HVDC capacity study between Finland and Sweden

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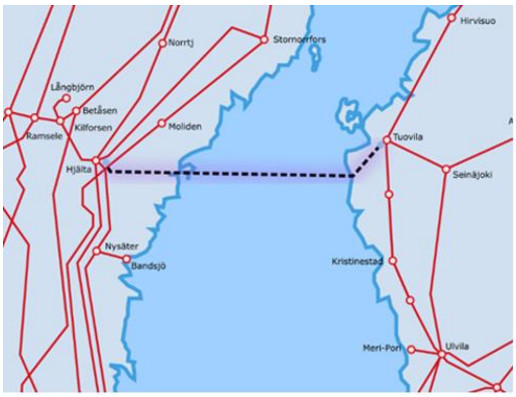

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SVENSKA KRAFTNÄT

FINGRID

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1 Summary

Svenska kraftnät and Fingrid have prepared a joint study to analyse the possibility of installing a new HVDC connection to replace the existing Fenno-Skan 1 connection, as was recommended in the previous cross border study at 2016. Also, based on the findings in the previous study, additional studies were ordered to estimate the possibilities to use the Fenno-Skan 1 cable as a metallic return current path for Fenno-Skan 2 connection even after decommissioning of Fenno-Skan 1 connection.

For the new connection, two alternatives were examined:

- Kvarken, 800 MW HVDC connection between SE2 and FI,
- Fenno-Skan, 800 MW HVDC connection between SE3 and FI.

Grid studies were performed to investigate the feasibility of integrating the alternatives into the system. Only the Kvarken alternative was found feasible without additional internal reinforcements due to fault ride through (FRT) issues with the Fenno-Skan alternative.

A technical study found it possible to use the Fenno-Skan 1 cable as a return current path for the Fenno-Skan 2 connection even after the decommissioning of Fenno-Skan 1 converter stations, thus avoiding additional investments for a new return current cable for Fenno-Skan 2.

The routing, environmental aspects and permissions for the both alternatives have been investigated and both alternatives were found to be almost equally feasible in this respect, based on present information. Additionally, it was noticed that with the Kvarken alternative the Swedish connection point could possibly be changed from Hjälta to Stornorrfors. That would shorten the connection by almost 100 km and reduce the investment cost up to 25%, in addition the environmental impact would be significantly lower for the Kvarken alternative. However, more thorough grid studies would be needed to confirm if that change of connection point is possible

In the market studies, the socio-economic benefits of the two HVDC alternatives were evaluated from a Nordic perspective, both in monetary and qualitative terms. The results indicated that a new HVDC connection between Sweden and Finland is beneficial. However, the market benefits are mainly seen in the 2040 situation, while the benefits in 2030 situation are rather modest. In 2029, Fenno-Skan 1 connection has been operating 40 years, which is considered as typical life-time of an HVDC connection. To evaluate the possibility to extend the life-time beyond 40 years, an assessment about the measures, their costs and risks to extend Fenno-Skan 1 life-time shall be performed, in order to find the most economical timing to replace it with a new HVDC connection.

As a summary, it would be good to analyse the above mentioned issues and also follow how the electricity market situation is developing compared to current estimation for 2030. When more information is available, this study should be updated to be a basis for future investment decisions. In this way, the uncertainty would be reduced concerning the future benefits, the remaining lifetime of Fenno-Skan1 as well as the feasibility of an alternative routing for the Kvarken alternative.

2 Introduction

2.1 Background

Finnish and Swedish TSO's had a joint study to investigate future cross-border capacities between Finland and Sweden, and the study was published October 2016. The main result from that study was to increase the cross-border transmission capacity by adding the 3rd AC-line between SE1 and Finland.

In addition, it was found to be beneficial to install a new HVDC-connection between Sweden and Finland to replace the existing Fenno-Skan 1 connection. By 2029, Fenno-Skan 1 has been operational for 40 years, which is considered as typical life-time of an HVDC system. Of the HVDC alternatives, the Kvarken connection between SE2 and Finland was found to be technically more advantageous than adding a HVDC in parallel with Fenno-Skan 2 connection between SE3 and Finland. However, due to uncertainties regarding the possible solution required to arrange metallic current path for Fenno-Skan 2 return current, it was uncertain which one of the alternatives has a higher socio-economic benefit.

As a conclusion, it was found necessary to have further studies concerning the solution for Fenno-Skan 2 return current path, the technical and system related issues for the HVDC alternatives and to confirm the socio-economic benefit.

The Nordic Grid Development Plan 2019 project was started at 2017, and the aim of that project is among other things to include introduction and evaluation of possible new transmission lines (as so called "bilateral studies"). It was decided to include the Kvarken/Fenno-Skan connection to that plan as a bilateral study between Fingrid and Svenska kraftnät.

2.2 Scope

2.2.1 Studied alternatives

As mentioned above, there are two HVDC alternatives to compare, the Kvarken between SE2 and Finland and Fenno-Skan between SE3 and Finland. Both alternatives are expected to have a capacity of 800 MW in this study, even though the size of the actual connection might be different due to available technology at the time of investment.

2.2.2 Assumptions and limitations

The most important assumptions and limitations are listed below:

- The market simulations were performed for the 2030 and 2040.

- The market simulations were based on the common Nordic scenario developed by all Nordic TSO's in a joint project.
- The commissioning of the new HVDC and the de-commissioning of the Fenno-Skan 1 HVDC are both assumed to take place in the beginning of the year 2029.
- Therefore, from 2029, the net transfer capacities between Finland Sweden are assumed to be:
    - 2000/2000 MW between Finland and SE1 in both Kvarken and Fenno-Skan HVDC alternatives, and
    - 800/800 MW between Finland and SE2 and 800/800 MW between Finland and SE3 in Kvarken alternative or
    - 0/0 MW between Finland and SE2 and 1600/1600 MW between Finland and SE3 in Fenno-Skan alternative.
- The net transfer capacities within Sweden were set to:
    - 3300/3300 MW between SE1 and SE2 for the 2030 and 4300/4300 MW for the 2040[1].
    - 7800/7800 MW between SE2 and SE3 for the 2030 and 10500/10500 for the 2040. The increase is motivated by the strategic decision taken by Svenska kraftnät's board in May 2018 to upgrade existing 220 kV lines in cross section 2 to double circuit 400 kV lines.
    - 7200/3600 MW between SE3 and SE4 (both 2030 and 2040).
- The net transfer capacity between northern and southern Finland was set to 5000 MW southwards and 3500 MW northwards for the year 2030, due to the decided commissioning of the fifth and planned sixth line of the north-south cross section (P1). For the year 2040, the net transfer capacity was increased by 1000 MW in both directions after the planned seventh line of the north south cross section (P1), to 6000/4500 MW.
- All Swedish nuclear power is assumed to be closed by 2040, and it is covered with a significant increase in wind power.
- In this study, it has been assumed that after Fenno-Skan 1 has been de-commissioned, it still can be used as a metallic return path for Fenno-Skan 2 current. Aspects related to this assumption are discussed in Chapter 4.2. This is a major difference compared to the previous cross-border study, where it was assumed that a new metallic return path need to be provided to

[1] Even if there currently are no plans to increase this capacity, it was increased in this analysis. This is due to that in the Nordics scenario there were price differences SE1-SE2. In such scenario Svenska kraftnät would likely increase the capacity with for example reactive measures and /or reinvest in new lines with higher capacity when existing lines reach their technical lifetime.

avoid the continuous use of sea electrodes. Therefore, there are no more any investment cost deductions in the Fenno-Skan alternative, opposite to the previous study.

- The day-ahead energy-only market was simulated.
- Power system simulations were performed for the year 2030 and partly also for the year 2040.

Some of these assumptions and limitations were tested by sensitivity analysis throughout the study. For specific details about certain assumptions and scenarios, see chapter 6.2.

2.3 Outline

This study examined the issues raised in the previous cross-border study. The grid studies were performed in order to compare the benefits of the Kvarken alternative and the Fenno-Skan alternative. A technical study with support from external cable design and manufacturing experts was prepared concerning the future of the existing Fenno-Skan cables.

Both HVDC alternatives were simulated in market models, one at a time, to estimate the impact on market benefits, which is the consumer and producer surplus as well as the congestion rent. The socio-economic welfare was set against the estimated investment costs to get an indication of which grid alternative was the most beneficial. Finally, other factors specified to be included in the full CBA analysis were studied for both alternatives (for the CBA content, see chapter 7.1.2).

Route and permitting studies were performed for both alternatives.

3 Grid studies

3.1 Introduction

The two alternatives from section 2.2 were studied from a grid and power system perspective in order to determine if the alternatives were feasible and which reinforcements or other measures would be required in order to realise them.

For the grid alternatives, thermal loading and stability issues were examined in order to determine the reinforcements required. The investment cost for the needed reinforcements were estimated to be incorporated in the total cost for each grid alternative. Fingrid determined the requirements for establishing these connections on the Finnish side, while Svenska kraftnät determined the requirements for the connections on the Swedish side.

The earlier grid studies was completed 2016 in the Cross-border capacity study. In 2018, the Swedish internal North/South study was completed. The conclusion from the study was to replace the old 220 kV-powerlines with new double-circuit 400 kV-powerlines in Sweden as seen in the Figure 1.

The North/South study includes approx. 80 projects divided into 6 packages and will be commissioned 2023-39.

The reinforcements for cross-section SE2-SE3 and the FS area are:

- Betåsen – Hjälta
- Upgrade of Kilforsen – Ramsele
- Hjälta – Odensala
- Kilforsen – Västerås – Hamra (double-circuit)
- Västerås – Karlslund
- Midskog – Borgvik
- Storfinnforsen – Hallsberg

The Grid studies for the SE3-FI alternative were updated based on the completion of the North/South study.

Figure 1 The area of interest for the Swedish internal North/South study

3.2 Alternative SE2-FI, 800 MW HVDC connection

3.2.1 Thermal constraints

For the HVDC connection between SE2 and Finland, the stations Hjälta on the Swedish side and Tuovila on the Finnish side have been considered for reasons described below. See Figure 2 for an overview.

Figure 2 Overview of Alternative Kvarken, an HVDC connection between SE2 (Hjälta) and Finland (Tuovila).

Swedish side

Four operating conditions were examined by varying wind power production such that:

- Future wind power is evenly distributed
- There is no wind power production
- Future wind power is located in the east of Sweden
- Future wind power is located in the west of Sweden

These were implemented in the shared network database.

The thermal loading was examined both with and without the cross-border connection in operation, in order to investigate which network reinforcements were required for establishing the connection, and which could be considered as necessary to fulfil the requirements for the assumptions.

The substation Hjälta was chosen as the connection point on the Swedish side. Hjälta is an important node in eastern SE2, meshing several 400 kV lines in the area. The fact that the grid is well meshed around Hjälta was viewed as an important factor making Hjälta a feasible choice compared to neighbouring substations.

The results from the load flow simulations show that there were two 400 kV branches near Hjälta whose thermal capacities are exceeded regardless of the cross-border connection. These two branches are Kilforsen-Ramsele and Kilforsen-Hjälta. Both branches are parts of a series of lines connecting the eastern and western parts of SE2. The results show that an uneven distribution of generation, load and export could lead to high flows from east to west or vice versa, especially coupled with high transfer from SE2 to SE3. With grid alternative SE2-FI, the thermal capacities of the previously mentioned branches were further exceeded, indicating that reinforcements are needed. See Table 1 for a comparison of the loadings before and after the new grid alternative between SE2 and FI.

Table 1 Comparison of branch loadings for alternative SE2-FI

Branch	Contingency	Worst loading before the connection [%]	Worst loading with SE2-FI alternative [%]
Hjälta-Kilforsen	Vargfors-Tuggen-Norrtjärn	**103**	**119**
Kilforsen-Ramsele	Långbjörn-Storfinnforsen	**120**	**135**

There was also an issue with transit of power through the 220 kV grid that runs parallel to the line between Kilforsen and Hjälta. When the Hjälta-Kilforsen branch was faulted or taken out of service the power found a path through the parallel 220 kV branches with large over loads as a result. The issue exists even without the implementation of grid alternative SE2-FI but was further worsened by it.

Svenska kraftnät has made a grid study that aimed to address internal limitations in SE1 and SE2. This study was finished during 2018. The issues with thermal overloads described above were addressed in that study. A new branch between Betåsen and Hjälta/Nässe and an upgrade of the Kilforsen-Ramsele branch was proposed together with a number of upgrades of individual switchyard components. The board took a strategic decision of the reinforcements in May 2018. With the proposed reinforcements, the described issues, including the transit through the 220 kV grid, would be resolved and the transfer capacity of 800 MW for alternative SE2-FI would be achievable.

All of the thermal issues that were described above exist regardless of whether alternative SE2-FI is established. The necessary reinforcements should thus be realised regardless. No investment costs associated with the reinforcements should therefore be included for alternative SE2-FI.

In order to avoid having to limit the capacity of the new HVDC connection it is important that the proposed reinforcements are commissioned before the link is taken into service. The reinforcements are scheduled to be commissioned 2027.

The voltage levels around Hjälta were also studied with alternative SE2-FI modelled as a conventional HVDC link, i.e. without additional capacity for reactive power support. The voltage levels were within acceptable limits in all the studied scenarios and contingencies. Very little difference could be seen with the new HVDC connection. This indicates that there is no major need for additional voltage support in the area and a VSC link cannot be motivated purely from the perspective of its capacity for voltage support.

Due to the troublesome routing around Hjälta there might be necessary to study another connection-point on Swedish side instead of Hjälta.

Finnish side

The connection point on Finnish side was determined to be Tuovila. Tuovila is located close to coast and is the only substation with multiple 400 kV line connections on the coast near Kvarken. The 400 kV transmission lines connected to Tuovila are recently built and have high transfer capacity. The thermal loading of the lines was checked with load flow calculation for every hour of the year for the simulated scenarios. With 800 MW capacity, no additional reinforcements are needed. In Finnish "Grid Vision" study, which was performed by Fingrid in 2017, there were studies done for different scenarios in year 2040. Also in these cases reinforcements were only needed if there was more than 800 MW interconnection connected to Tuovila. Also extreme development of wind power in the region combined with Kvarken interconnection could trigger need for reinforcements, but those costs are not appointed to this project.

The voltage levels around Tuovila were also studied with alternative SE2-FI modelled as a conventional HVDC link, i.e. without additional capacity for reactive power support. The voltage levels were within acceptable limits in normal operating conditions. This indicates that there is no major need for additional dynamic voltage support in the area and a VSC link cannot be motivated purely from the perspective of its capacity for voltage support. Still, the changes in the generation portfolio in long term are uncertain and dynamic voltage support could be required in future.

3.2.2 Dynamic constraints

In terms of dynamic constraints, the HVDC connection between SE2 and Finland would not significantly alter the oscillations in the power system. As shown in Figure 3, a 100 ms AC grid fault followed by the loss of Fenno-Skan 2 (FS2) remains the worst contingency when power is transferred from Finland to Sweden through the northern AC connections. The loss of the HVDC connection between SE2 and Finland would clearly have a less severe impact on the system than loss of FS2, as it is located further north than FS2, and is further away from generators which are inclined to swing against each other.

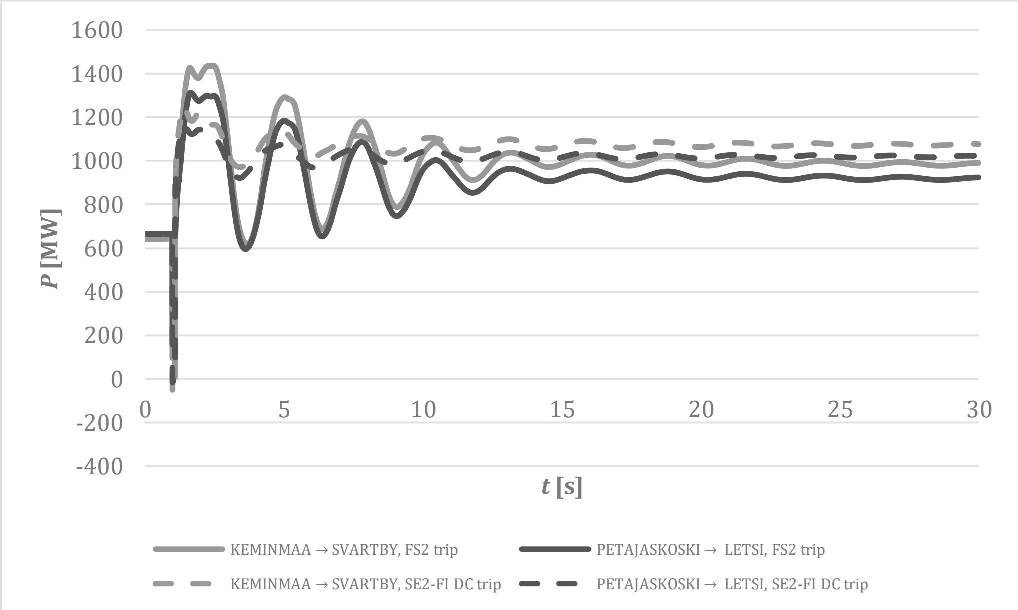

Figure 3 Comparison of transfer on AC border connections after trip of FS2 (solid lines) and trip of SE2-FI HVDC connection (dashed lines).

3.2.3 Summary of alternative SE2-FI, 800 MW HVDC connection

Alternative SE2-FI could be implemented in the grid without any additional reinforcements. On the Swedish side, there are some projects that have to be implemented before the HVDC-link can be used without risking having to limit the capacity after certain faults.

3.3 Alternative SE3-FI, 800 MW HVDC connection

By 2029 the Fenno-Skan 1, which connects Swedish station Dannebo and Finnish station Rauma, has been in operation for 40 years, which is considered as typical life-time of an HVDC system. A natural placement for a new HVDC connection from Finland to SE3 would therefore be between Dannebo and Rauma, as shown in Figure 4.

Figure 4 Overview of Alternative Fenno-Skan, an HVDC connection between SE3 (Dannebo) and Finland (Rauma).

3.3.1 Thermal constraints

Swedish side

In the Cross-border study, the same four operation conditions that have been examined by Svenska kraftnät for alternative SE2-FI have also been examined for alternative SE3-FI. The station Dannebo, north of Stockholm, was studied as a connection point on the Swedish side, for the SE3-FI alternative.

Results from the earlier study was that transfer of power from SE3 to Finland did not lead to any complications in the Swedish network.

Transferring 800 MW power from Finland to Dannebo resulted in a number of overloads, especially if there is a lot of wind power produced in the east of Sweden. The overloads occurred on the lines Hamra – Finnböle, Hamra – Åker and Hedenlunda – Glan.

Since the Cross-border study was published Svenska kraftnät has worked on a strategy for the powerlines crossing SE2 to SE3 in the North/South study. The study also addressed the problems with the estimated increasing loads in Uppsala and Västerås.

In May 2018, the North/South study was finished and the board took a strategic decision for reinvest the existing 400 kV and 220 kV-lines crossing cross section 2 in Sweden. Part of the solution is to strengthen the grid with two new 400 kV-powerlines to Västerås and two new 400 kV-powerlines to Uppsala/Odensala. These four new powerlines will make the situation much better in the area and when these are in operation ~2030, all the overloads mentioned above will disappear.

Finnish side

The West Coast cross-section of Finland is quite heavily loaded already in the base scenarios without new transmission capacity between SE3 and FI. Therefore even a quite modest cross-border capacity increase would trigger the need to reinforce the 400 kV AC network in southwest Finland. The lines Rauma–Lieto and Huittinen-Forssa are heavily loaded in situations where there is transfer from SE3 to FI. If one of those lines trips the loading on the remaining lines exceed the capability of an acceptable range.

A new transmission line between Rauma and Lieto was included in the investment costs in the Sweden Finland capacity study, as it was clearly required to achieve increased HVDC import capacity from Sweden.

Fingrid has studied the triggering factors for internal reinforcements in southwest Finland in an internal long-term grid reinforcement study, which looked at multiple scenarios. In some scenarios, both transmission connections between Huittinen-Forssa and Rauma-Lieto need to be doubled. Power duration curves of those lines are visible in the figures below in case of Fenno-Skan and Kvarken alternatives.

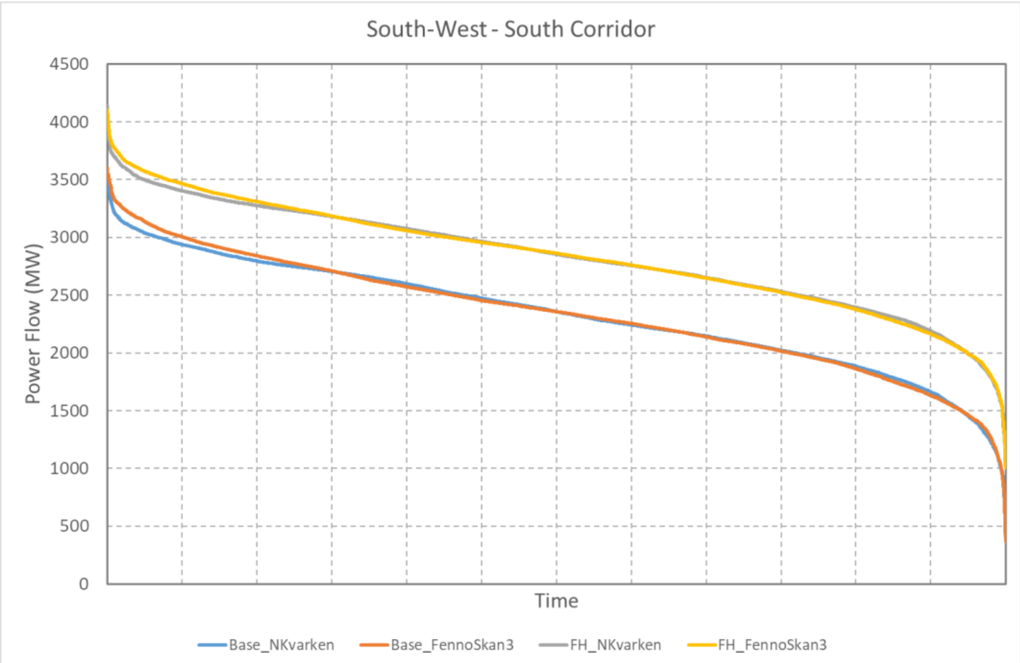

Figure 5 Duration curves of power flow on the southwest – south corridor with different 2030 scenarios.

The Figure 5 indicates that flows on the constrained southwest – south corridor is rather invariant of alternatives Kvarken or Fenno-Skan. The clear difference can be seen with alternative location of generation in Finland (in figure Base vs FH).

Instead, the difference is visible on loadings of the connecting lines of the alternative terminal stations Tuovila and Rauma, see Figure 6 below.

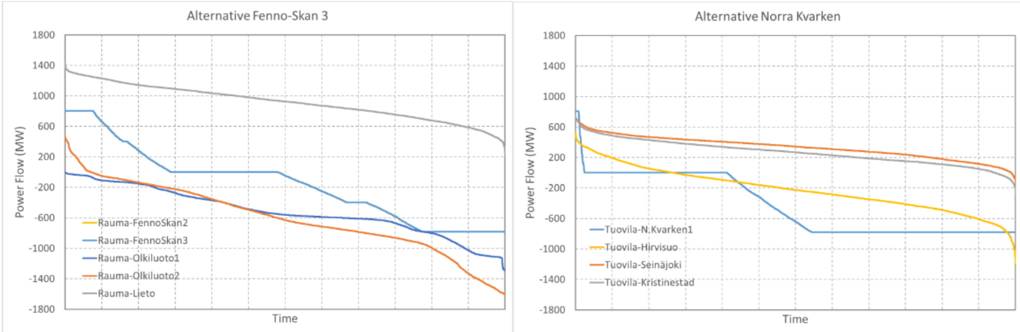

Figure 6 Comparison of duration curves of power transfer on connecting lines of alternative terminal stations Rauma (Fenno-Skan) and Tuovila (Kvarken). Note that in the Fenno-Skan alternative the duration curve of Rauma-Fenno-Skan overlaps completely the curve of Rauma-Fenno-Skan 2.

The connection alternative Kvarken and Tuovila terminal station can well cope with the present configuration the predicted transmission capacity demand. For the Fenno-Skan alternative and Rauma terminal station the existing outgoing AC-lines reach quite high levels of power transfers, so the proposed reinforcement a new Rauma – Lieto line (in parallel of the existing line Rauma – Lieto) is well justified.

3.3.2 Dynamic constraints

Svenska kraftnät's grid codes requirement for fault ride through (FRT) says that a machine must remain connected to the network after a 250 ms three phase short circuit at the nearest meshed transmission network point after a line is tripped.

Previous calculations, based on the grid and production as it is today, showed that the critical clearing time for Forsmark 3 marginally meets the requirements. An increase in the transfer from Dannebo will stress the system even further.

As mentioned in 3.1 a new North/South strategy was decided. This strategy with new 400 kV power lines changes the conditions in the area around Forsmark 3 and Fenno-Skan. Therefore, a new fault ride through study was made in May 2018. The results from the study showed that the reinforcements in the area will make the situation better but it is still restrictions in the area and it is not possible to increase the transfer from Finland to Sweden due to the fault ride through.

3.3.3 Summary of alternative SE3-FI, 800 MW HVDC connection

Alternative SE3-FI could not be implemented in the grid without any additional reinforcements, on the Finnish side Rauma-Lieto must be built. The projects in the North/South study are very vital for the overload conditions in the area. Due to the fault ride through in the area around Dannebo it is not possible to handle increased power transfer above 550 MW on the Fenno-Skan alternative.

3.4 Conclusions from the grid studies

Alternative SE2-FI, 800 MW HVDC connection, was found to be feasible. The alternative required some reinforcements near Hjälta on the Swedish side due to thermal limitations. These reinforcements would, however, be needed regardless of the new connection and were not included in the cost for the alternative. On the Finnish side, no reinforcements were required. From a system perspective, this was found to be better location for a new HVDC connection due to dynamic performance (see chapter 3.2.2).

Alternative SE3-FI, 800 MW connection is not feasible. It would require reinforcements in southwest Finland. A new 400 kV transmission line between Rauma and Lieto in Finland would be needed. When the new powerlines in the North/South strategy in Sweden, nearby Dannebo, are implemented there are no overloads in the area. Due to the fault ride through in the area around Dannebo it is not possible to handle increased power transfer above 550 MW on the Fenno-Skan alternative.

4 Technical review of the HVDC alternatives

4.1 Background and the scope of the review

The joint cross-border capacity study in 2016 provided an extensive review of the technical and technology aspects related both to Fenno-Skan and Kvarken HVDC alternatives. Therefore, the main scope of this study was to address the most relevant recommended action identified in 2016 and to review if there has been such changes in HVDC technology or in relevant configurations, which could have significant impact on the assumptions related to cost components, technical risks and opportunities estimated and identified in 2016.

Considering the target of this capacity study, the main question identified in 2016 with major direct impact on cost-benefit assessment was the use of Fenno-Skan 1 cable either as return circuit of Fenno-Skan 2 monopole or as neutral return circuit of new FS bipole. This chapter concentrates mainly to summarize the outcome of the related conclusions.

4.2 The future use of Fenno-Skan 1 HVDC cable

4.2.1 Background

Fenno-Skan 1 was commissioned in 1989, having the rated power of 500 MW, rated voltage of 400 kV DC and rated current of 1316 A. By 2029, Fenno-Skan 1 has been operational for 40 years, which is considered as typical life-time of an HVDC system. In 2016 study, the feasibility to use Fenno-Skan 1 cable after 2029 as part of Fenno-Skan 2 configuration was identified as the only technology related factor having decisive impact on cost of new HVDC alternatives. Due to complexity of Fenno-Skan 1 cable related technical question, during 2016 study it was not possible to formulate a firm position about the feasibility. Therefore, a need to invest into a new metallic return cable of Fenno-Skan 2 was considered as starting point of analysis in 2016 and consequently the cost of investment was deducted from the planned Fenno-Skan alternative, which inherently removes the need for Fenno-Skan 2 metallic return.

For this study, a third party expert assessment was ordered to ensure that best available information was applied as basis for conclusions. The third party assessment was delivered by a project team consisting of experienced HVDC cable experts with insight to design and manufacturing of relevant HVDC cable technology. The output of that assessment was applied to support the inputs from other sources by the HVDC cable technology experts at Fingrid and Svenska kraftnät.

4.2.2 The main conclusions of the Fenno-Skan1 cable future use assessment

Three main different future use scenarios for Fenno-Skan 1 HVDC cable were studied.

1) The Fenno-Skan 1 cable as metallic return for the Fenno-Skan 2 link.
2) The Fenno-Skan 1 cable as metallic return neutral of a bipolar link with the Fenno-Skan 2 link and a new Fenno-Skan 3 link.
3) The Fenno-Skan 1 cable as redundant main circuit cable for the Fenno-Skan 2 link.

Based on the best available information it was concluded that the Fenno-Skan 1 cable can be successfully used as a return cable for the Fenno-Skan 2 link. Similarly, use as a metallic neutral return circuit of the Fenno-Skan 2 and a possible future Fenno-Skan is considered feasible. However, it appears that similar applications, where HVDC cable would be applied for such use it was not original designed for, do not exist at the moment. This would be the first time for such an application for an existing HVDC cable. Therefore, both of these options involve inherently risks, but based on best available information these are considered either as moderate or minor. The main risks and their consequences are further discussed in section 4.2.3.

The future use of the Fenno-Skan 1 cable as redundant main circuit cable up to operational voltage of 400 kV for the Fenno-Skan 2 cannot be considered feasible because even temporary use of FS1 cable in such manner presents a very high risk of insulation failure. The risk is considered very high especially due to the concerns related to present condition of Fenno-Skan 1, which have resulted into decrease of its present normal operational voltage down to 320 kV.

4.2.3 The main risks related to possible future use of Fenno-Skan 1 cable

The main identified risk in the possible future use of Fenno-Skan 1 as return or neutral cable is short term cable damage from oil over pressure in the cable insulation when operated with 1662 A instead of original rated current of 1316 A. The risk could be higher in case the Fenno-Skan 1 cable is used as Fenno-Skan 2 return cable, than in case it is being used as the neutral return cable of the Fenno-Skan bipole. To understand better the factors affecting this risk and thus to provide further validation for the main conclusions presented in section 4.2.2, tests using Fenno-Skan 1 cable spare lengths are needed.

It must be acknowledged that reusing existing Fenno-Skan 1 instead of using a new cable will inherently somewhat increase the risk of possible outages of Fenno-Skan 2 return cable. The outages may lead into lower availability of Fenno-Skan 2 and may cause additional costs due to cable repairs. In addition to further validation provided the recommended tests, the risk related to outages could be partially managed by using the sea electrode as temporary current path during the possible return circuit failures.

4.2.4 Further clarification needs

In addition to the proposed tests described in section 4.2.3, it was concluded that additional costs related to future use of Fenno-Skan 1 with higher nominal current may be due to need to reinvest to new cable terminations, primary equipment in neutral circuit components at converter stations and the earth cable connecting Dannebo from shore line to the stations. While the cost of these possible changes is minor as compared with the investment cost of a new cable dedicated for use as a metallic return circuit, the feasibility of these components and costs related to possible modification needs should be investigated as part of possible future work.

4.3 Conclusion from technical review

4.3.1 The future use of Fenno-Skan 1 cable

The main result of the assessment is that based on best available information, Fenno-Skan 1 cable can be considered as feasible solution either for Fenno-Skan 2 metallic return circuit or for metallic neutral return circuit of possible new Fenno-Skan bipole. Therefore, the use of existing Fenno-Skan 1 cable as Fenno-Skan 2 return cable shall be the starting point for the cost assessment of any new HVDC system between Finland and Sweden. However, it must be acknowledged that reusing old Fenno-Skan 1 cable involves some technical risks, which investment into a new HVDC cable designed for dedicated metallic return circuit use would not have as discussed in section 4.2.3.

4.3.2 The status review of HVDC technology and relevant configurations

Based on the review done in connection of this work, the assessment related to HVDC technology and relevant configurations presented by the joint cross-border capacity study can be considered still as valid. For converter technology both LCC and VSC options are considered feasible technology options at this stage.

4.3.3 Recommended next actions

The main recommendations related to next actions are based on the assessment of the Fenno-Skan 1 cable feasibility as the metallic return circuit of FS2 or possible new Fenno-Skan bipole configuration. To gain further understanding about main risk related to recommended future use and validate some of the conclusion made during this assessment, laboratory tests for a HVDC cable sample representative for Fenno-Skan 1 cable must be performed. Additionally, as discussed in the section 4.2.3 the impact of the increase in continuous current on feasibility of Fenno-Skan 1 cable accessory components and the neutral circuit primary equipment shall be further investigated.

Depending on the selection of the possible new HVDC interconnector location (SE2-FI or SE3-FI) and the time frame of the investment, more detailed investigations related to end of the life-time of Fenno-Skan 1 converter stations shall be launched. Additionally, it can be concluded that the other main actions related to HVDC technology include but are not limited to the ones identified in 2016 (repeated below):

1. The extent of the refurbishment of Fenno-Skan sea electrode shall be evaluated in case the preferred configuration benefits from use of the Fenno-Skan 1 cable.
2. Necessary technical clarification to determine the measures for managing system security risks (ensuring technical quality) should be started in case the preferred configuration is based on bipolar use of Fenno-Skan 2 and alternative SE3-FI.
3. Clarification about the different approaches affecting the availability of Fenno-Skan 1 as a back-up connection for the period of commissioning, trial and warranty of new possible HVDC connection should be started.

5 Routing and permissions

5.1 Routing and environmental aspects

In this chapter, the routing and main environmental aspects for the two grid alternatives, the Kvarken between SE2 and Finland and the Fenno-Skan between SE3 and Finland, are described.

5.1.1 Finland

The basics of the interconnector route options are shown in Table 2 and in Figure 7. More specific information regarding the essential features within and nearby the suggested Finnish corridors can be found in Appendix 1. The studied routes are to be considered preliminary and are based on a desktop study. The presented environmental data is based on regional land use plans and geographic information systems.

Table 2 Alternatives in numbers.

			Onshore part		Offshore part
		Length (km)	Length (km)	Parallel to an existing transmission line	Length (km)
SE 2 - FI Kvarken	Tuovila-Murtoinen	27	27	27	-
	Murtoinen-Vadbacken	26	26	-	-
	Vadbacken-Korsnäs alternatives				
	Vadbacken-Korsnäs via North	8	8	-	-
	Vadbacken-Korsnäs via South	10	10	-	-
	Korsnäs-EEZ alternatives				
	ALT Kvarken North	69	-	-	69
	ALT Kvarken South via North	81	-	-	81
	ALT Kvarken South via South	82	-	-	82
	Total SE2 – FI Kvarken	**130–145**	**61–63**	**27**	**69–82**
SE3 - FI Fenno-Skan	Lieto-Soukkaperkko	83	83	83	-
	Soukkaperkko-Rauma	9	9	9	-
	Soukkaperkko-Rihtniemi	25	25	25	-
	Rihtniemi-EEZ via North	122	-	-	122
	Rihtniemi EEZ via South	119	-	-	119
	Total SE3 – FI Fenno-Skan via North	**239**	**117**	**117**	**122**
	Total SE 3 – FI Fenno-Skan via South	**236**	**117**	**117**	**119**

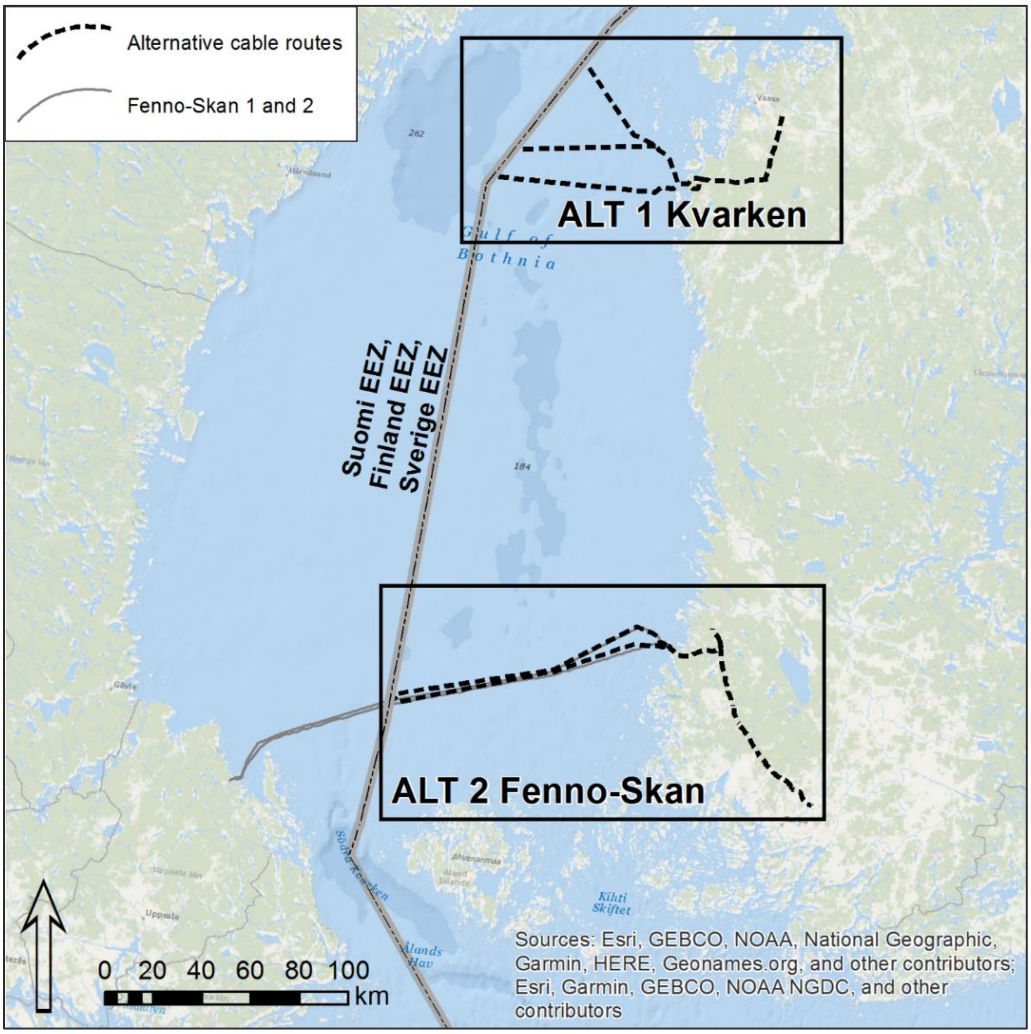

Figure 7 General map of the route alternatives SE2 – FI Kvarken and SE3 – FI Fenno-Skan.

SE2 – FI Kvarken

SE2 – FI Kvarken consists of a transmission overhead line from Tuovila to the coastline of the Sea of Bothnia (Korsnäs) and an offshore cable from Korsnäs to the Exclusive Economic Zone (EEZ) Finland/Sweden (Figure 8). Sub-alternatives have been studied for both onshore and offshore sections. The total length of the Finnish part in alternative SE2-FI Kvarken is 130-145 km depending on the combination of sub-alternatives.

The onshore section is 61 km (via north) or 63 km (via south). From Tuovila to Murtoinen the transmission line route is parallel with existing transmission lines for 27 km. A new infrastructure corridor is needed between Murtoinen and Korsnäs. In this section, two sub-alternatives have been studied between Vadbacken and Korsnäs.

The offshore cable is in a new infrastructure corridor. Three sub-alternatives from Korsnäs to EEZ have been studied: Kvarken North (KN, offshore length 69 km), Kvarken South via north (KSn, offshore length 81 km) and Kvarken South via south (KSs, offshore length 82 km).

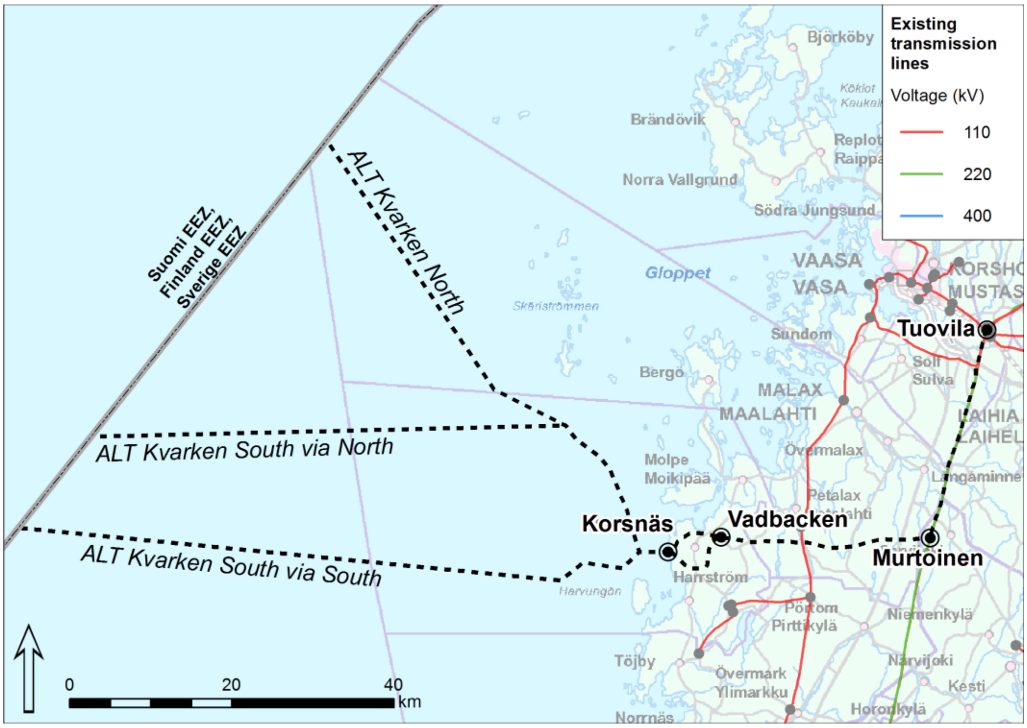

Figure 8 Alternative SE2 – FI Kvarken (transmission line Tuovila – Korsnäs and offshore cable to EEZ).

SE3 – FI Fenno-Skan

SE3 – FI Fenno-Skan consists of a transmission overhead line from Lieto via Rauma to the coastline of the Sea of Bothnia (Rihtniemi) and an offshore cable from Rihtniemi to the EEZ Finland/Sweden (Figure 9). Sub-alternatives have been studied for the offshore section. The total length of the Finnish part in alternative SE3-FI Fenno-Skan is 239 or 236 km.

The onshore section is 117 km. It is parallel to existing transmission lines.

The offshore cable is roughly in parallel with Fenno-Skan 1. The two sub - alternatives studied differ near Rihtniemi: via north (offshore length 122 km) and via south (offshore length 118 km). A route on the south side of the present cables is not included in this study.

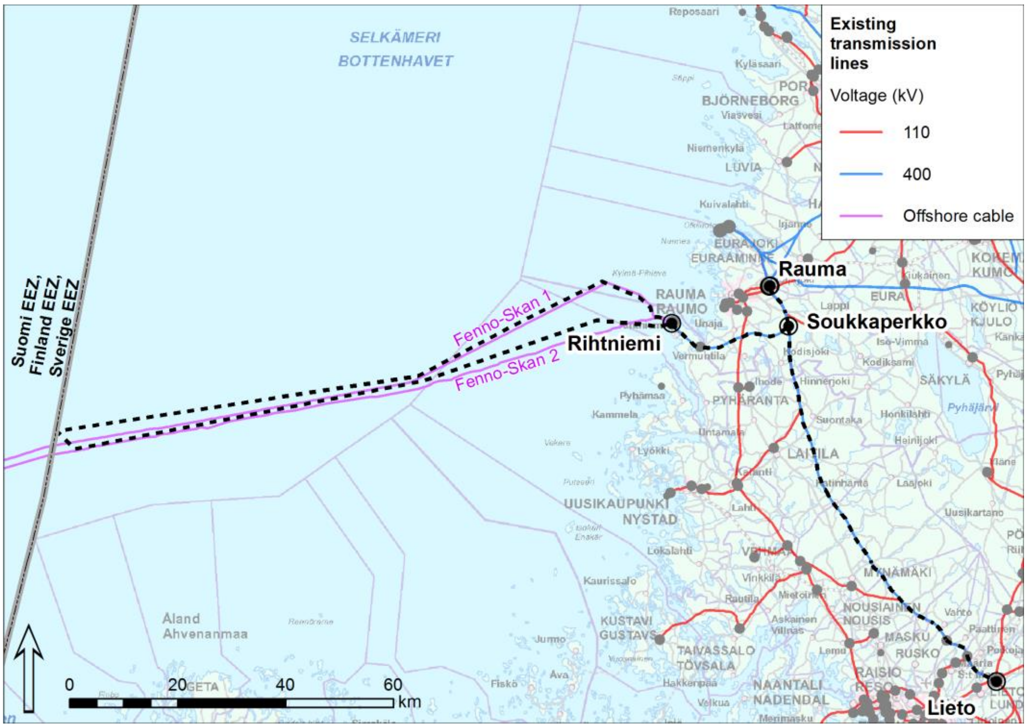

Figure 9 Alternative SE3 – FI Fenno-Skan (transmission line Lieto – Rauma – Rihtniemi and offshore cable to EEZ).

5.1.2 Sweden

The alternative routes, described in the following chapters, are the result of a desktop study based on available geographic information regarding various social and environmental aspects of national, regional or municipal importance.

Several alternative corridors were identified and studied in the initial phase of the study. Based on the current level of knowledge the alternatives that were deemed most suitable for further investigation were selected and presented in this report.

The selection resulted in two clear options for the passage across Kvarken; North and South as well as a passage across the Åland Sea.

More specific information regarding the essential features within and nearby the presented corridors can be found in Appendix 2.

SE2-FI Hjälta-EEZ Sweden/Finland
The passage over Kvarken would be located in the counties of Västernorrland and Västerbotten by the east coast in the middle part of Sweden and reaches to the EEZ (Sweden/Finland) about 50-90 km out in the Sea of Bothnia. Forests in an undulating terrain with many lakes and watercourses characterize the area. The terrain consists of rock and moraine and various soil conditions. The marine geology consists of sedimentary rock covered by postglacial and glacial masses of soft clay, sand and bouldery moraine.

The two main alternatives investigated pass to the north and south of Kvarken as shown in Figure 10. These are further divided into shorter sections where two or three alternative corridors are possible. Since there are several possible combinations of corridors between the different sections this report does not present one joint corridor that stretch all the way from Hjälta to the EEZ.

All corridors investigated within the Kvarken passage originates at Hjälta and consist of overhead lines on land and sub-marine cables at sea. The overhead line on land is approximately 120 km in the northern alternatives and approximately 75 km in the southern alternative. The sub-marine cables between the Swedish shore and EEZ are approximately 50 km in the northern alternatives and approximately 80-90 km in the southern alternative.

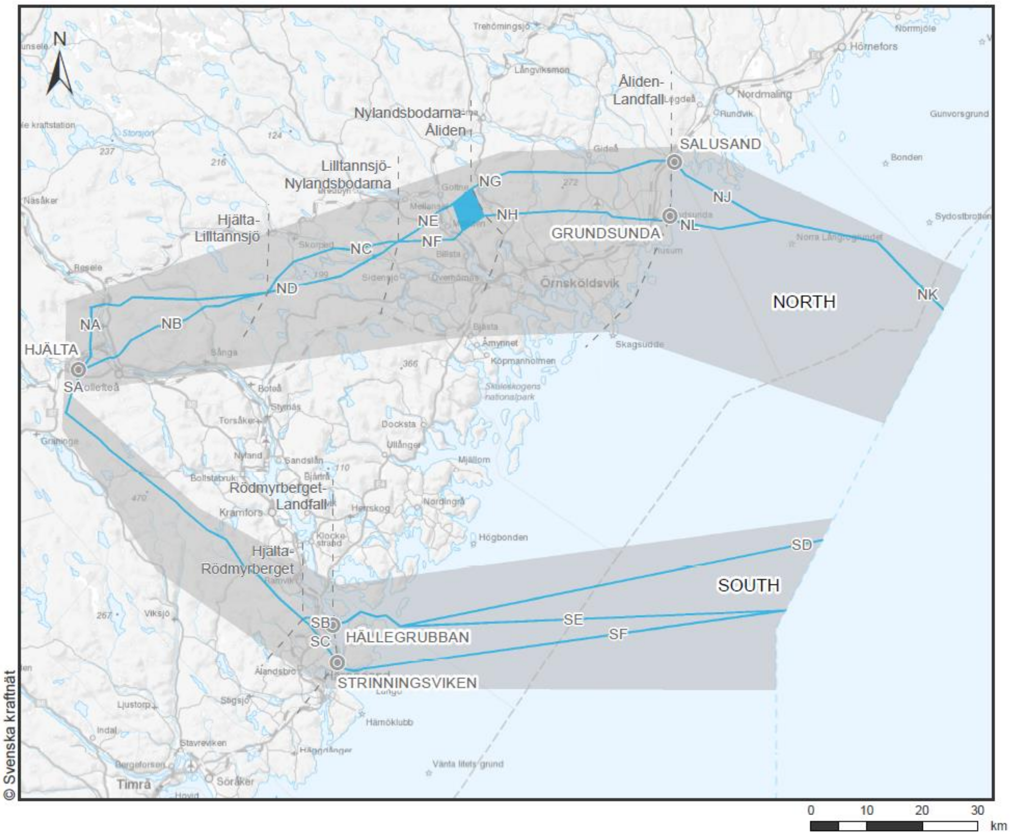

Figure 10 Overview of investigated corridors for the northern and southern alternatives across Kvarken.

SE3-FI Dannebo-EEZ Sweden/Finland

The passage over Åland Sea would be located in the county of Uppsala on the east coast of Sweden. The marine geology consists of sedimentary and crystalline rock partially covered by glacial and postglacial clay. The surface substrate contains of boulders and gravel. Rocks are visible at several places.

The corridors investigated for this passage originates at Dannebo and consist of an underground cable at land and a sub-marine cable at sea. The corridors are subdivided into three sections. Since there are several possible combinations of corridors between the different sections this report does not present one joint corridor that stretch all the way from Dannebo to the EEZ.

The underground cable on land is approximately 2 km and the sub-marine cables between the Swedish shore and EEZ are approximately 80 km long. The investigated corridors mainly goes parallel with existing power cables (XL7 S3 A2 and XL8 S4 A2) as shown in Figure 11.

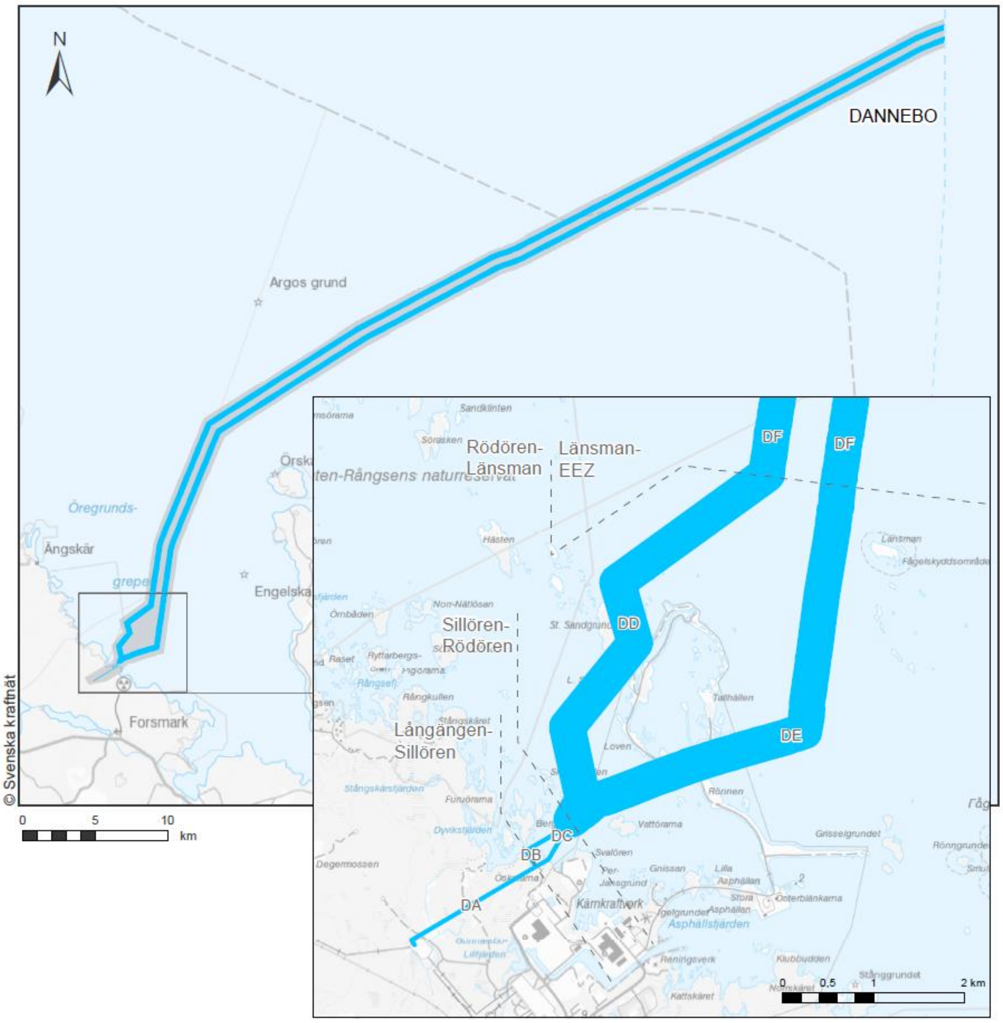

Figure 11 Overview of investigated corridors for the alternative passage across Åland Sea.

5.2 Permit processes in Finland and Sweden

The permission processes in Sweden and Finland are complex, time-consuming and require the involvement of a variety of authorities. A list of the main permits required in Finland and Sweden are shown in Table 3 and Table 4. The ESPOO convention has to be followed for cross-border projects in the Baltic Sea that may have environmental impacts on other countries. The overall Swedish permit process takes approximately five to six years, while the Finnish process is estimated to take four to five years.

Table 3 Permits in Finland

Process	Permits	Authorities	Timescale
EIA for interconnection	-	Regional Centre for Economic Development, Transport and the Environment Ministry of Environment (Cross-border impacts)	16-24 months
Bottom survey permit process	Exploration of sea bottom	Water area owners (Geotechnical surveys)	1-4 months
	Surveys in Finnish economic zone (Economical Zone Permit)	Council of State	6 months
	Right to perform surveys in Finnish waters	The Finnish Defence Forces	1-2 months
Construction license process	Construction license	Energy Market Authority	3-6 months
	Construction license for Cross border transmission	Ministry of Employment and Economy	9 months
Land acquisition process	Survey permit	National Land Surveying	3-4 months
	Expropriation permit	Council of State	6-12 months
Permission to build in water areas	Water permit	Finnish Regional State Administrative Agency	10-14 months
	Economical Zone Permit	Finnish Government	6 months
Permission to build substations	Building permit	Municipality	1-2 months

Process	Permits	Authorities	Timescale
Permission to build on important conservation areas	Act reform	Finnish parliament	2-3 years
Agreement with owners of intersecting cables and pipelines	Bilateral agreement	Owners of cables and pipelines	6 months

Table 4 Permits in Sweden

Process	Permits	Authorities	Timescale
Bottom survey permits	Exploration of the continental shelf	Ministry of Enterprise and Innovation	4-8 months
	Right to perform surveys in Swedish waters	Swedish Defence Authority	1-4 months
Concession process	Concession incl. consultation and EIA	Energy Markets Inspectorate, Ministry of the Environment	5-6 years
Land acquisition process	Right of way	Cadastral Authority	6 months
Permission to build in water process	Permit incl. consultation and EIA	Land and Environment Court	2-4 years
	Right to lay cables in the territorial sea	The Legal, Financial and Administrative Services Agency	
Building permit process	Building permit	Municipality	1-2 years

5.3 Conclusions regarding routes and permits

The overall conclusion it that both main alternatives are considered feasible based on current information. However, there are different difficulties associated with the different alternatives which are briefly described below. More detailed information can be found in the Appendix 1 and Appendix 2. It is also important to consider that in the next phase more detailed studies are required and the routes, particularly at sea, need to be more deeply investigated.

SE2-FI Hjälta-Tuovila

On the Finnish side in SE2 – FI Kvarken the onshore part is situated in new infrastructure corridor between section Murtoinen-Korsnäs (34/36 km and 56/57 %). The new corridor changes living environment and cultural landscape of villages. There is no dense inhabitation, but few villages. In total, the onshore part in this alternative is shorter (61/63 km) than the onshore part in SE3 – FI Fenno-Skan (117 km). Both onshore and offshore sections bypass nature values. At least preliminary Natura assessments are required, but no special routing or permitting risks are identified.

On the Swedish side the onshore parts of the two options North and South present similar challenges regarding construction in hilly terrain but they differ in several other aspects. North is approximately 45 km longer than South and the landscape has a higher presence of agricultural and residential areas in North than in South. In North there are also several larger watercourses that need to be crossed and along these riverbanks there is a high presence of residential buildings. The lower presence of residential areas in South makes this option less accessible with a greater need for construction of new roads than in North. The overall social and environmental impact onshore is estimated to be higher in North than in South.

The offshore part also differs in length (North 50 km, South 80-90 km) and somewhat in depth but otherwise there are similar conditions in both North and South. The corridors cross coastal routes for shipping and in some cases areas of interest for the Commercial Fishery. However, this is regarded as risks that can be handled and partly solved by means of protection of the sea cables.

If a future connection between SE2-FI is considered the best option for system and market reasons it is recommended to investigate an alternative connection point instead of Hjälta, due to difficulties regarding terrain and infrastructure around Hjälta as well as the long and hilly distance between Hjälta and the shoreline.

SE3-FI Dannebo-Rauma/Lieto

On the Finnish side in SE3 – FI Fenno-Skan the onshore part is parallel to existing transmission lines. There is plenty of dense inhabitation in the immediate vicinity and surrounding areas. The offshore cable route crosses the Bothnian Sea National Park (Finnish name Selkämeri National Park) and major risks are identified concerning permitting and timetables, as an act reform is needed. There are also Natura areas and at least preliminary Natura assessments are also required both onshore and offshore.

On the Swedish side, the onshore distance is only 2 km long and runs parallel with existing cables. The route does not present constructional difficulties. Areas of national interests are touched which could possibly be a cause of conflict but it is not considered very likely. The offshore part crosses areas of interest for the Commercial Fishery and several coastal routes for shipping. This is however regarded as risks that can be handled and partly solved by means of protection of the sea cables.

An overall comparison of estimated social and environmental impact associated with the different alternatives indicates that the Fenno-Skan alternative has a substantially lower impact than the Kvarken alternatives on the Swedish side. However, on the Finnish side the Fenno-Skan alternative is much more difficult to implement, so as a conclusion both alternatives are almost equally feasible.

6 Market studies

6.1 General approach

In the market studies, the market simulation results were provided to estimate the market benefits, transmission losses and differences in system adequacy for both HVDC alternatives.

The market model that was mainly used in this study is “EFI’s Multi-area Power-market Simulator” (EMPS), although some simulations were also done with “Better Investment Decision” (BID3). The BID3 model is better adapted to capture the behaviour of thermal production whilst the hydro modelling is more thoroughly developed in EMPS. The differences in the model methodology provided additional robustness and reliability to the results.

The simulation years 2030 and 2040 were selected, as the agreed common Nordic scenario was prepared for those years. In addition to the Nordic scenario, the analysis was supplemented with eight sensitivity cases.

In the market simulations, 31 historical weather years ranging from 1982 to 2012 were utilised to capture possible variation of hydro inflow, wind, solar and temperature. In the EMPS model each week was divided into three hour blocks in Svenska kraftnät’s data and into ten non-sequential price periods in Fingrid’s data. In the BID3 model an hourly time resolution was used.

6.2 Scenarios and basic assumptions

6.2.1 Scenarios

The common Nordic scenario for 2030 and 2040 was created as a part of Nordic Grid Development Plan (NGDP) 2019, by joint taskforce of all Nordic TSO’s. The comprehensive description of the scenario is presented in a separate document that can be found from the documentation of NGDP19.

The methodology behind the common Nordic Scenario was to select the most suitable ENTSO-E TYNDP scenario, and to modify that in order to reach the most likely future development from Nordic perspective. From ENTSO-E storylines, the “Sustainable Transition” (ST) scenario was chosen due to the most suitable storyline, with reasonable assumptions, like commodity prices. However, the common view in the Nordic Scenario group was that it needed higher amounts of RES generation, more power demand flexibility and somewhat higher level of power demand in some new demand types, like electric vehicles, heat pumps and new industry. With these changes, the input data for Continental

Europe was modified to reach a development that was thought to be more likely.

For the Nordic countries, each TSO was responsible to deliver their expert estimate view concerning the future development. Some issues, like the electric vehicle market shares, were discussed together to harmonize the inputs.

Based on the initial data, the next step was to do the modelling in market simulation models. During that process the input data was further fine-tuned in order to have realistic national balances, power price levels and reasonable profitability to power generation.

The fuel and CO2 prices used in the Nordic scenario are presented in the Table 5:

Table 5 Coal, gas and CO_2 prices [€/MWh]/[€/t] (excluding inflation).

Type	2030	2040
Coal	8,6	9,0
Gas	18	20
CO_2	33	35

The power demand in Nordic countries is presented in the Table 6:

Table 6 Electricity demand [TWh/a].

Type	2020	2030	2040
Denmark	37	46	53
Finland	89	94	96
Norway	136	149	149
Sweden	142	153	164
Nordic total	404	442	462
Baltic countries	29	31	35

The main power generation in Nordic countries is presented in the Table 7:

Table 7 Electricity generation from hydro, wind, solar and nuclear [TWh/a].

Type	2020	2030	2040
Denmark			
wind	19	32	41
solar	0,9	2,0	7,5
Finland			
hydro	13	13	13
wind	7	10	27
solar	0,1	0,7	1,4
nuclear	32	35	20
Norway			
hydro	137	143	144
wind	11	13	22
solar	0	0,3	1,1
Sweden			
hydro	71	71	71
wind	18	39	82
solar	0,6	3,8	7,0
nuclear	52	42	0
Baltic countries			
hydro	3,5	3,5	3,5
wind	2,4	5,0	13
solar	0,1	0,4	1,1

6.2.2 Sensitivities

In addition to the common Nordic scenario, a sensitivity analysis was conducted to further test some of the assumptions made when constructing the scenario. The sensitivity analysis was performed only for

2040, i.e. year 2030 was assumed to be similar to base case in all sensitivities.

The sensitivities are described in the following sections:

- Swedish internal balance, where the target is to reduce the ~70 TWh/a surplus in northern Sweden (SE1 and SE2) and also reduce the ~60 TWh/a deficit in southern Sweden (SE3 and SE4), by assuming:
    - 10 TWh/a of the northern wind generation is constructed as off-shore wind to southern Sweden,
    - Oskarshamn 3 nuclear unit (1400 MW / ~9 TWh/a) is running beyond 2040 and
    - 15 TWh/a of new industrial power demand is added to northern Sweden, of which 3TWh/a is moved from southern Sweden to northern Sweden.
- Finnish and Baltic power balance has smaller deficit, from ~22 TWh/a to ~2, by assuming:
    - The RES generation (i.e. wind and solar) in Finland and Baltics is increased to cover an equal share of demand as in Sweden, by assuming 23 TWh/a of new wind power in Finland and 5 TWh/a of new wind power on Baltic countries.
    - On the other-hand, the Fennovoima NPP (~8 TWh/a) is not assumed to be commissioned in this scenario.
    - Additionally, the internal NTC between northern and southern Finland at 2040 is further increased by 1000 MW by assuming the 7th P1 line.
- Finnish and Baltic power balance has larger deficit, by assuming:
    - Fennovoima NPP (1200 MW) is not commissioned,
    - Estonia has closed all Eesti and Narva units (~400 MW), thus having the Auvere unit as the only major power plant.
- Large wind farms in northern Norway and northernmost Finland, by assuming:
    - 2000 MW / 8 TWh/a of wind power to Finnmark/Norway (NO4) and 1000 MW / 3,5 TWh/a of wind power to northernmost Finland.
    - 1000 MW transmission line from Finnmark (NO4) to northern Finland and a further 1000 MW increase to the internal NTC between northern and southern Finland by assuming the 7th P1 line.

    - 1000 MW increase in Norwegian internal NTC from Finnmark (NO4) to Trondelag (NO3).
- More flexible demand with closer to real-time market, which caused some difficulties due to modelling limitations. Because of those limitations, it was assumed that all demand have a flat hourly profile within a week. This might overestimate the future flexibility, but it provides information how large impact flexibility can have on market benefit results.
- Additionally, some individual transmission capacity items were analysed separately as (mini-)sensitivities:
    - SE3–NO1 transmission capacity increased by 1000 MW,
    - Konti-Skan 2 (SE3–DK1) removal, thus reducing SE3-DK1 capacity to 380/380 MW,
    - Russia - Finland, all DC connections are de-commissioned and thus no power flow between Russia and Finland.

6.3 Market simulation results

In this section high level market model outputs is displayed and analysed.

6.3.1 Prices

Resulting prices are presented in Table 8 below. These shouldn't be understood as forecasts of the actual price level, the main target here is to analyse the changes in price differences. In general, a new HVDC would increase the price in Sweden slightly both in 2030 and 2040. The price in Finland would decrease slightly in 2030 and significantly in 2040. The effect is larger in 2040 because of a tighter power balance in 2040. A connection SE2-FI decreases the price difference between SE2 and SE3 compared to a new SE3-FI connection. This is due to that the SE2-SE3 is congested in the southward direction and the main direction between Sweden and Finland is towards Finland.

Table 8 Annual average prices [EUR/MWh] from market simulations for 2030 and 2040 for both alternatives and without any new HVDC connection. The latter part of table presents 2040 results from sensitivity analysis for the Kvarken alternative.

Scenario	SE2	SE3	FI
2030 - no HVDC	46,5	47,9	49,8
2030 - Kvarken	47,3	48,1	48,2
2030 - Fenno-Skan	46,8	48,1	48,5

Scenario	SE2	SE3	FI
2040 - no HVDC	44,4	47,9	55,0
2040 - Kvarken	45,5	48,6	49,1
2040 - Fenno-Skan	45,3	48,9	49,3
2040 - SE internal bal.	48,0	48,4	50,8
2040 - FI high bal.	41,2	45,7	45,4
2040 - FI low bal.	50,1	53,1	69,2
2040 - Wind in north	41,0	44,9	42,0
2040 - Increased flex	44,0	46,9	47,4
2040 - SE3-NO1 +1000 MW	43,7	46,7	47,5
2040 - No KS2 reinv.	46,4	49,4	49,9
2040 - No trade w Russia	46,3	49,4	51,2

6.3.2 Balance

The balances for simulated scenarios and sensitivities are presented in Table 9 below. Balances are presented for the Kvarken / SE2-FI HVDC alternative only since the change in average annual balances between the grid alternatives is limited. In the Nordic reference scenario the Swedish balance is weakened from 2030 to 2040 because of the large decrease in nuclear generation is not fully replaced by new wind and solar production, even though a rapid development is expected. The Finnish balance is rather constant since decreased nuclear output is covered by new RES production.

Table 9 Annual average balance [TWh/a]

Scenario	SE	FI	DK	NO	Baltic
2030 - Kvarken	19	-15	0	13	-10
2040 - Kvarken	10	-17	7	22	-5
2040 – SE int. bal.	8	-16	7	22	-4
2040 – Fi high bal.	5	-7	7	20	-1
2040 - Fi low bal.	10	-24	7	21	-5

Scenario	SE	FI	DK	NO	Baltic
2040 - Wind north	9	-14	7	29	-5
2040 – Incr. flex	10	-17	7	22	-5
2040 - SE3-NO1 +1000 MW	10	-17	7	22	-5
2040 - No KS2	10	-17	7	22	-4
2040 – No trade w Russia	10	-17	7	22	-4

6.3.3 Flow

Flow duration curves for the Kvarken / SE2-FI as well as the Fenno-Skan / SE3-FI grid alternatives are presented in Figure 12 and Figure 13. Flows will be mainly towards Finland in most cases. The SE2-FI gives a higher degree of eastward flows as well as a higher utilization rate. In 2040 the flow has a larger component going towards Sweden, however the bulk is still going towards Finland. The utilization rate is also higher in 2040.

One conclusion that can be drawn is that even though the difference in energy balance between the countries decreases from 2030 to 2040 and the utilization rate of the interconnectors decreases the market benefits increases significantly. This highlights that the main value of interconnectors in the future goes from transfer energy in mainly one direction towards providing flexibility by transferring power in both directions in a more volatile power system.

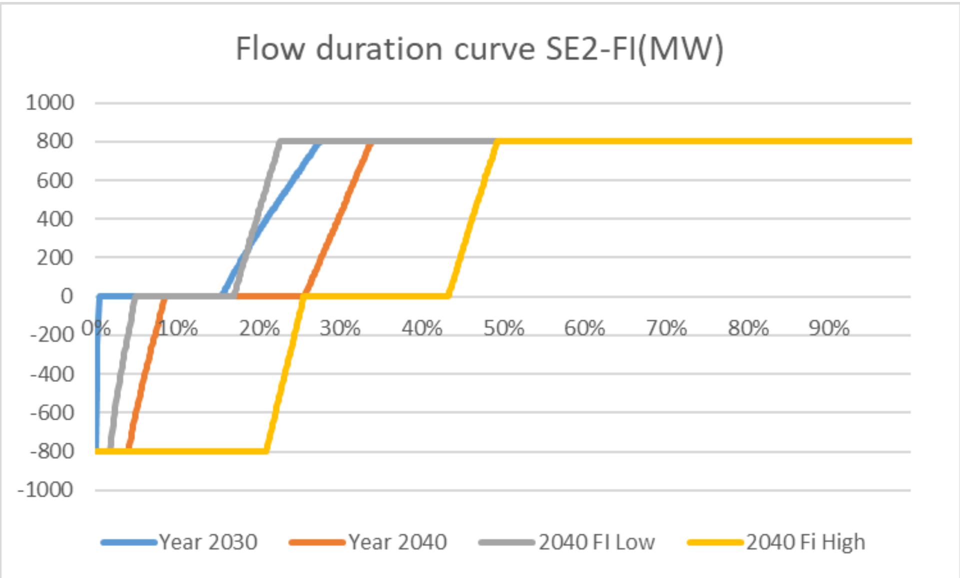

Figure 12 Flow duration curve Kvarken / SE2-FI.

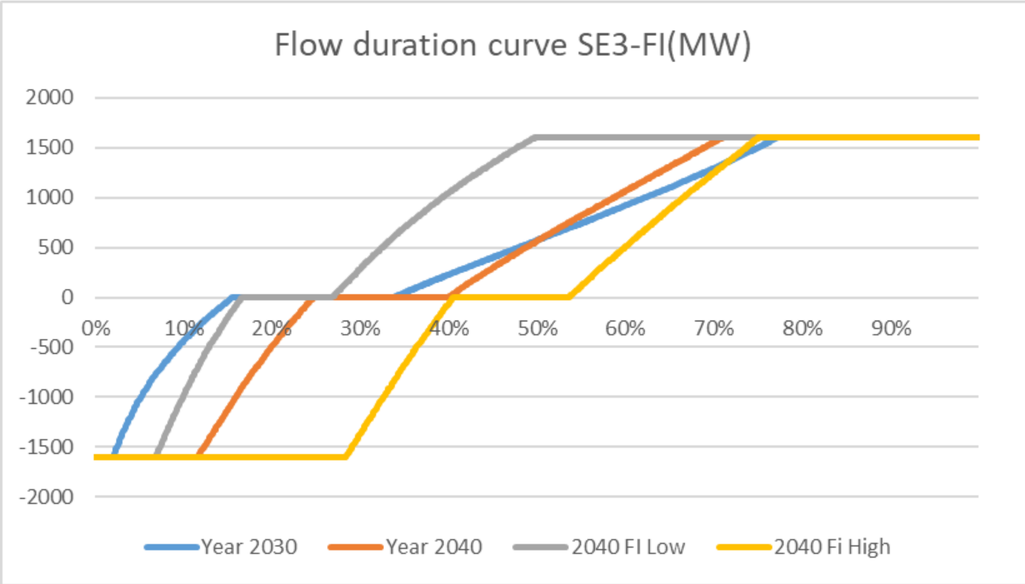

Figure 13 Flow duration curve Fenno-Skan / SE3-FI.

7 Cost-Benefit Analysis

7.1 Methodology and assumptions

When market simulation results were available, both alternatives were further assessed in a cost-benefit analysis (CBA). CBA is a methodology commonly used to calculate the public welfare of policies or projects, for example infrastructure developments. The aim of the CBA is to evaluate different socio-economic aspects in monetary terms. Net Present Values (NPV) are calculated to conclude if a project is beneficial or not and to be able to compare different solutions. In this study, the content and aspects of CBA analysis is based on the guidelines presented in a common Nordic study as a part of the NGDP 2019.

The more detailed description of the NPV calculation is provided in chapter 7.1.1.

The aspects of the CBA are presented in chapter 7.1.2. Only some of the aspects were possible to monetise in the CBA with current methods. The non-monetised aspects were evaluated with the help of qualitative reasoning and simulation results in a multi criteria analysis.

In order to calculate the NPV, certain assumptions concerning investment cost needed to be made, they are presented in chapter 7.1.3.

7.1.1 Net present value (NPV) calculation

In this chapter the methodology and the assumptions for the NPV calculations are described.

In the NPV calculation the future expected costs and revenues over a given period of time were converted into a NPV using a real discount rate of 4 percent, a valuation period (economical life time) of 40 years (25 years can be used as a sensitivity analysis) and a residual value of 0 (zero). All monetized values need to be in real prices as the real discount rate is used. The currency of the monetized values will be in Euros. These parameters are proposed by the common Nordic CBA taskforce, based on inputs from the European Commission and ACER, and accepted also by ENTSO-E for Project of Common Interest (PCI) assessment.

The costs of grid investments were estimated by utilising typical unit costs (in MEUR or MEUR/km) for different parts of HVDC connections and other equipment. The length of both alternatives were estimated based on expected routing. The cost for necessary equipment and other required internal reinforcements were included based on grid studies. The unit costs for HVDC connections can vary significantly depending on e.g. the supply/demand situation at the time of investment or the development of different technical solutions. Therefore, a price range of unit costs was estimated based on available data from recently commissioned and upcoming projects. Since especially the Kvarken alternative has rather long on-shore parts in addition to sea-cable, separate on-shore line unit costs were also estimated for both countries, and, for Sweden, the on-shore line costs were estimated for both overhead line and underground cable.

Market benefit, which is the consumer and producer surplus as well as the congestion rent, is regarded as the revenue for the HVDC alternatives. The market benefit calculations for both studied alternatives were performed for years 2030 and 2040, as described earlier, due to the common Nordic scenario. The NPV calculations were performed assuming that both alternatives are commissioned at 1.1.2029, thus the annual market benefit values for 2031-2039 were interpolated from the 2030 and 2040 market benefit results, and for the further years, the 2040 results were used. Additionally, a construction period of four years prior to the commissioning was assumed for both alternatives. The NPVs were discounted to the year 2018.

7.1.2 Aspects to evaluate

The aspects can be divided to Monetized and Non-monetized indicators. Monetized indicators are:

- investment costs,
- operational costs,
- market benefits,
- transmission losses and
- possibly integration of renewable energy (can also be evaluated as non-monetized indicator).

Non-monetized indicators are:

- environmental and social impact,
- CO2 emissions,
- security of supply,
- flexibility and trade balancing.

Depending on the project, it might be possible to evaluate all of the above indicators, or just a part of them. Main categories of indicators are shown below in the Figure 14.

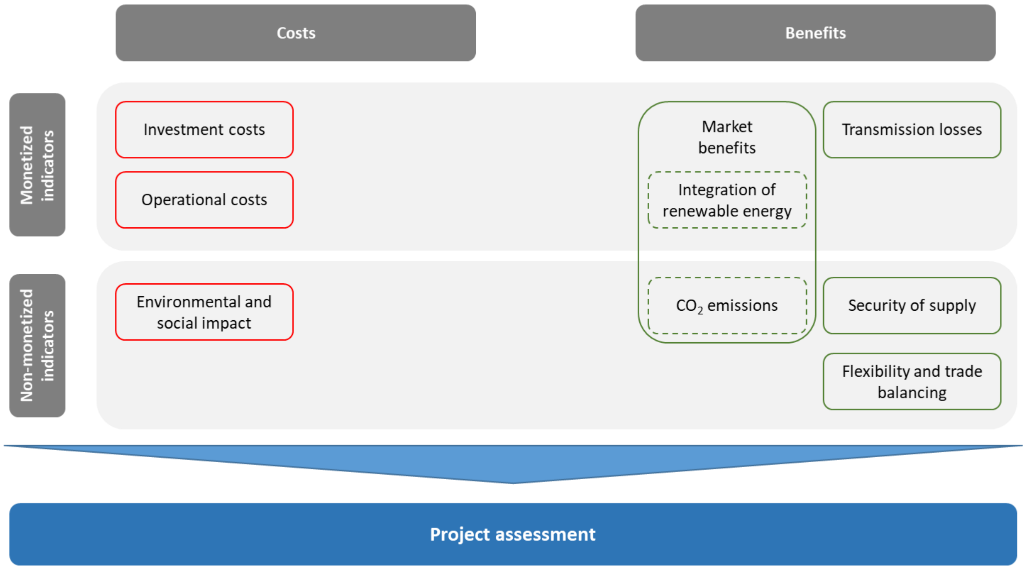

Figure 14 Overview of costs and benefits categorized in monetized and non-monetized indicators. The dotted lines indicates that integration of renewable energy and CO2 emissions are partly included in market benefits.

7.1.3 Investment cost

The grid investments were estimated by utilising typical unit costs (as MEUR or MEUR/km) for different types of power lines and other equipment. The power line investments were calculated by multiplying the expected distances with the typical unit costs.

The HVDC investment costs were estimated based on recently finalised projects, available information for planned future projects as well as assumptions made about technical development. Realised costs can vary significantly depending on the project. There are only a limited number of cable providers, which each have limited installation capacity, so in high demand situations with short notice, costs might be higher than otherwise expected. Sea-cable cost was estimated to be within a range of 0.7-1.5 MEUR/km. For the land-based part of the connection in Sweden an overhead line unit cost was estimated to be 0.6 MEUR/km (Fenno-Skan) or 1.0 MEUR/km (Kvarken), while in Finland a unit cost of 0.45 MEUR/km was used for both alternatives. For Sweden, the onshore part unit cost was also estimated for an underground cable with a value of 1.1 MEUR/km. The costs of the HVDC-converters were estimated to be 100 MEUR per unit, which is roughly the same as current price levels.

There is no need for additional internal reinforcements with the Kvarken alternative. The Fenno-Skan alternative requires internal reinforcement in Finland up to Lieto substation and the estimated cost, 60 MEUR, is included in the investment costs.

The investment costs for the grid alternatives used in the NPV calculations are presented in Table 10. The main difference compared to the previous cross-border study (2016) is that previously the Fenno-Skan investment cost was decreased by the estimated value of new metallic return path for Fenno-Skan 2 current. In this study, it is assumed that the de-commissioned Fenno-Skan 1 cable can be used as a return current path for Fenno-Skan 2, and therefore no new investments for Fenno-Skan 2 is needed. Otherwise, the increase in investment cost is due to some increase in sea-cable and HVDC-converter costs. A comprehensive investment cost table for both HVDC alternatives is presented in Appendix 3.

Table 10 Investment cost [MEUR] and cost range for the grid options

Alternative	Route	Inv cost [MEUR]	Cost span [MEUR]	Inv cost 2016 [MEUR]
SE2-FI	Hjälta-Tuovila	488	430-556	377
SE3-FI	Dannebo-Rauma-Lieto	495	415-576	237

7.2 Results

7.2.1 Market benefit

The Nordic market benefit results for the reference scenario are shown in the Table 11 below. For the year 2030, both HVDC alternatives show very moderate benefits on a Nordic level, although the total market benefit is somewhat higher since there is some increased market benefit for the Baltic countries. The market benefit results were taken from the Svenska kraftnät's EMPS model since it uses a finer time resolution, which is deemed to produce more accurate market benefit results. However, all simulations were also performed in Fingrid, and the market benefit results are supported by the results from the Fingrid modelling.

When analysing the reason for a rather large difference between 2030 and 2040 benefits, it can be noticed that the area price differences between Finland and Sweden are increasing significantly, even though the national energy balances are not that different (see chapter 6.3). The increase in power price in Finland from 2030 to 2040 seem to be comparable to the increase in marginal production costs of gas-fired CCGT units. Additionally, the increasing amount of weather dependent generation is causing more periods with high prices, as the relative impact of low wind situations is turning to much more significant. However, the Swedish power price does not have similar increase from 2030 to 2040, probably due to access to large hydro reservoirs and stronger connections to continental Europe.

Table 11 Nordic market benefit results for SE2-FI and SE3-FI for 2030 and 2040 reference scenario.

Scenario	Cons [MEUR/a]	Prod [MEUR/a]	Cong.rent [MEUR/a]	Market benefit [MEUR/a]
SE2-FI Ref 2030	49	29	-75	3
SE3-FI Ref 2030	41	-1	-35	5
SE2-FI Ref 2040	421	-144	-213	64
SE3-FI Ref 2040	368	-146	-161	61

When comparing the 2030 results to the 2025 results from the previous cross-border study (2016), the relative change of market benefit for the Nordics is rather large, decreasing from 13 to 3 MEUR/yr. However, the change in market benefit for the whole modelled area is rather small. The difference compared to the previous study is likely to be a result of certain changes in Finnish and Swedish energy balances. The Finnish balance is somewhat less in deficit, mainly due to increased wind capacity forecast. The Swedish balance has several changes compared to the previous study, but perhaps the most significant difference is that in this study there is an assumption that one nuclear reactor will be closed between 2020 and 2030 (in addition to Ringhals 1 and 2). Additionally, some of the Finnish benefits in the previous study might be seen in this study as Baltic benefits. Comparison results are presented in Table 12. One should note that the distribution among areas is quite sensitive for small changes in the scenario however the total benefits is more stable to small changes.

Table 12 Market benefit results comparison between current and 2016 cross-border study.

SE2-FI	Market benefit Nordic [MEUR/a]	Market benefit total [MEUR/a]
Ref 2030	3	9
Ref 2025 – 2016 Study	13	10
Ref 2040	64	41
Ref 2035 – 2016 Study	54	42

The market benefit from the new interconnectors is distributed differently among countries as well as consumers, producers and TSO's. The market benefit distribution for the Kvarken / SE2-FI alternative in the

2030 and 2040 reference scenario shown in Table 13 and Table 14 below. Although the numbers vary between the simulated sensitivities the main distribution effects is representative for all sensitivities. The results show that Finland gains most of the benefits and for Sweden the results are negative while Norway and Denmark also increase their market benefit slightly. Especially the Finnish consumers would gain from the new interconnector, which would decrease the average price in 2040 by 6 EUR/MWh.

In Sweden producers gains more than the consumers lose and the reason why the net is negative is that the congestion rent decreases. However the decreased congestions rent will affect the grid users i.e. consumers and producers as the TSOs use the congestion rent to reinforce the grid.

Table 13 Distribution of market benefits for alternative Kvarken (SE2-FI), 2030.

SE2-FI - 2030	Cons	Prod	Cong	Tot
FI	147	-115	-19	12
SE	-50	88	-54	-16
NO	-44	52	-3	5
DK	-4	4	1	1
Nordic	49	29	-75	3

Table 14 Distribution of market benefits for alternative Kvarken (SE2-FI), 2040.

SE2-FI - 2040	Cons	Prod	Cong	Tot
FI	620	-410	-96	113
SE	-135	194	-129	-71
NO	-52	61	7	15
DK	-12	12	6	6
Nordic	421	-144	-213	64

The results from the sensitivities described earlier in **Error! Reference source not found.** are summarised below in Table 15.

Table 15 Market benefit results on a Nordic level for all sensitivities.

	Kvarken SE2-FI	compared to reference	Fenno-Skan, SE3-FI	compared to reference
Ref 2040	64		61	
SE internal balance	52	-12	52	-9
FI high balance	169	105	173	112
FI low balance	468	404	452	391
Wind in north	14	-50	22	-39
Increased flex	56	-8	59	-2
SE3–NO1 +1000 MW	66	2	69	8
No KS2 reinvestment	61	-3	59	-2
No trade w Russia	89	25	87	26

In the case with an altered Swedish internal balance, there is no difference with respect to market benefit between the two alternatives. This is because when the balance is shifted there is no longer any price difference between SE2 and SE3, which in turn makes SE3-FI as beneficial as SE2-FI.

In the case with a stronger Finnish balance, the market benefit increases significantly for both alternatives compared to the reference scenario. The balance is strengthened only by RES production and nuclear is decreased. This leads to a larger amount of surplus situations in Finland where more export capacity is needed. On the other end the need for imports is increased in situations with low RES productions since there is less nuclear than in the reference scenario.

When the Finnish and Baltic balance is weakened by less nuclear and thermal the market benefit for both alternatives increases compared to the reference scenario.

The scenario with more wind and transmission in the north decreases the benefits for both options significantly. This is mainly due to that new transmission capacity to the surplus areas in northern Norway decreases the need for additional import capacity from Sweden.

When more flexibility is assumed on the demand side the market benefit for the SE2-FI decreases, however, for the SE3-FI alternative it decreases significantly less. This sensitivity decreases the bottleneck SE2-SE3, which explains why the market benefit for a SE3-FI connection is less affected.

Increased capacity between SE3 and NO1 increases the market benefit especially for the SE3-FI alternative as this would allow flexible Norwegian hydropower to be exported thru SE3.

If Konti-Skan 2 (SE3-DK1) is not reinvested the market benefit would decrease marginally for the SE2-FI alternative and increase for the SE3-FI alternative.

If there is no energy trading with Russia benefits would increase significantly as both Finnish power and energy balance would be weakened hence the benefits for more imports would increase.

7.2.2 Transmission losses

New transfer capacity between Finland and Sweden will affect the total grid losses in the system.

In this study, the grid losses were approximated on a system level. As the utilised market models do not have a grid topology, the method was to extract hourly simulation data from the market study and incorporate it in the PSS/E model where the system grid losses could be estimated. As this methodology was relatively time consuming the approach was used only for the reference scenario and for the year 2030. The method of combining market model data with the PSS/E data is an approximation with uncertainties, and therefore it was concluded that the 2030 losses could also be used for the 2040.

The results are presented in the Table 16. The difference between alternatives is mainly due to possibility to have the Fenno-Skan alternative as bipole connection with existing Fenno-Skan2, thus providing lower transmission losses.

Table 16 Estimated change in grid losses [GWh/y] for the grid alternatives

Scenario	No new projects (total grid losses)	Kvarken / SE2-FI	Fenno-Skan / SE3-FI
Ref 2030	12221	-40	-107
Ref 2040	12221	-40	-107

The change in grid losses were then multiplied with the average annual electricity price for Sweden and Finland to estimate the yearly decrease in cost of losses. The estimated annual cost of the grid losses is presented in Table 17.

Table 17 Estimated annual cost [MEUR/y] for grid losses for the reference scenario and the grid alternatives.

Scenario	Kvarken / SE2-FI	Fenno-Skan / SE3-FI
Ref 2030	-1,9	-5,1
Ref 2040	-1,9	-5,1

7.2.3 Net present value

The NPVs on a Nordic level for the reference are presented in Table 18, for the definitions of NPV, see chapter 7.1.1. As explained in the previous chapter, the losses calculation is an approximation with uncertainties, and therefore the results are presented for both alternatives without and with estimated transmission losses. For those costs components that are estimated with an uncertainty range, the average value is used to calculate the NPVs.

Table 18 Net present value [MEUR] on a Nordic level, including investment and maintenance cost, socio-economic welfare as well as grid losses.

	Ref w/out losses	Ref with losses
Kvarken, SE2-FI	239	264
Fenno-Skan, SE3-FI	213	281

As mentioned above in chapter 7.1.3, the cost of sea cables are estimated to be in range of 0.7-1.5 MEUR/km, and in Sweden the max cost are estimated with an onshore cable instead of an overhead line. The Table 19 is presenting the whole uncertainty range for both alternatives without transmission losses.

Table 19 Net present value [MEUR] w/out losses, including uncertainty range in investment cost.

	min NPV	mean NPV	max NPV
Kvarken, SE2-FI	190	239	281
Fenno-Skan, SE3-FI	155	213	271

In Figure 15, the accumulated NPVs for each year of the analysis period are shown for the HVDC alternatives in the reference scenario. The break-even time (BET), the time period when the cost and revenues are equal, is reached in 15-20 years for both HVDC alternatives after the commissioning date.

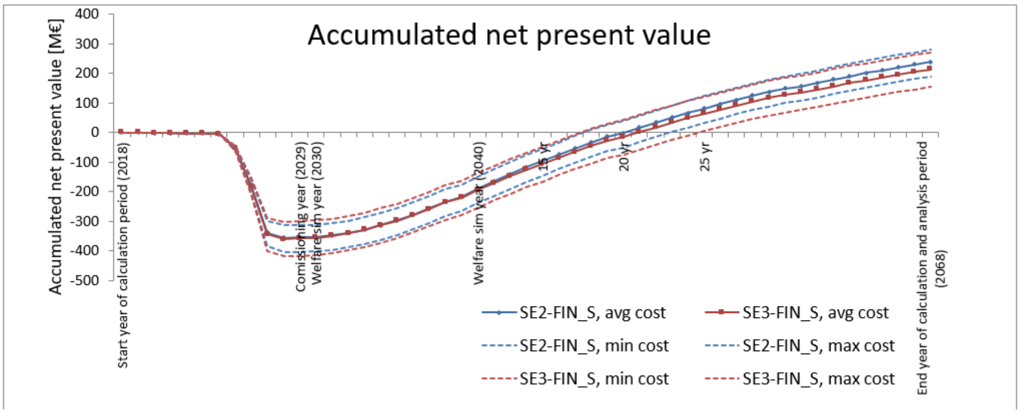

Figure 15 Accumulated net present value with losses with uncertainty range [MEUR]

In Table 20 there are presented the NPV costs (as average) and NPV revenues, again with and without losses.

Table 20 Net present values divided to costs and revenues [MEUR]

	NPV costs	NPV revenue w/out losses	NPV w/out losses	NPV revenue with losses	NPV with losses
Kvarken, SE2-FI	380	619	239	644	264
Fenno-Skan, SE3-FI	385	598	213	665	281

Concerning the analysed sensitivities, the total NPV [MEUR] for both alternatives are given in Table 21. The presented values are calculated without transmission losses.

Table 21 NPV [MEUR] w/out losses with sensitivity cases

	Kvarken SE2-FI	compared to reference	Fenno-Skan, SE3-FI	compared to reference
SE internal balance	125	-114	128	-85
FI high balance	1236	997	1277	1064
FI low balance	4077	3838	3927	3714
Wind in north	-236	-475	-157	-370

	Kvarken SE2-FI	compared to reference	Fenno-Skan, SE3-FI	compared to reference
Increased flex	163	-76	194	-19
SE3–NO1 +1000 MW	258	19	289	76
No KS2 reinvestment	210	-29	194	-19
No trade w Russia	476	237	460	247

As it can be seen, only the sensitivity case with high wind power installation in Northern Norway and Finland together with strong connection between Finland and Norway and internally in Norway is yielding negative net present value for the HVDC alternatives. Additionally some other sensitivities like changes in SE internal balance and increased flexibility are somewhat lowering the net present value, but being still positive. The sensitivities that alter the FI balance are all increasing the net present values.

The above analysis is done with base assumptions of commissioning year 2029 and an analysis period of 40 years. As mentioned in chapter 7.1.1, the net present value can also be calculated with 25 years analysis period (as a sensitivity). The commissioning year has certain impact to net present values, as the market benefits are different for the simulated years 2030 and 2040, and as there is used a 4% real discount rate. These items are illustrated in the Figure 16.

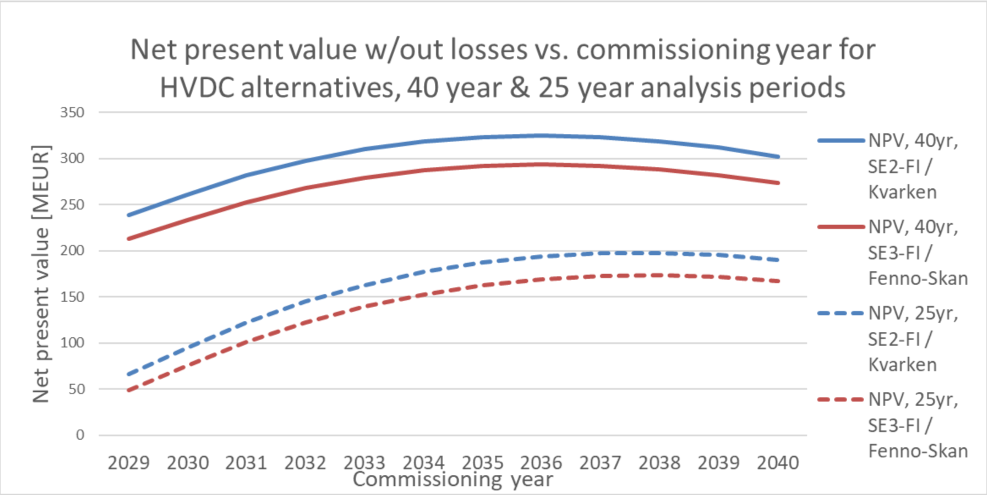

Figure 16 Net present value [MEUR] w/out losses as a function of commissioning year.

It can be noticed that net present value is somewhat increasing, if the commissioning year is postponed to mid 2030's, and then again decreasing towards 2040.

In the above analysis the market benefits were assumed to have a linear increase between 2030 and 2040, as described in the chapter 7.1.1. That assumption is tested with sensitivities were major part of the increase is occurring either during the first or the last years of the period. These developments for the Kvarken alternative are presented in the Figure 17. The impact to Net Present Value is shown in Table 22.

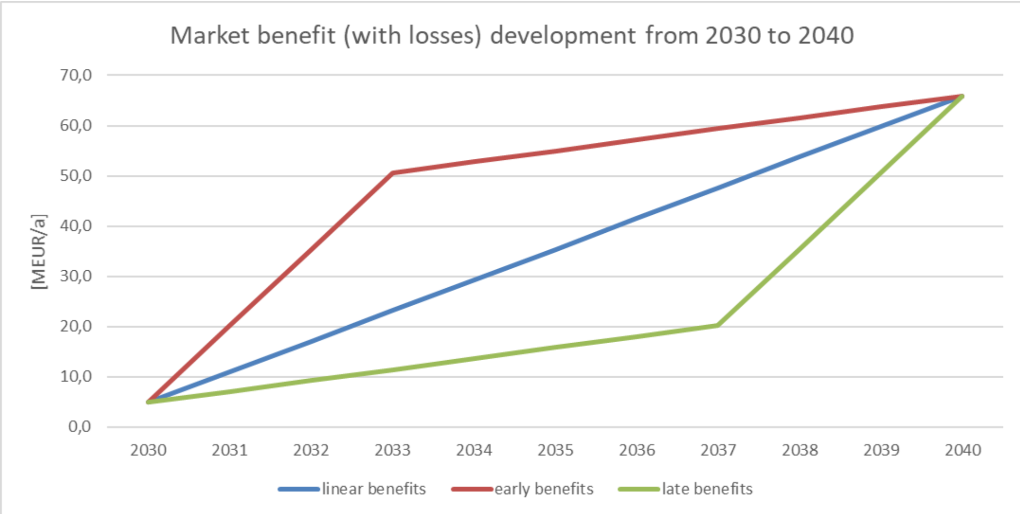

Figure 17 Alternate market benefit developments for the Kvarken alternative

Table 22 Net Present Value [MEUR] with losses with alternate market benefit developments.

	linear benefits	early benefits	late benefits
Kvarken, SE2-FI	264	337	195

7.2.4 Security of supply / System adequacy

System adequacy describes the ability of the system to meet demand at all times. This requires that sufficient generation capacity is available and that (sufficient) transmission capacity is in place. Transmission capacity makes it possible to meet demand in one area with generation capacity that is located in another area. Adequacy refers to the relationship of available generation and load, which is balanced via network infrastructure.

The effect of new interconnector capacity between Sweden and Finland on system adequacy was analysed with a probabilistic method which follows the method used for the ENTSO-E Mid-Term adequacy

Forecast (MAF) 2018ed. (for a full description of the method see Appendix 1 in the same report).

The analysis was performed with BID3 market modelling tool. This study uses adequacy indices listed below to measure the change in system adequacy:

- expected energy not reserved (EENR),
- value of lost reserves (VoLR),
- loss of reserves expectancy (LORE),
- expected energy not served (EENS),
- loss of load expectancy (LOLE) and
- value of lost load (VoLL).

Table 23, Table 24 and Table 25 show the overall results of the analysis which indicate that both interconnectors would increase the system adequacy of the Nordics in year 2040. The study did not show any significant adequacy concerns in 2030. Kvarken alternative seems to be marginally better even though the differences between the alternatives are quite insignificant especially taking the stochastic nature of the analysis into account.

The improved adequacy level can be measured with or without system reserves. This study analysed both cases in order to differentiate the impact of tight adequacy situations on the day-ahead market and the impact those situations would have on end-consumers. Expected energy not reserved, value of lost reserves and loss of reserves expectancy describe the adequacy level in the day-ahead market where system reserves are not available. These results show how much energy, how valuable and during how many hours system reserves would be needed to avoid load curtailment.

Most studies use energy not served, loss of load expectancy and value of lost load as common indices which intuitively refer to the impact showing to the end-consumer as load curtailment. However, adequacy issues in the day-ahead market do not necessarily mean load curtailment for the end-consumer. This study estimated the impact on the end-consumer by adding the capacity equal to the current system reserves to the simulated system and evaluated if then the system would be enough to cover the demand that was not met during the day-ahead markets.

This method assumes that system reserves can be used for resolving adequacy issues and that no other market measures are in place between day-ahead markets and real-time operation. This is not the perfect representation of the real market and operation but it gives an approximate estimation.

Table 23 shows the expected energy not reserved in MWh on average for the Nordics in total. Both interconnector reinforcements decrease the expected energy not reserved by a total around 6000 MWh in a year on average in 2040 where Kvarken is slightly better alternative compared to Fenno-Skan. In 2030, the results indicated that there is no specific adequacy concern in the Nordics.

Table 23 Change in total Nordic expected energy not reserved (EENR) in MWh in a year on average. The table shows negative values when interconnector investment decreases the total EENR in the Nordic, which can be seen as a positive effect.

	2030		2040	
scenario	EENR	Δ EENR	EENR	Δ EENR
Reference	130		12000	
SE2-FI	400	+260	5500	-6500
SE3-FI	470	+240	6000	-6000

The differences are insignificantly low in 2030, which are related to the stochastic nature of the method. In 2040, both interconnectors clearly increase the adequacy level in Finland. They also provide a small increase in adequacy level in Sweden SE4. Compared to Fenno-Skan alternative, Kvarken decreases the energy not reserved on an average of 200 MWh more in Finland and 130 MWh more in Sweden SE4.

Table 24 shows the value of lost reserves (VoLR) in millions of euros in a year on average. Value of lost reserves indicates monetary costs of using system reserves to avoid load curtailment, which results in reduced level of system security. Both interconnector investments decrease the value of lost reserves in the Nordic by an average of 18-19 M€ in 2040 with the assumption that the cost of lost reserves is 3000 €/MWh. With an assumption of 10 000 €/MWh, the benefit of value of decreased lost reserves increases to 60-65 M€ in an average year. There is no significant change in 2030.

Table 24 Change in total Nordic value of lost reserves (VoLR) [MEUR/a] in a year on average with an assumed cost of 3000 €/MWh and 10 000 €/MWh. Positive values can be considered as added benefit to SEW calculations since positive values show positive change in value of lost reserves.

	2030		2040	
scenario	VoLR	Δ VoLR	VoLR	Δ VoLR
Reference	0.40 - 1.3		36 – 120	
SE2-FI	1.2 – 4.0	-0.8 – (-2.7)	17 – 55	+19 – 65
SE3-FI	1.1 – 4.7	-0.7 – (-3.4)	18 – 60	+18 – 60

The value of lost reserves was calculated with two values, with the current day-ahead market cap value of 3000 €/MWh and with 10 000 €/MWh. The current market cap value is a conservative assumption for the assumed value of lost reserves, whereas the higher value of the range shows an optimistic estimate. Commonly used values for the value of lost load normally range between 2 000 - 25 000 €/MWh depending on the country, customer type and time of the lost load. Also, the market cap value in 2030 and 2040 is speculative.

Table 25 and Table 26 show the change in loss of reserves expectancy in both years 2030 and 2040 in the reference case and with both interconnector options. The results indicated that the loss of reserves expectancy decreases clearly in Finland and slightly in Sweden SE4 with both interconnectors. The interconnectors don't have a significant effect on adequacy level in Denmark and Norway.

Table 25 Change in loss of reserves (LORE) in hours in a year on average for Finland and Sweden. The table shows negative values when the average loss of reserves expectancy decreases. Negative values show then increased level of adequacy.

		2030		2040	
Country	**scenario**	LORE	Δ LORE	LORE	Δ LORE
Finland	**Reference**	0.2		9.9	
	SE2-FI	0.2		2.6	-7.3
	SE3-FI	0.2		2.8	-7.1
Sweden	**Reference**	0		0	
SE1	**SE2-FI**	0		0	
	SE3-FI	0		0	

		2030		2040	
Sweden	**Reference**	0		0	
SE2	**SE2-FI**	0		0	
	SE3-FI	0		0	
Sweden	**Reference**	0		0.1	
SE3	**SE2-FI**	0		0.2	+0.1
	SE3-FI	0		0.2	+0.1
Sweden	**Reference**	0		0.5	
SE4	**SE2-FI**	0		0.3	-0.2
	SE3-FI	0		0.3	-0.2

Table 26 Change in loss of reserves (LORE) in hours in a year on average for Denmark and Norway. The table shows negative values when the average loss of reserves expectancy decreases. Negative values show then increased level of adequacy.

		2030		2040	
Country	**scenario**	LORE	Δ LORE	LORE	Δ LORE
Denmark	**Reference**	0		0.2	
DK1	**SE2-FI**	0		0.2	
	SE3-FI	0		0.2	
Denmark	**Reference**	0.5		5.5	
DK2	**SE2-FI**	0.8	+0.3	5.6	+0.1
	SE3-FI	0.8	+0.3	5.4	-0.1
Norway	**Reference**	0		0	
	SE2-FI	0		0	
	SE3-FI	0		0	-

The analysis did not show any hours of loss of load or energy not served in Finland in all scenarios and during both years. This means that there are enough system reserves in place to cover the extra demand that can't be met at the day-ahead markets, which can be seen in the above table. This means that load curtailment would not be needed.

However, the amount of loss of reserves expectations suggests that there are hours when there is a reduced system security level especially in Finland but also a small chance in the southern parts of the Sweden during a series of unlikely events occurring simultaneously.

There is not a standardised allowed level of loss of load hours in the Nordics but values ranging between 3 – 8 h/a are commonly used in different European countries. Most countries don't account for system reserves in adequacy studies. This means that the results for loss of reserves expectation of this study can be compared with the allowed loss of load expectation levels of other countries. The increase in interconnector capacity between Sweden and Finland would then set the adequacy level of Finland below commonly allowed levels.

7.2.5 Environmental and social impact

Environmental and social impacts are analysed in the chapter **Error! Reference source not found.**, with various possible routings. The expected lengths in kilometres are provided for each routing option as well as information concerning terrain and areas with nature values or population (summary of lengths in Table 27).

As a summary, it can be estimated that both main alternatives, Kvarken and Fenno-Skan, are just as good in this context. The Kvarken alternative is more difficult to implement on Sweden due to long on-shore part with difficult terrain from Hjälta to coastline. Then again, the Fenno-Skan alternative is more difficult in Finland due to Bothnian Sea National Park and dense population within on-shore routing.

Table 27 Estimated lengths of the HVDC alternatives

Length in [km]	Onshore Finland	Onshore Sweden	Offshore	Total
Kvarken, SE2 - FI	61-63	80-120	119-172	300-315
Fenno-Skan, SE3 - FI	117	2	199-202	318-321

7.2.6 Integration of renewable energy (partly included in market benefits)

In this study there are not any specific renewable energy projects that are depending on the realization of either of the alternatives. However, these grid alternatives are promoting the increase of renewable energy generation as there are more possibilities to export possible surplus generation to neighboring countries as well as import replacement generation when there is scarcity in renewable generation.

7.2.7 Flexibility and trade balancing

The impact to the amount of congestion hours between Sweden and Finland is presented in Table 28 for 2030 and in Table 29 for 2040. An hour is rated as congested when there is a full flow and price difference between areas.

Table 28 Amount of congested hours between Sweden and Finland at 2030

	Reference w/out HVDC	with Kvarken	with Fenno-Skan
SE1-FI	43%	16%	26%
SE2-FI	N/A	16%	N/A
SE3-FI	36%	18%	16%
SE2-SE3	20 %	13%	20%

Table 29 Amount of congested hours between Sweden and Finland at 2040

	Reference w/out HVDC	with Kvarken	with Fenno-Skan
SE1-FI	52%	31%	36%
SE2-FI	N/A	32%	N/A
SE3-FI	55%	37%	37%
SE2-SE3	23%	20%	24%

7.3 Conclusions from the Cost-Benefit Analysis

From the results, new HVDC connection between Sweden and Finland seem to be beneficial, although the main benefits are realizing in the 2040 situation. The Kvarken alternative from SE2 to FI has somewhat higher NPV compared to the Fenno-Skan alternative from SE3 to FI, without estimated transmission losses. The Kvarken alternative has also slightly lower investment costs mainly because it does not require any additional internal reinforcements.

When also the transmission losses are estimated and included in analysis, the Fenno-Skan alternative has a bit higher NPV.

Concerning security of supply, the difference between these alternatives is rather insignificant.

Environmental and social impacts are more significant in Sweden with the Kvarken alternative as it has rather long onshore connection that need to be routed through greenfield areas. The Fenno-Skan alternative can mainly utilize existing corridors, although in Finland there are major actualization and timetable risks concerning Selkämeri National Park which new offshore cable crosses. In this context, both alternatives can be considered as equal.

From other aspects, there are no clear differences between alternatives.

As a summary from the CBA, there is no clear ranking between these two alternatives.

However, during the finalization of the study, it was noted that the Kvarken alternative could possibly be routed in Sweden to Stornorrfors, instead of Hjälta. That would shorten the total routing by 60-100 km, thus reducing investment costs by 60-100 MEUR. With that change, the Kvarken alternative would most likely be clearly more beneficial than the Fenno-Skan alternative.

8 Summary and conclusions

8.1 Comparison of the connection alternatives

In this chapter, the main differences between the studied alternatives are presented. The different aspects are covered throughout the report but are presented here in a condensed manner in an attempt to make a comparison easier. An attempt has been made to summarise the significant positive and negative aspects of each alternative and the way in which the alternatives compare to each other.

8.1.1 Alternative Kvarken, SE2-FI, 800 MW HVDC connection

Advantages

An HVDC connection between SE2 and Finland is relatively easy to implement from a grid perspective, as the number of reinforcements needed are limited. From a technical perspective the alternative is also considered easier to implement compared to alternative SE3-FI since it offers a greenfield solution without interfaces to existing equipment.

Compared to alternative SE3-FI, an HVDC connection between SE3 and Finland, alternative SE2-FI reduces the overall strain on the Swedish tie lines between SE2 and SE3, potentially reducing the congestions between SE areas.

With analyzed setup, alternative SE2-FI provides rather equal NPV compared to alternative SE3-FI. However, the connection point in Sweden might be possible to move from Hjälta to Stornorrfors, which would reduce the investment cost significantly. From the market perspective that would increase the net present value and provide bigger benefits for consumers and producers.

Due to the geographical separation from the existing HVDC connection FS2, this alternative is better from a system stability and security point of view.

Disadvantages

Due to the nature of greenfield project, the Kvarken alternative, with Hjälta as connection point, has bigger environmental impact in Sweden, and it has rather long onshore parts. The environmental impact can be reduced by replacing Hjälta with Stornorrfors, as that connection point is relatively close to coastline.

The losses are slightly bigger as this alternative is in practice introducing 4 HVDC cables between Sweden and Finland (incl. Fenno-Skan 2), while the Fenno-Skan alternative could be configured as bipole with Fenno-Skan 2 resulting in only 2 cables.

8.1.2 Alternative Fenno-Skan, SE3-FI, 800 MW HVDC connection

Advantages

Alternative SE3-FI provides better support in case of power flow towards Sweden as it connects to a deficit area in Sweden.

The use of Fenno-Skan 1 cable as neutral return cable of the new Fenno-Skan bipole instead of return current path of Fenno-Skan 2, reduces the risk related to use of Fenno-Skan 1 cable beyond the typical operational life-time of an HVDC cable.

The losses for this alternative are lower compared to the Kvarken alternative.

The environmental impact in Sweden is very low due to very short onshore routing and possibility to use existing infrastructure for the converter station.

Disadvantages

Alternative SE3-FI is not feasible as due to the fault ride through (FRT) in the area around Dannebo it is not possible to handle increased power transfer above 550 MW towards Sweden. Additionally, the projects in the Swedish North/South study are very vital to avoid the overload conditions in the area, which can create some timetable risks.

Alternative SE3-FI is also more difficult to implement in Finland due to the need for grid reinforcements and other measures as it increases transmission through already strained parts of the grid.

The alternative is more technically challenging than the Kvarken since it involves integrating a new HVDC connection with the existing Fenno-Skan 2. Measures will have to be taken in order to minimise the risk of bipole failure and simultaneous tripping of both links.

Environmentally this alternative is much more challenging in Finland as the offshore cable route crosses the Bothnian Sea National Park (Finnish name Selkämeri National Park) and major risks are identified concerning permitting and timetables, as an act reform is needed. Also the onshore part need to be routed through a very narrow corridor with dense inhabitation in the immediate vicinity and surrounding areas.

8.2 Summary and conclusion

Two HVDC alternatives, the Kvarken from SE2 to Finland and the Fenno-Skan from SE3 to Finland were evaluated in this study.

Grid studies were performed to investigate the feasibility of integrating the different alternatives into the system. The Kvarken alternative was considered feasible while the Fenno-Skan alternative has fault ride through (FRT) issues, which will limit the usability and maximum capacity. Moreover, the Fenno-Skan alternative requires more grid reinforcements compared to the Kvarken alternative, which can create an increased timetable risk.

In a technical review of the HVDC alternatives the need for a metallic return path for Fenno-Skan 2 was assumed to be done by utilizing the Fenno-Skan 1 cable. Therefore, the Fenno-Skan 2 return current issues are not directly influencing the NPV comparison of the HVDC alternatives. However, as the SE3 to FI HVDC alternative will mainly be used in a bipole configuration with Fenno-Skan 2, this configuration does risk the tripping of both HVDC connections. The SE2 to FI HVDC alternative was considered to be a more straightforward technical solution.

The routing, environmental aspects and permissions for the both alternatives remaining after the grid study have been investigated. Some risks were identified, but based on current information both alternatives are feasible.

The benefits of the proposed alternatives were evaluated from a socio-economic perspective in the market studies. The results indicate that increased capacity between Sweden and Finland is beneficial both in monetary terms and in qualitative terms. The alternatives render in general high positive NPVs and were found advantageous regarding potential trade of ancillary services, system adequacy and potential of integrating renewable energy sources.

When comparing the two HVDC alternatives the SE2 to FI HVDC connection has more advantages overall.

After considering the factors addressed in this report, it was concluded that a new HVDC connection between SE2 and FI increases socio-economic welfare as well as improves the technical performance of the system. However, as most of the benefits are realizing in the 2040 situation which is by default uncertain, it would be beneficial to have further studies in order to find the most optimal timing for the new HVDC connection. Market development need to be followed in order to determine the validity of the 2030 assumptions as well as the high level trends which effects the 2040 assumptions, thus decreasing the uncertainty in the results. To evaluate the possibility to extent Fenno-Skan 1 life-time beyond 40 years, which is considered as typical life-time of an HVDC system, an assessment about the measures, their costs and risks to extend Fenno-Skan 1 life-time shall be performed. The aim is to maintain the current cross-border capacity until the new HVDC connection is in use. Also, grid studies are needed to find out if the connection point in Sweden can be moved from Hjälta to for example Stornorrfors.

Appendix

Appendix 1 Routing Finnish side

	SE2 -FI Kvarken (transmission line Tuovila – Korsnäs and offshore cable to EEZ)	SE3 – FI Fenno-Skan (transmission line Lieto-Rauma-Rihtniemi and offshore cable to EEZ)
Environmental values	All alternatives have potential conflicts with nature conservation **Onshore** ▪ Both sub-alternatives pass Natura 2000 area with SPA designation (Kackurmossen FI0800018); requires at least preliminary Natura assessment. ▪ Sub-alternative Korsnäs N bypasses Natura 2000 area with SCI/SPA designation (FI0800130 Merenkurkun saaristo) located 580 m from the route. Requires at least preliminary Natura assessment. ▪ Sub-alternative Korsnäs N intersects shortly with a Finiba area (Hälsön matalikot), which is mainly open sea without islets and islands. ▪ Sub-alternative Korsnäs N bypasses the Finiba area of Kvarken Archipelago located 370 m from the route. ▪ Mainly forestry areas, agricultural land approx. 15 % of the transmission line. **Offshore** ▪ All sub-alternatives: Patchy reef bottoms (potential) along corridor. Probability of Zostera, Chara or Fucus communities very small. Routes are not situated in Baltic ringed seals or grey seals breeding area. ▪ All sub-alternatives bypass a Natura area with SCI and SPA designation (FI0800130 Merenkurkun saaristo) located 1420 m (KN and KSn) or 1980 m (KSs) from the route. ▪ KN and KSn partly intersects with IBA area (Merenkurkku archipelago), KSs bypasses IBA area. ▪ Sub-alternative KSs bypasses a Natura area with SCI and SPA designation (FI0800135 Närpiö Archipelago) located 1470 m from the route	All alternatives have potential conflicts with nature conservation **Onshore** ▪ Bypasses several Natura 2000 areas and Nature conservation areas; conflicts are unlikely. **Offshore** ▪ All sub-alternatives: Patchy reef bottoms (potential) along corridor. Probability of Zostera, Chara or Fucus communities very small. Routes are not situated in Baltic ringed seals or grey seals breeding area. ▪ Sub-alternative North intersects with Bothnian Sea National Park 11 km length and one Finnish Important Bird Areas (Finiba), Coastal area of Uusikaupunki. ▪ Sub-alternative South intersects with Bothnian Sea National Park 5 km length and bypasses a Natura area with SCI and SPA designation (FI0200072 Uudenkaupungin saaristo) located 220 m from the route ▪ Sub-alternative South intersects one Finnish Important Bird Areas (Finiba), Coastal area of Uusikaupunki. ▪ Conflict with Bothnian Sea National Park in both sub-alternatives, need for act reform. ▪ Agricultural areas common, 29 % of onshore transmission lines length.
Inhabited areas	▪ Inhabitation is concentrated on villages and it is partly relatively dense. Passes through several small villages. ▪ Overall 16-19 residences and 1-3 holiday homes max. 150 meters from the route. ▪ ALT 1 Kvarken N has slightly less inhabitation in the proximity than ALT 1 Kvarken S.	▪ Passes or bypasses several villages. ▪ Overall 63 residences and 20 holiday homes max. 150 meters from the route. ▪ Southern part of the route has significantly dense inhabitation even though it is an area outside population centers. It may be necessary to pull down some residential buildings in Aurajokilaakso.
Infrastructure and other	**Onshore** ▪ Sub-alternative Kvarken South passes through wind park area **Offshore**	**Onshore** ▪ Residential buildings near corridor, see above; inhabited areas **Offshore** ▪ Both alternatives cross with 2 cables.

technical obstacles	▪ 1 shipping lane crossing and 1 local boat route (2 local boat routs in alternative KSs) ▪ Sub-alternative KN and KSn pass through offshore wind park reservation along the edge appr. 12 km length ▪ Sub-alternative KSs passes through wind park reservation in the middle of the area. ▪ None known offshore cables or pipelines.	▪ Fenno-Skan via North crosses three shipping lanes, and the cable corridor is situated near or along one shipping lane at an approx. 9 km section. ▪ Fenno-Skan via South crosses three shipping lanes.
Landscape values and cultural heritage	▪ Passes through two regional landscape areas. Bypasses three regional landscape areas. ▪ The most environmentally sensitive landscapes are agricultural landscapes related to old settlements. ▪ 10-11 archaeological findings near transmission line (< 100 m) and one wreck in offshore cable corridor (less than 1000 m in sub-alternatives KN and KNs).	▪ Wide areas of cultural landscape and old settlement are characteristic to the route. Several valuable areas on the influenced area. ▪ The most environmentally sensitive area is the Aurajoki river valley. ▪ 15 archaeological findings near transmission line (< 100 m) and 1 wreck near offshore cable corridor (less than 1000 m).
Surface and ground waters	▪ Crosses several small rivers, widest crossing approx. 20 meters. ▪ Crosses one ground water area. ▪ Sea flood area in sub-alternative Korsnäs N.	▪ Crosses 3 rivers. Widest crossings approx. 30 meters. ▪ No ground water areas in close proximity.

Appendix 2 Routing Swedish side - Essential features of the presented transmission line alternatives[2]

Table 1. *Conflicting interests present within studied corridors in investigation area North of the Kvarken alternative. Table continues on the next page.*

NORTH	Natural Environments	Cultural Environments	Recreation/Outdoor activities	Natural resources	Buildings	Infrastructure
Hjälta-Lilltannsjö						
NA	Nature reserve, Klippen NI Conservation, River Ångermanälven 3 Habitat Protection Areas	1 Ancient Monument 2 Other Cultural Remains	NI Recreation, Övre Ådalen	NI Reindeer Husbandry Näsåker core area, Voernese Sami village	73 Buildings whereof 21 residential, Hjälta/Brobacken, Forsmo	NI Road, Road 90 NI Railway, Ådalsbanan and Stambanan
NB	NI Conservation, Ångermanälven Natural monument, Nyåkersberg 5 Biotope Protection Sites	2 Other Cultural Remains	NI Recreation, Övre Ådalen Illuminated ski/run tracks at Nyåkersberg Recreational area Hallstaberget	Prospecting permits, Fannbyåsen, 1 and 2 NI Reindeer Husbandry Näsåker core area, Voernese Sami village	91 Buildings whereof 41 residential, Berg (Sollefteå)	NI Road, Road 90 NI Railway, Ådalsbanan
Lilltannsjö - Nylandsbodarna						
NC	NI Conservation, Övre Nätraån 7 Biotope Protection Sites	1 Other Cultural Remains	-	Wind Power Area, Stormyrberget Wind Farm	3 Buildings whereof 1 resident	-
ND	NI Conservation, Övre Nätraån Habitat Protection Area 4 Biotope Protection Sites	5 Ancient Monuments. 2 Other Cultural Remains	-	-	95 Buildings whereof 26 residential, Myre	-
Nylandsbodarna-Åliden						
NE	Natura 2000, Moälven. NI Conservation, Moälven NI Protected Watercourses, Moälven 2 Habitat Protection Areas	1 Ancient Monument. 1 Other Cultural Remains 1 Shielding	-	-	148 Buildings whereof 47 residential, Flärke	NI Railway, national rail to Örnsköldsviks harbour (Mellansel-Örnsköldsvik)
NF	Natura 2000, Moälven. NI Conservation, Moälven NI Protected Watercourses, Moälven 2 Habitat Protection Areas	1 Ancient Monument	-	-	78 Buildings whereof 25 residential, Moliden	NI Railway, national rail to Örnsköldsviks harbour (Mellansel-Örnsköldsvik)

[2] Tables from the report "New DC interconnection between Sweden and Finland over Kvarken or Åland sea. Feasibility study, social and environmental aspects" Svenska kraftnät, 2018.

Table 1. *Conflicting interests present within studied corridors in investigation area North of the Kvarken alternative.*

Åliden-landfall point						
NG	NI Conservation, Saluån NI Protected Watercourses, Moälven 6 Habitat Protection Areas	4 Ancient Monuments. 6 Other Cultural Remains	-	Water Protection Area, Gideå Gideheden Wind Power Area, Municipal Area 9, Prästliden	50 Buildings whereof 12 residential, Saluböle	NI Road, E4 NI Railway, Botniabanan NI Airport, Influence Area Örnsköldsvik airport
NH	NI Conservation, Idbyån Habitat Protection Area, Torsböle Natural monument, Vallen 3 Habitat Protection Areas	Other Protected Cultural Values, Grundsunda church Designated Cultural Area in municipal plan, Grundsunda church environment	Trails, Arnäsleden Torsböle	Extraction Permit (peat), Tvärbäcksmyran	95 Buildings whereof 22 residential, crossing Gideälven/Grundsunda	Ni Road, Road 1067 and E4 NI Railway, Botniabanan RI Airport, Influence Area Örnsköldsvik airport
Landfall point -EEZ						
NJK	-	-	-	-	-	NI Shipping, 2 fairways
NLK	-	-	-	-	-	NI Shipping, 2 fairways

Table 2. *Conflicting interests present within studied corridors in investigation area South of the Kvarken alternative.*

SOUTH	Natural Environments	Cultural Environments	Recreation/Outdoor activities	Natural resources	Buildings	Infrastructure
Hjälta - Rödmyrberget						
SA	2 Biotope Protection Sites, Stormyråsen and Långviksbodarna 9 Habitat Protection Areas	2 Ancient monuments 3 Other cultural remains	-	Permitted extraction (peat), Mörttjärnsmyran Wind power area, Knäsjöberget and Vitberget	21 Buildings whereof 7 residential	NI Road, Road 87
Rödmyrberget - Landfall point						
SB	Nature reserve, Långvattenhöjden	6 Ancient monuments 5 Other cultural remains	NI Recreation, Höga Kusten. Designated quiet area	-	32 Buildings whereof 9 residential	NI Road, Road E4 NI Railway, Ådalsbanan
SC	-	4 Ancient monuments 5 Other cultural remains	Designated quiet area	Wind power area, Möckelsjöberget	2 Buildings whereof 0 residential	NI Total defence, marine training area NI Road, E4 NI Railway, Ådalsbanan
Landfall point - EEZ						
SD	NI Conservation, Höga Kusten	World Heritage Site	NI Mobile recreation NI Continuous coastline Designated quiet area	NI Fisheries	6 Buildings whereof 3 residential	NI Shipping, 3 fairways NI Total defence, marine training area
SE	NI Conservation, Höga Kusten	World Heritage Site	NI Mobile recreation NI Continuous coastline Designated quiet area	NI Fisheries	6 Buildings whereof 3 residential	NI Shipping, 3 fairways NI Total defence, marine training area
SF	NI Conservation, Höga Kusten	Other Cultural Remains – ship wreck site	Designated quiet area	NI Fisheries	24 Buildings whereof 9 residential	NI Shipping, 3 fairways NI Total defence, marine training area

Table 3. *Conflicting interests present within studied corridors in the investigation area of the Åland Sea alternative.*

ÅLAND SEA	Natural Environments	Cultural Environments	Recreation/Outdoor activities	Natural resources	Buildings	Infrastructure
	Långängen - Sillören					
DA	NI Conservation, Forsmark - Kallrigafjärden 1 Habitat Protection Area	Designated cultural area in municipal plan, Arkösund - Forsmark 3 Other cultural remains	NI developed coastline, Arkösund - Forsmark	Polluted areas at the station	5 Buildings whereof 2 residential	-
	Sillören - Rödören					
DB	-	Designated cultural area in municipal plan, Arkösund - Forsmark	NI developed coastline, Arkösund - Forsmark	NI Fisheries	2 Buildings whereof 2 residential	-
DC	-	Designated cultural area in municipal plan, Arkösund - Forsmark	NI developed coastline, Arkösund - Forsmark	NI Fisheries	2 Buildings whereof 2 residential	-
	Rödören - Länsman					
DD	-	Designated cultural area in municipal plan, Arkösund - Forsmark	NI developed coastline, Arkösund - Forsmark	NI Fisheries. Wind power area municipal plan, Forsmark wind farm and Grepen	-	NI Shipping, 1 fairway
DE	Nature reserve, Länsman bird protection area	Designated cultural area in municipal plan, Arkösund - Forsmark	NI developed coastline, Arkösund - Forsmark	NI Fisheries. Wind power area municipal plan, Forsmark wind farm and Grepen	6 Buildings whereof 0 residential	NI Shipping, 1 fairway
	Länsman - EEZ					
DF	Nature reserve, Länsman bird protection area	Designated cultural area in municipal plan, Arkösund - Forsmark	NI developed coastline, Arkösund - Forsmark	NI Fisheries	-	NI Shipping, 6 fairways

Appendix 3 Investment cost

Project	Location		Capacity [MW]		Length [km]				Cost per km cable/line [MEURO/km]					Cost cable/line [MEUR]			Cost / station converters etc		Internal reinforcment [MEUR]		Total cost [MEUR]			Total cost per km [MEUR]		
	SE	FIN	SE->FIN	FIN->SE	total	SE	FIN	sea	SE / line	SE / cable	FIN	sea min	sea max	min	max (SE w line)	max (SE w cable)	SE	FIN	SE	FIN	avg (SE w line)	min (SE w line)	max (SE w cable)	avg (SE w line)	min (SE w line)	max (SE w cable)
SE2-FIN_S	Hjälta	Tuovila	800	800	307	100	62	145	1	1,1	0,45	0,70	1,50	229	345	355	100	100	1	0	488	430	556	1,59	1,40	1,81
SE3-FIN_S	Dannebo	Rauma	800	450	320	2	117	201	0,6	1,1	0,45	0,70	1,50	195	355,35	356,35	100	100	0	20	495	415	576	1,55	1,30	1,80

Appendix 4 Market Simulation results

Annual average prices

	Nord FS 204	rd Kvark 2	ord Ho 204	NoRu Ho	NoRu Kvark	NoRu FS	NoKS FS	NoKS Ho	NoKS Kvark	Hasle FS	Hasle Ho	Hasle Kvark	Flex FS	Flex Ho	Flex Kvark
SE	47.3	47.3	46.3	47.0	48.1	48.0	48.0	47.2	48.1	45.3	44.5	45.4	45.5	44.8	45.7
NO	42.0	42.2	41.8	41.9	42.3	42.2	42.0	41.7	42.2	42.5	42.2	42.6	41.9	41.7	42.0
FI	49.3	49.1	55.0	61.1	51.2	52.2	50.8	55.6	49.9	48.3	53.9	47.5	48.1	53.2	47.4
DK	47.0	46.9	46.6	46.9	47.2	47.3	47.4	47.1	47.3	46.0	45.8	46.1	45.9	45.6	45.9
BALT	50.9	50.7	52.1	53.5	51.5	51.8	51.5	52.6	51.2	49.9	51.2	49.7	49.8	50.8	49.6
NORDEN	44.3	44.3	44.3	45.0	44.8	44.7	44.6	44.6	44.6	43.9	44.0	44.0	43.6	43.7	43.6
SVER-SNO1	44.3	45.2	43.4	44.1	46.0	45.4	45.6	44.3	46.0	43.0	41.8	43.3	43.3	42.1	43.7
SVER-SNO2	45.3	45.5	44.4	45.0	46.3	46.1	46.2	45.2	46.4	43.7	42.8	43.7	43.9	43.1	44.0
SVER-SNO3	48.9	48.6	47.9	48.6	49.4	49.4	49.5	48.8	49.4	46.6	46.0	46.7	46.8	46.2	46.9
SVER-SNO4	48.9	48.6	47.9	48.6	49.4	49.4	49.4	48.8	49.4	46.6	46.0	46.7	46.8	46.2	46.9
DK1	44.2	44.2	44.1	44.1	44.2	44.2	44.0	44.0	44.1	44.2	44.2	44.3	44.0	43.9	44.0
DK2	49.4	49.2	48.8	49.3	49.8	49.9	50.1	49.7	50.0	47.8	47.4	47.8	47.6	47.2	47.6
DE	45.7	45.7	45.6	45.7	45.7	45.7	45.7	45.6	45.7	45.7	45.7	45.7	45.6	45.6	45.6
NL	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7
PL	53.5	53.4	53.6	53.9	53.7	53.7	53.7	53.8	53.6	52.9	53.1	52.9	52.8	53.0	52.9
GB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
FIN-SYD	49.4	49.1	55.1	61.1	51.2	52.2	50.9	55.6	49.9	48.4	54.0	47.5	48.2	53.2	47.4
FIN-NORD	49.3	49.1	55.0	61.0	51.2	52.1	50.7	55.6	49.9	48.2	53.9	47.5	48.1	53.2	47.4

	i Low Kvar	Fi Low Ho	Fi Low FS	Se Bal FS	Se Bal Ho	E Bal Kvar	orWind F	orWind H	rWind Kv	Fi High FS	i High Kvar	Fi High Ho	ord FS 203	rd Kvark 2	ord Ho 203
SE	51.8	49.3	51.7	48.1	47.3	48.2	43.1	43.0	43.3	43.5	43.6	42.9	47.6	47.8	47.3
NO	43.2	42.5	43.0	42.6	42.4	42.6	40.0	39.9	40.1	39.9	40.0	39.9	46.3	46.4	46.1
FI	69.2	109.1	70.5	50.9	56.4	50.8	42.9	43.5	42.0	46.1	45.4	58.4	48.5	48.2	49.8
DK	49.0	48.1	49.2	46.9	46.6	47.0	45.1	45.1	45.1	45.5	45.6	45.4	47.8	47.8	47.7
BALT	60.0	70.4	60.6	51.0	52.2	51.0	47.7	48.0	47.5	45.3	45.2	46.5	52.4	52.4	52.8
NORDEN	47.7	49.9	47.7	44.9	45.0	44.9	41.5	41.4	41.5	41.8	41.8	42.6	46.9	47.0	46.8
SVER-SNO1	49.9	46.4	49.0	47.8	46.8	47.9	40.7	39.9	40.8	39.3	39.6	38.1	46.8	47.2	46.5
SVER-SNO2	50.1	47.0	49.4	47.9	47.1	48.0	41.1	40.6	41.0	41.7	41.2	41.0	46.8	47.3	46.5
SVER-SNO3	53.1	51.0	53.4	48.3	47.6	48.4	44.6	44.8	44.9	45.5	45.7	45.2	48.1	48.1	47.9
SVER-SNO4	53.0	51.0	53.4	48.3	47.5	48.4	44.6	44.8	44.9	45.5	45.6	45.2	48.2	48.1	47.9
DK1	44.6	44.4	44.6	44.1	44.0	44.1	43.5	43.6	43.6	43.2	43.3	43.3	47.0	47.0	46.9
DK2	52.5	51.1	52.9	49.4	48.9	49.4	46.6	46.6	46.7	47.6	47.5	47.2	48.8	48.8	48.7
DE	45.8	45.8	45.8	45.6	45.6	45.6	45.4	45.4	45.4	45.2	45.2	45.2	46.1	46.0	46.0
NL	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.4	46.4	46.4
PL	55.5	55.3	55.7	53.2	53.4	53.3	52.0	52.2	52.0	51.4	51.5	51.7	54.5	54.5	54.7
GB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	49.1	49.1	49.1
FIN-SYD	69.2	109.2	70.5	50.9	56.4	50.8	42.9	43.5	42.0	46.1	45.4	58.4	48.5	48.3	49.8
FIN-NORD	69.2	109.1	70.4	50.9	56.4	50.8	42.9	43.5	42.0	46.1	45.4	58.3	48.5	48.2	49.8

Annual average balances

	Nord FS 204	rd Kvark 2(	ord Ho 204	NoRu Ho	NoRu Kvark	NoRu FS	NoKS FS	NoKS Ho	NoKS Kvark	Hasle FS	Hasle Ho	Hasle Kvark	Flex FS	Flex Ho	Flex Kvark
SE	9.6	9.7	9.4	9.4	9.6	9.6	9.6	9.4	9.6	9.7	9.5	9.8	9.7	9.5	9.7
NO	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.4	21.5	21.5	21.5	21.5	21.6	21.5	21.6
FI	-16.8	-16.8	-16.5	-16.4	-16.8	-16.6	-16.6	-16.5	-16.8	-16.5	-16.4	-16.8	-16.6	-16.5	-16.8
DK	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.6	6.7	6.7	6.7	6.7	6.6	6.6	6.6
BALT	-4.5	-4.5	-4.1	-3.8	-4.3	-4.3	-4.4	-4.0	-4.4	-4.7	-4.2	-4.7	-4.6	-4.2	-4.6
NORDEN	21.0	21.1	21.1	21.2	21.1	21.2	21.2	21.0	21.0	21.4	21.2	21.2	21.3	21.1	21.2
SVER-SNO1	27.0	27.1	27.0	26.9	27.0	27.0	27.0	26.9	27.1	27.2	27.1	27.2	27.1	27.0	27.1
SVER-SNO2	43.9	43.9	43.8	43.8	43.8	43.9	43.9	43.8	43.8	43.9	43.9	43.9	43.9	43.8	43.9
SVER-SNO3	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.7	-51.7	-51.6	-51.6	-51.7	-51.6
SVER-SNO4	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7
DK1	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.0	8.0	8.0
DK2	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5
DE	-5.4	-5.5	-6.2	-5.8	-4.9	-5.0	-5.6	-6.2	-5.5	-6.0	-6.6	-5.9	-5.5	-6.1	-5.4
NL	0.3	0.3	0.2	0.2	0.4	0.3	0.3	0.2	0.3	0.4	0.3	0.4	0.2	0.1	0.2
PL	-4.6	-4.6	-3.9	-3.4	-4.2	-4.2	-4.4	-3.8	-4.4	-5.1	-4.3	-5.1	-4.6	-3.9	-4.6
GB	-10.2	-10.1	-10.5	-10.3	-9.9	-10.0	-10.4	-10.6	-10.3	-9.5	-9.8	-9.4	-10.3	-10.5	-10.2
FIN-SYD	-35.5	-35.5	-35.2	-35.1	-35.4	-35.3	-35.3	-35.2	-35.5	-35.3	-35.2	-35.5	-35.4	-35.2	-35.5
FIN-NORD	18.7	18.7	18.7	18.7	18.6	18.7	18.8	18.7	18.7	18.8	18.8	18.7	18.8	18.7	18.7

	i Low Kvar	Fi Low Ho	Fi Low FS	Se Bal FS	Se Bal Ho	E Bal Kvar	NorWind F	NorWind H	rWind Kv	Fi High FS	i High Kvar	Fi High Ho	ord FS 203	rd Kvark 2(	ord Ho 203
SE	9.5	9.2	9.5	8.2	8.1	8.2	8.5	8.4	8.5	4.8	4.6	4.9	18.6	18.6	18.5
NO	21.3	21.2	21.2	22.1	22.0	22.0	28.9	28.9	28.9	20.4	20.4	20.4	13.0	13.0	13.0
FI	-24.5	-23.1	-24.3	-16.1	-15.8	-16.1	-14.1	-14.2	-14.4	-6.7	-6.8	-7.2	-15.0	-15.1	-14.6
DK	6.8	6.8	6.8	6.7	6.7	6.7	6.6	6.6	6.6	6.5	6.5	6.5	0.2	0.2	0.1
BALT	-4.5	-4.1	-4.5	-4.5	-4.1	-4.5	-5.3	-5.2	-5.3	-1.1	-1.2	-0.9	-9.6	-9.6	-9.4
NORDEN	13.2	14.1	13.3	20.9	20.9	20.9	29.9	29.6	29.6	25.1	24.8	24.6	16.7	16.7	17.0
SVER-SNO1	27.0	26.9	26.9	15.2	15.2	15.2	26.5	26.4	26.4	23.7	23.5	23.7	16.0	16.0	16.0
SVER-SNO2	43.7	43.6	43.7	31.6	31.5	31.6	43.6	43.6	43.7	42.9	42.8	43.0	33.3	33.3	33.3
SVER-SNO3	-51.4	-51.5	-51.4	-28.9	-29.0	-28.9	-51.9	-51.8	-51.8	-52.0	-52.0	-52.0	-17.4	-17.4	-17.5
SVER-SNO4	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.7	-9.8	-9.8	-9.8	-13.4	-13.4	-13.4
DK1	8.1	8.1	8.1	8.0	8.0	8.0	8.0	8.0	8.0	7.9	8.0	8.0	3.2	3.2	3.2
DK2	-3.4	-3.4	-3.4	-3.5	-3.5	-3.5	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-5.2	-5.2	-5.2
DE	-2.4	-3.8	-2.5	-5.4	-6.2	-5.4	-9.1	-9.1	-8.9	-8.4	-8.2	-8.6	0.0	0.0	-0.5
NL	0.9	0.6	0.8	0.2	0.2	0.3	-0.4	-0.4	-0.3	-0.3	-0.2	-0.3	1.5	1.6	1.4
PL	-2.1	-1.4	-2.0	-4.6	-4.0	-4.6	-6.2	-5.9	-6.2	-5.7	-5.7	-5.3	-6.0	-6.0	-5.8
GB	-8.7	-9.4	-8.8	-10.1	-10.4	-10.0	-12.0	-12.0	-11.9	-11.8	-11.7	-11.8	-7.3	-7.2	-7.4
FIN-SYD	-34.7	-33.5	-34.6	-35.1	-34.9	-35.1	-36.1	-36.1	-36.2	-28.0	-28.1	-27.9	-22.6	-22.6	-22.2
FIN-NORD	10.2	10.4	10.3	19.0	19.1	19.0	21.9	21.9	21.8	21.3	21.3	20.7	7.6	7.6	7.6