.100.000	USD/km	
Length of transmission line	320	km	
Transmission Line Cost	352.000.000	USD	
ASSUMTIONS			
Interest rates	6%	yearly	
Economic Lifetime	35	years	
Capacity Assumption	600	MW	
Power Production Capability	4389	GWh/year	
Utilization	7315	hours/year	83,5% Capacity Factor
CALCULATIONS & RESULTS	Value	Unit	
Demolition at end of lifetime	35.200.000	$	10,00% of Capital Costs
Yearly Costs			
Capital Costs	24.594.678	$/year	6,99% of Capital Costs
Operation & Maintenance	5.280.000	$/year	1,50% of Capital Costs
Sum Production Cost	29.874.678	$/year	
Transmission Specific Cost	**6,81**	**USD/MWh**	

A2.10 IceScot Submarine Power Cable

Table A2.10.1 Levelized Costs for IceScot Submarine Power Cable

600 MW IceScot Submarine Power Cable			21.03.2011 / SJ	
COST ESTIMATES	Value	Unit	Comments	
Length of Submarine Power Cable	1.070	km		
Length specific Cost	1.962.617	USD/km		
MW Specific Cost	3.500.000	USD/MW		
Submarine Power Cable	2.100.000.000	USD		
ASSUMTIONS				
Interest rates	6,0%	yearly		
Economic Lifetime	40	years		
Installed Capacity	600	MW		
Power Production Capability	4389	GWh/year		
Utilization	7315	hours/year	83,5%	Capacity Factor
CALCULATIONS & RESULTS	Value	Unit		
Demolition at end of lifetime	210.000.000	USD	10,00%	of Capital Costs
Yearly Costs				
Capital Costs	140.926.148	USD/year	6,71%	of Capital Costs
Operation & Maintenance	94.500.000	USD/year	4,50%	of Capital Costs
Sum Production Cost	235.426.148	USD/year		
Production Specific Cost	**53,64**	**USD/MWh**		
Energy Market Price	80,50	USD/MWh	50,1%	Uplift
Sales Income	353.295.180	USD/year		
Payback Period	**12,3**	**years**		
IRR Internal Rate of Return	**12,19%**	**yearly**		

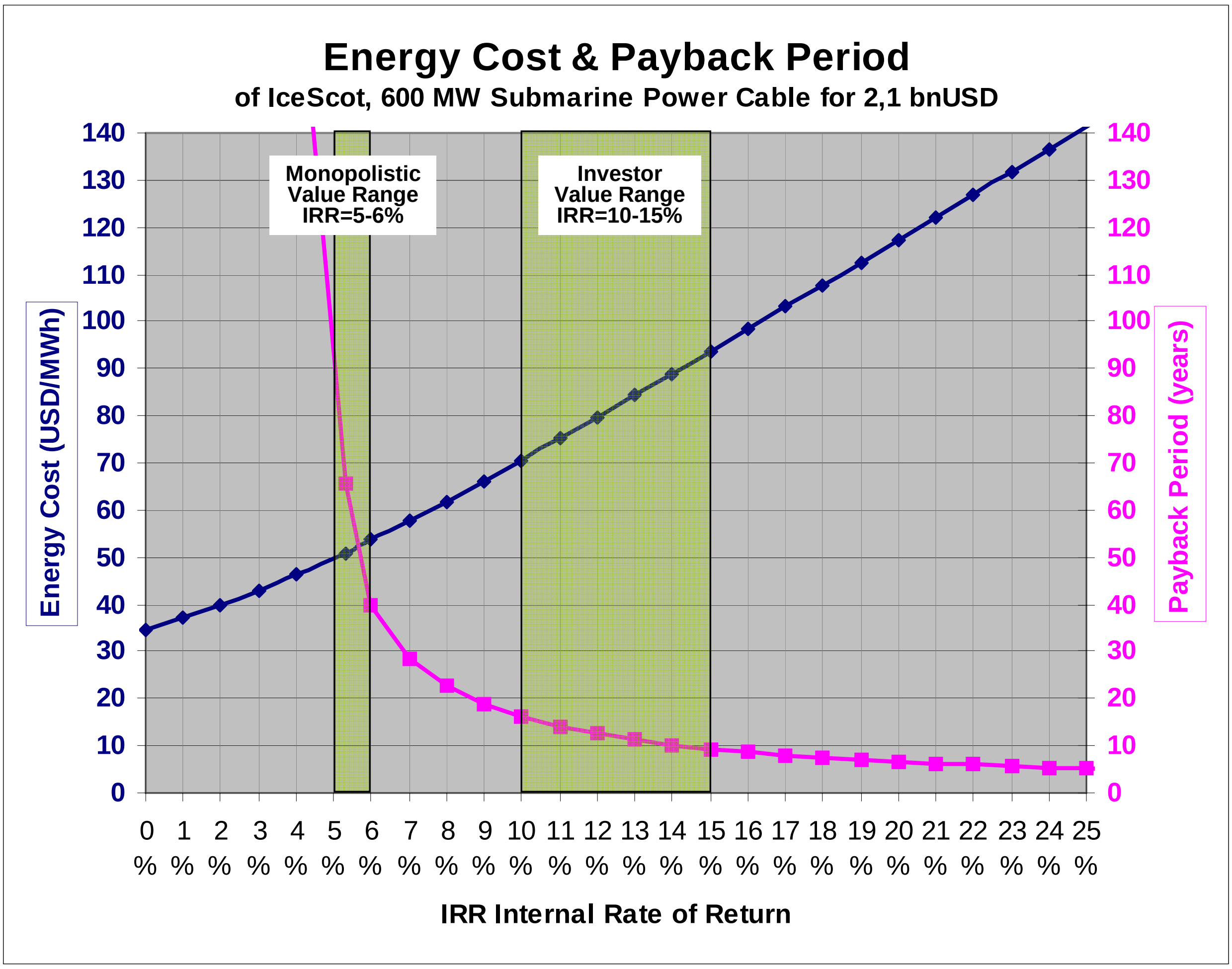
Production cost is assumed 53,65 USD/MWh according to assumptions of 6% interest rate and 40 years of lifetime. The interest rate is long term, low risk (= public bonds).

Similar assumptions have traditionally been used by the monopolies of the power business in Iceland for the past decades, i.e. interest rates between 5% and 6% and lifetime of 40 years. This is shown leftmost in figure A2.10.1 where 6% IRR corresponds to lifetime of 40 years.

It could be argued that the submarine cable should be built by a separate company, owned by investors, may it be domestic and/or foreign investors. These investors, driven by private financing rate depending on project risk assessment, are likely to insist on an IRR Internal Rate of Return higher than 5-6%. In figure A2.10.1 we assume investor request of 10-15% IRR with corresponding payback period of 16 to 9 years and required energy prices of 70-94 USD/MWh. Table A2.10.1 shows a case with Energy sales price of 80,50 USD/MWh giving IRR = 12,8% and Payback period of 12,3 years. Working with one number let us assume a require energy price for the submarine power cable of 80,50 USD/MWh. This is equivalent of 80,50/53,65 - 1 = 50% uplift as used in Chapter 1 Summary.

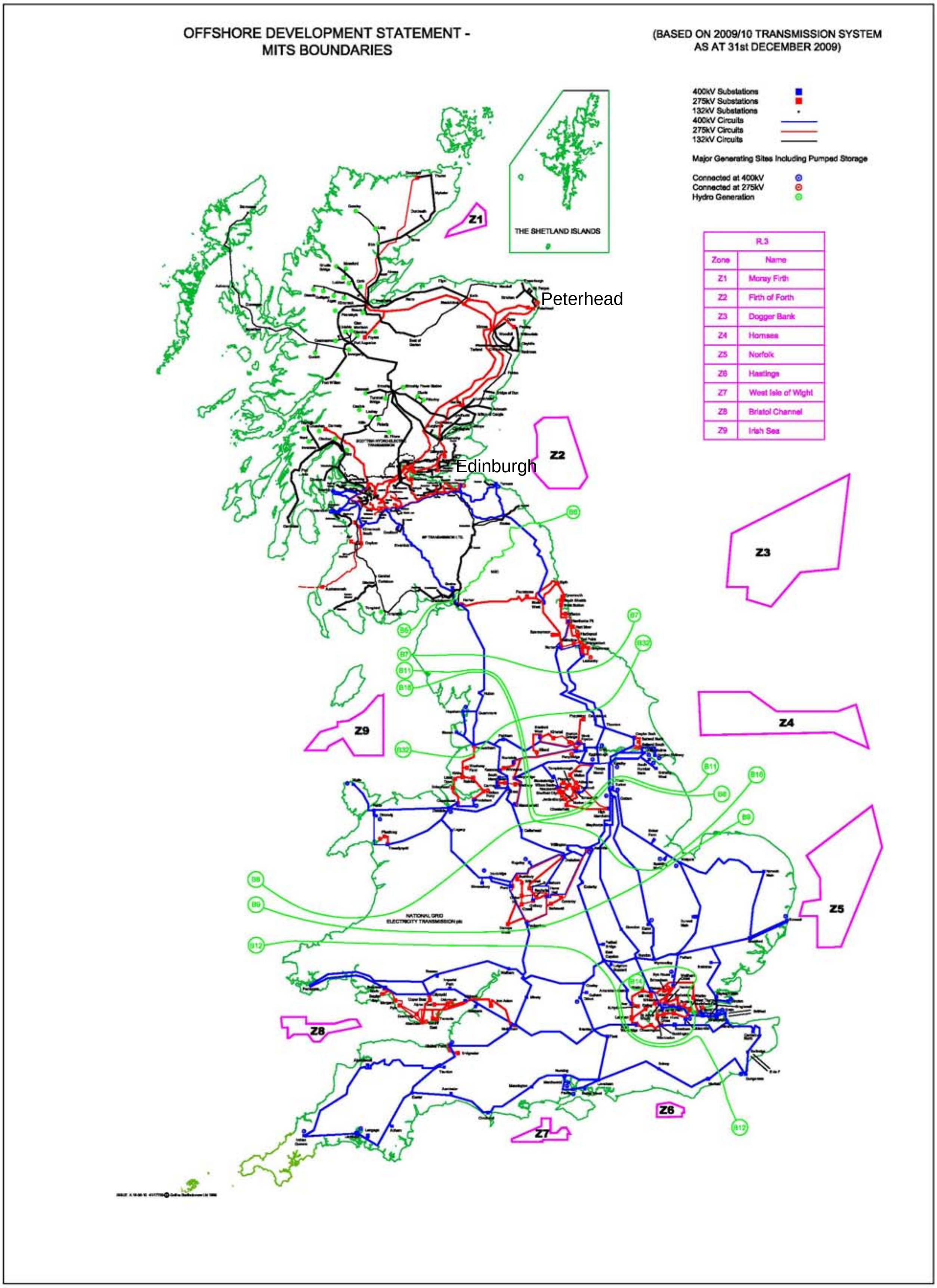
Pricing the submarine cable this way is driven by the approach that if something unforeseen would happen, i.e. price competition from nuclear energy in the European Market, then there would be a substantial risk of driving the cable out of business and in such case it would be idle. This is different with power plants and transmission lines in Iceland that would be qualified to be used for other purposes.

Figure A2.10.1



Appendix 3. UK Transmission System

See [12]



R.3	
Zone	Name
Z1	Moray Firth
Z2	Firth of Forth
Z3	Dogger Bank
Z4	Hornsea
Z5	Norfolk
Z6	Hastings
Z7	West Isle of Wight
Z8	Bristol Channel
Z9	Irish Sea

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