Grid connection of near-shore wind farms

Energinet.dk ejer energiens motorveje og er med til at omstille Danmark til vedvarende energi

Grid connection of near-shore wind farms

Published by Energinet.dk in response to the Danish Ministry of Climate, Energy and Building's order of 29 January 2013: 'Order concerning the establishment of landing facilities and the completion of preliminary studies for six near-shore wind farms at North Sea South, North Sea North, Sæby, Sejerø Bay, the coastal waters off Småland and Bornholm.'

Frontpage photo: Photo of the offshore Wind Farm at Samsø, Sweco Architects A/S

For a copy of the report, please contact:
Energinet.dk
Tonne Kjærsvej 65
DK-7000 Fredericia
Tel. +45 7010 2244
The report can also be downloaded at:
www.energinet.dk
March 2015

Contents

1. Introduction

This report is prepared as part of Energinet.dk's response to the Danish Ministry of Climate, Energy and Building's order dated 29 January 2013: 'Order concerning the establishment of landing facilities and the completion of preliminary studies for six near-shore wind farms at North Sea South, North Sea North, Sæby, Sejerø Bay, the coastal waters off Småland and Bornholm.'

The report addresses item 4 of the order concerning the completion of an analysis of possible landing solutions for alternative wind farm sizes in the six selected locations for a total of 450 MW installed wind energy. Wind farm sizes of up to 200 MW in increments of 50 MW are examined.

The purpose is to define connection solutions, the need for reinforcements in the underlying transmission grid and the related costs in order to help the authorities to prioritise and select the locations for the erection of near-shore wind turbines.

The report contributes:

- Standardised solutions that are coordinated with the subtransmission grids.
- Defined needs for grid reinforcements of the transmission grid in conformity with Network Development Plan 2013.
- Estimated solution costs for each location and as a function of the size of the connected capacity.

The report is a brief summary based on detailed background documentation supplemented by detailed appendices.

2. Conclusion

Based on the locations selected for the erection of near-shore wind turbines, analyses have been conducted to identify the technical and financial conditions for the different sizes of the connected capacities. Analyses have been conducted of connected wind turbine capacity of 50, 100, 150 and 200 MW in order to determine the technically and financially optimum connection solution based on four standard concepts.

For most of the selected locations, the technically and financially optimum solution for connection of 50 and 100 MW wind power capacity will be to bring power ashore using 50-60 kV cables from the offshore wind farm to an existing 132-150/50-60 kV substation. For large 150 and 200 MW wind farms, a connection solution with a deployed substation established with a 150-132/33 kV transformer close to the landing point will be the most ideal solution from a technical and financial perspective. The analyses only include the cost of establishing the onshore part of the connection facility.

The analyses have shown that the connection of wind turbine capacity may require reinforcements of the underlying transmission grid. This would be the case if the selected locations in the North Sea are used. The scope of the necessary reinforcements depends on the size and distribution of the connected power at the location. The costs of the necessary grid reinforcements have been included in the financial analyses.

If a turbine owner presents a solution which is overall socio-economically cheaper to establish than the socio-economic solutions recommended in this report, it is recommended to examine the possibilities for implementing the turbine owner's solution.

3. Method

All locations are analysed in order to determine the technically and economically optimum solution for landing facilities depending on the size of the connected capacity. The analyses are based on four different standard landing solution concepts, which all address the capacity in question. The standard concept with the lowest total costs for each location and size of connected capacity (50, 100, 150 and 200 MW) is indicated as the preferred connection solution.

The following are included in the calculation of the total costs:

- Costs for the establishment of connection facilities from the seashore to the existing transmission grid, including any necessary substation rebuilding.
- Costs for any necessary reinforcements of the underlying transmission grid. If the reinforcements are included in Energinet.dk's Network Development Plan 2013, only acceleration costs (if any) are included.
- Estimated operating and maintenance costs during the facilities' lifetime.
- Capitalised transmission losses over a period of 25 years.

All costs are in constant 2014 prices. When calculating the costs for accelerating already planned reinforcements, the real interest rate published by the Danish Ministry of Finance is used. The real interest rate is used in socio-economic calculations, currently 4% p.a. in year 0-35 and 3% p.a. in year 36-70.

Moreover, the costs are estimated at varying degrees of breakdowns of the onshore connection facilities, resulting in a loss of production. The economic impact of the different connection solutions has been calculated, just as the profitable solutions to reduce these costs are indicated at different wind farm sizes.

If the reinforcements in the Network Development Plan are accelerated, resulting in acceleration costs, the increased costs of this do not mean that the costs of the Network Development Plan as a whole will increase as other investments may be postponed. The calculated acceleration costs must be used to assess the total costs of connecting one wind farm in one location instead of another location and not as a basis for an assessment of any additional costs for the Network Development Plan.

3.1 Standard concept

The analyses of the optimum connection methods are based on four overall standard concepts covering different voltage levels and principles. The standard concepts are described in more detail in

Appendix 1 and fulfil all Energinet.dk's Grid dimensioning criteria for the connection of production facilities[1].

	Description	Connection [kV]	Landing [kV]
Standard concept 1	A simple advanced substation must be established close to the landing point with a xx/33 kV transformer.	132-150 or 50-60	33
Standard concept 2	The 33 kV cables from the offshore wind farm are routed all the way up to an existing substation, which is expanded with a xx/ 33kV transformer.	132-150	33
Standard concept 3		50-60	33
Standard concept 4	50-60 kV cables are routed from the offshore wind farm to an existing 50-60 kV substation.	50-60	50-60

The four standard concepts are assessed financially and technically for all possible combinations of offshore wind farm sizes and geographical location. In some cases technical conditions will render one or more of the four standard concepts unusable, just as differences in local conditions in some cases will result in deviations and adjustments of the standard concepts. The financial impact of this is included in the assessment of the total costs of the individual solutions and is included in the descriptions of each location.

The standard concepts allow for the offshore wind farms to be established with landing cables at 33 kV and 50-60 kV. Consequently, the standard concepts do not allow for the offshore wind turbines to deliver, for example, 10 kV or other voltage. The following assumes that 60 kV landing cables are laid and connected to the existing 50-60 kV grid, dispensing with the need for transformation between two adjacent voltage levels.

In all standard concepts, the offshore wind farm's connection transformer is erected on land as the establishment, operation and maintenance of an offshore transformer platform are assessed to be significantly more expensive in relation to the short distance from the offshore wind turbines to the shore.

No calculations of the construction costs of an advanced substation with a 132-150/50-60 kV transformer have been made, ie the landing cables are established with 50-60 kV and transformation is carried out at the 132-150 kV

[1] Energinet.dk's Grid dimensioning criteria (in Danish) from May 2013 can be found at www.Energinet.dk.

level. This option is therefore not included in the environmental impact assessment of the advanced substations either.

3.2 Grid analyses

The necessary reinforcements of the underlying transmission grid are determined on the basis of load-flow analyses of the transmission grid in 2020, when the near-shore wind turbines are due to be established and commissioned. The analyses are based on the analysis assumptions for 2013 prepared by Energinet.dk supplemented by the wind turbine projects for which a bank guarantee had been furnished as at 1 September 2013. The results of the load-flow analyses are used as a preliminary basis for the environmental impact assessments to be carried out for the individual grid reinforcement needs.

Further robustness analyses have subsequently been carried out of the need for grid reinforcements in connection with integration of several wind turbine projects, for which bank guarantees were known to have been furnished as at 1 January 2014. The analyses showed that the wind turbines' production put a heavy strain on the transmission grid in Western Jutland, necessitating further reinforcements.

3.3 Construction costs

Estimated unit prices of subcomponents have been used in the calculation of the construction costs. For the 132-150-400 kV components, the unit prices are determined on the basis of previous construction projects, and for the 33-50-60 kV components the unit prices are partly based on a dialogue with grid companies and partly on the unit prices in Energinet.dk's compensation scheme. When the final design of decided wind turbine projects is completed, the specific costs of the individual projects may deviate from the screening prices stated in the report as both the component prices and connection method may change due to procurement conditions as well as local grid and geographical conditions.

The calculations of the costs of the individual connection solutions are carried out in increments of 50 MW, ie for connection of 50, 100, 150 and 200 MW near-shore wind farms established in the six selected locations[2]. The calculations cover the costs of facilities established from the seashore and towards the existing transmission grid.

3.4 Calculation of loss costs

Transmission losses are estimated on the basis of an estimated production profile for the offshore wind farms. For North Sea South and North Sea North, a historical duration curve for Horns Rev 2 is used, for Sæby and Sejerø Bay a historical duration curve for Anholt is used, while for the coastal waters off

[2] For Bornholm, calculations have only been made for 50 MW wind farms as per the agreement with the Danish Energy Agency of 23 January 2014.

Småland and Bornholm a historical duration curve for Rødsand 2 is used. All duration curves are selected for the period mid-2013 to mid-2014.

For use in the calculation of the total connection solution costs, the capitalised transmission losses are included in the 33 or 60 kV cable connection from the edge of the offshore wind turbine location and up to the shore via the wind farm corridor for the export cables and on to the nearest onshore transformation point. The length of the wind farm corridors varies from location to location, but is included in the loss calculations as the length of the export cables in the individual wind farm corridor will be relatively firm. Costs relating to transmission losses in the internal grid between the offshore wind turbines are not included as the erection pattern and thereby the cable cross-section is not known at present.

Furthermore, a calculation has been made of an increase in the total system losses in the power system in Jutland and on Funen and Zealand at various combinations of installed wind power capacity in the selected locations.

3.5 Estimation of operating and maintenance costs

For estimation purposes, the total expected costs for the operation and maintenance of the connection solutions are based on a fixed percentage of 3% of the total construction costs, and are reflected in the allocation of the costs associated with the connection of the individual wind farms.

3.6 Cost allocation

In connection with the establishment of the facilities, the costs relating to the offshore landing facilities must be paid by the turbine owner. In addition, Danish Energy Agency has presented a proposal for onshore cost allocation, which means that all costs relating to the onshore facilities up to a defined onshore point of connection must be paid by the turbine owner.

If permission to establish a near-shore substation in the individual location is obtained, the point of connection will be the secondary side of the transformer on the near-shore substation, and the turbine owner must then pay all costs up to this point, including the costs of any distribution system between the transformer and the export cables from the wind farm. The secondary side of the transformer is the transformer's bushing on the side which has the same voltage level as the export cables from the wind farm.

The turbine owner also owns the facilities up to the point of connection and is thus responsible for paying all operating and maintenance costs and costs relating to transmission loss up to the point of connection.

If the wind farm's size and the distance to the existing grid require the establishment of a near-shore substation, the turbine owner must pay the costs associated with the development of the substation land, including the costs of acquiring the land. The ownership and future maintenance of the land will subsequently be transferred to the local grid company or Energinet.dk depending on the voltage level on the primary side of the transformer. If additional land is to be purchased adjacent to an existing substation with a view to placing the transformer there instead, the turbine owner must pay the costs relating to the acquisition and development of the land.

If public authority requirements render the establishment of a near-shore outdoor AIS substation impossible due to visual conditions or other conditions, the turbine owner must pay the additional costs incurred for the establishment of an indoor GIS substation instead. Another option is to move the transformation point further inland, thereby extending the export cables correspondingly, resulting in higher costs for the turbine owner.

The aim is to place the transformer as close to the landing point as possible in the designated locations, so that the total costs, including the transmission loss costs, can be optimised as much as possible.

If permission to establish a near-shore substation in a location is obtained, but the size of the wind farm would make it more economical to lay, for example, 60 kV cables from the landing point and all the way up to the existing grid instead of establishing a near-shore substation, the point of connection will remain at the location where the near-shore substation could have been established. In this way, the point of connection remains in the same geographical location regardless of the size of the wind farm. If permission to establish a near-shore substation in a location cannot be obtained, the point of connection is moved to the existing 132-150 kV grid.

In other words, the turbine owner bears all costs associated with the connection of the wind farm up to the point of connection, allowing the connection facility to be dimensioned on the basis of power loss and economic conditions.

Energinet.dk or the local grid company establishes and pays all costs relating to the connection of the transformer to the existing grid, including costs for the transformer and the connection facility itself on the primary side of the transformer as well as the laying of cables up to the point where the near-shore substation can be placed.

In other words, Energinet.dk or the local grid company pays all costs associated with the connection of the transformer, allowing the transformer and its connection to the existing grid to be dimensioned on the basis of power loss and economic conditions.

4. Assumptions

The preparation of the individual solutions and the calculation of the associated costs are based on the following assumptions.

4.1 Grid analyses

The integration of production from the near-shore wind farms and the necessary related grid reinforcements is based on Energinet.dk's Network Development Plan 2013 and the cable action plan for cabling installed until around 2017-2018.

In addition, the grid analyses are based on Energinet.dk's analysis assumptions from 2013, which, among other things, specify the distribution of different production methods which in 2013 were applicable in 2020. This includes the different onshore wind turbine projects, for which a bank guarantee had been furnished as at 1 September 2013.

4.2 Grid dimensioning criteria

When integrating production from wind turbines and other local production, the grid is not dimensioned according to n-1, ie the breakdown of a single component can, in principle, disconnect the producer(s) in question.

In the event of a breakdown in the meshed transmission grid, ie facilities larger than 100 kV, the aim is to be able to purchase the wind turbines' entire production for 40 hours.
A meshed transmission grid is defined as substations with more than one 132-150 kV supply.

4.3 Financial assumptions

The following financial assumptions have been used for the calculation of the costs:

- The year of calculation is 2020, the first full year of operation. The facilities are expected to be commissioned over the course of 2019.
- The real interest rate is fixed at 4%.
- The lifetime is fixed at 25 years for the offshore wind farms and the connection facility, and 40 years for reinforcements in the rest of the grid.
- The capitalised transmission loss is calculated for 25 years corresponding to the lifetime of the offshore wind farms.
- The costs are in constant 2014 prices.

The calculation of the transmission loss costs is based on the current analysis assumptions from 2013, including the expected electricity prices towards 2020. If the expected electricity prices change in the individual years, the transmission loss cost will also change.

Where possible, standard unit prices have been used to calculate the construction costs of the individual solutions. For 50-60 kV solutions, the unit prices for cables and bays of the compensation scheme are used.
For 33 kV facilities, the unit prices are determined on the basis of a 10 kV facility with an estimated supplement assessed in cooperation with several grid companies. In addition, the costs of 33 kV facilities are assessed in relation to the connection of the National Test Centre for Large Wind Turbines in Østerild, Denmark.

The costs of 132-150-400 kV facilities are based on Energinet.dk's internal screening prices for cables and substations.

4.4 Export cables

The cross-sections of the export cables and the inter-array cables in the individual near-shore wind farm must be chosen on the basis of power loss and economic conditions, for which reason the transmission capacities and the number of export cables may vary to take account of local conditions.

No more than six export cables are expected to be landed.

It is assumed that the wind turbines will either deliver 33 kV or 50-60 kV. 33 kV is standard while 50-60 kV is not yet widespread. Today, only test turbines are known to deliver 60 kV.

It is assumed that the wind turbine must have a certain power rating before it is profitable to offer wind turbines delivering 50-60 kV. In order for the connection of 50-60 kV wind turbines to be profitable, it must be possible to loop between the wind turbines, as the export cable costs otherwise will be disproportionately high compared to standard 33 kV wind turbines, where this is possible.

Commercial wind farms where the individual connected wind turbines deliver 50-60 kV are not known. Therefore, this is not a known technology at present.

When calculating the number of export cables from the wind farms, a transmission capacity of approx. 36 MW per 33 kV cable and a transmission capacity of approx. 75 MW per 60 kV cable are assumed. At 50 kV a transmission capacity of approx. 58 MW per cable is expected. The assessment of the transmission capacity is based on the offshore wind turbines being able to deliver and absorb reactive power corresponding to Cos phi 0.95.

The above and thus the costs incurred for the connection of the individual wind farms assume that a 630 mm^2 onshore Al-PEX cable is laid in a close trefoil formation, but other cross-sections, including Cu-PEX cables, may also be relevant as the cables must be chosen on the basis of power loss and economic conditions. Submarine cables are not included.

The individual cable systems are assumed to be installed in separate cable trenches. A close trefoil formation is assumed, and the individual cable trench is assumed to be 0.8 metres wide at the top, with an assumed distance of 1.2 metres between each cable trench, ie 2 metres between each cable system. No transmission capacity reduction is assumed due to the laying of parallel cables as separate cable trenches are assumed as mentioned above. If this part can be optimised, for example by installing two cable systems in a wider trench, resulting in a larger cross-section, it should be done if this can reduce the total costs.

4.5 33 kV switchgear and 33 kV building

It is assumed that a 33 kV GIS is used for the connection of 33 kV export cables from the wind farm which are placed in a suitable building either at a new deployed substation or at an existing substation. Whether a 33 kV AIS can be used has not been further investigated.

For a 200 MW wind farm, a 4 kA single busbar is anticipated, with the option of a double busbar. The transmission capacity of the bar can be selected individually depending on the wind farm size. However, it should be considered whether it would be possible to include the different switchgears in the same tender procedure, so that only one type of switchgear is purchased, which may help to limit the number of spare parts.

The following transmission capacities (at 33 kV and Cos phi 0.95) are assumed for the individual 33 kV bays:

Bay type	[kA]	[MW]
Line bay	1.25	67
Transformer bay	2.50	135
Bus sectionalizer	2.5	135

The busbar is expected to be divided in two separated by a bus sectionalizer when connecting a wind farm larger than 100 MW.

The number of bays depending on the wind farm size is therefore as follows:

Bays	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Line bay	2	3	5	6
Transformer bay	1	1-2[*]	2[**]	2[**]
Bus sectionalizer	0	0	2[***]	2[***]
Metering bay	1	1	2	2
Total	4	5-6[*]	11	12

It is assumed that there will be two different building sizes for the 33 kV facility, a smaller building up to 100 MW and a larger building up to 200 MW.

[*]Depending on the size of the 50-60 kV transformers, see section 4.7.1 and section 4.7.3.

**A transformer bay will be needed for each busbar as the busbar will be divided in two by means of the bus sectionalizer.
***A bus sectionalizer is expected to consist of two bays.

4.6 Transformers

The transformers will be optimised for the individual wind farm, ensuring that it is selected on the basis of power loss and economic conditions. The turbine owner must compensate the inter-array cables and the export cables in such a way that no reactive power is exchanged in the point of connection in line with the applicable provisions of Energinet.dk's current '*Technical regulation 3.2.5 for wind power plants with a power output greater than 11 kW*'. However, following agreement with the electricity supply undertaking, reactive compensation at no load can be placed elsewhere in the public electricity supply grid.

4.7 Construction costs

Construction costs include the initial facilities that are expected to be established. In the following, it is specified what elements are included in the individual standard concepts. For all standard concepts, the costs are calculated for an outdoor substation with outdoor transformers.

4.7.1 Standard concept 1 – advanced 132-150/33 kV substation or advanced 50-60/33 kV substation

The 33 kV cables are routed up to an advanced 132-150/33 kV substation or a deployed 50-60/33 kV substation.

See sections 5.2 to 5.7 for details on the location of the deployed substations. A deployed substation will not be established on the island of Bornholm.

The above includes costs for the 33 kV onshore cables and a 33 kV switchgear with the necessary bays for the connection of cables, transformer and metering bay. The 33 kV switchgear includes building costs. Also included are costs incurred for a 132-150/33 kV transformer and connection of the transformer in a 132-150 kV transformer bay. The same applies to a 50-60/33 kV transformer.

If a 100 MW wind farm is connected in a deployed 50-60 kV substation, two transformers are included as near-shore wind farms connected to the 50-60 kV grid rely on the use of transformers which can absorb 50 MW. If it makes more socio-economic sense to connect only one transformer, this solution should be chosen.

It is assumed that a simple deployed substation will be established, where either the 132-150 kV cable or the 50-60 kV cable is terminated in front of the transformer in question and connected to the transformer through a simple transformer bay.

The deployed substation is connected to the existing grid via a standard line bay. See the figure in section 9.1 for more details.

Costs relating to land acquisition and a small control building have been added in respect of the deployed substation.

Also included are any acceleration costs regarding the transmission grid.

4.7.2 Standard concept 2 – connection of 33 kV in existing 132-150/50-60 kV substation

The 33 kV cables are routed from the chosen landing point up to the existing 132-150 kV substation.

The above includes costs for the 33 kV onshore cables and a 33 kV switchgear with the necessary bays for the connection of cables, transformer and metering bay. The 33 kV switchgear includes building costs. Also included are costs incurred for a 132-150/33 kV transformer and connection of the transformer in a 132-150 kV transformer bay. See the figure in section 9.2 for more details.

Also included are any acceleration costs regarding the transmission grid.

4.7.3 Standard concept 3 – connection of 33 kV in existing 50-60 kV substation

The 33 kV cables are routed from the chosen landing point up to an existing 50-60 kV substation which is capable of absorbing the power.

For North Sea South and North Sea North, the 33 kV cables are routed up to the nearest 150/60 kV substation as the existing 60 kV grid is already under heavy strain from production. If the near-shore wind farms are connected to the existing 60 kV grid, the 60 kV grid must be reinforced by replacing the existing overhead lines with underground cables. Given that the overhead lines are already under heavy strain from onshore wind turbine production, further reinforcements will be required for integrating a near-shore wind farm into the existing 60 kV grid.

For North Sea South and North Sea North, the possibility of connecting 50 MW and 100 MW has been examined.

For Sæby the 33 kV cables are also routed either up to the 150/60 kV Dybvad substation or to the 150/60 kV Starbakke substation as much of the 60 kV grid around Sæby and Frederikshavn has already been placed underground. The entire overhead line 60 kV grid around Frederikshavn has been replaced with underground cables. If a near-shore park is connected to the existing 60 kV grid, additional underground cabling will be required in the 60 kV grid already placed underground as the underground 60 kV grid has not been designed to absorb such levels of power.

For Sæby, the possibility of connecting 50 MW and 100 MW has been examined.

For Sejerø Bay, the 33 kV cables are routed up to the 50 kV Røsnæs substation, regardless of whether the western or the eastern landing point is used. A wind farm with a maximum capacity of 50 MW may be connected to the 50 kV grid, which requires replacing the existing 50 kV overhead line with underground cables and replacing partial underground cabling between Røsnæs and Kalundborg with new cables. The cable route is very narrow approaching Kalundborg, making the establishment of additional cable systems difficult. It is therefore proposed to replace the existing partial underground cabling and the overhead line to Røsnæs.

For Sejerø Bay, the possibility of connecting 50 MW has been examined.

For the coastal waters off Småland, the possibility of connecting 33 kV cables in the existing 50 kV substation at Stigsnæs Power Station via a 50/33 kV transformer is not examined as there is not enough space at the 50 kV facility to accommodate the transformer and 33 kV switchgear.

For Bornholm, the 33 kV cables are routed straight to the 60 kV Rønne South substation, from which two 60 kV cables and an overhead line originate. A maximum of 50 MW from a near-shore wind farm may be integrated into the existing 60 kV cable to Sweden, when taking into account the other known production on Bornholm.

The above includes costs for the 33 kV onshore cables and a 33 kV switchgear with the necessary bays for the connection of cables, transformer and metering bay. The 33 kV switchgear includes building costs. See the figure in section 9.2 for more details as standard concept 3 is basically identical to standard concept 2.

For a 50 MW wind farm, a 50-60/33 kV transformer and connection of it with a 50-60 kV transformer bay is included. For a 100 MW wind farm, two transformers are included as near-shore wind farms connected to the 50-60 kV grid rely on the use of transformers which can absorb 50 MW. If it makes more socio-economic sense to connect only one transformer, this solution should be chosen.

Also included are any acceleration costs regarding the transmission grid.

4.7.4 Standard concept 4 – connection of 50-60 kV in existing 50-60 kV substation

The 50-60 kV cables are routed from the chosen landing point up to an existing 50-60 kV substation which is capable of absorbing the power.

For North Sea South, North Sea North, Sæby, Sejerø Bay and Bornholm, the same conditions regarding choice of solution and principles apply as for standard concept 3.

For the coastal waters off Småland, the 50 kV cables are laid straight to the 132/50 kV substation at Stigsnæs Power Station connected to a 50 kV line bay. Further expansion is not possible.

The costs of the 50-60 kV onshore cables and a number of 50-60 kV connection bays corresponding to the number of cables have been calculated for the above. At Stigsnæs Power Station it is only possible to connect the near-shore wind farm in one 50 kV bay.

Also included are any acceleration costs regarding the transmission grid.

5. Technical and financial analyses

For each of the six selected locations, grid analyses and financial calculations have been performed to determine the technically/financially optimum landing solution for wind farm sizes up to 200 MW in increments of 50 MW. The grid analyses are performed on the basis of Energinet.dk's usual calculation assumptions and methods supplemented by up-to-date knowledge of future wind turbine projects. The costs are determined on the basis of general budget prices for the facility components used, including design and establishment costs. The total costs associated with operation and maintenance as well as transmission loss during the connection facility's lifetime are also included based on an estimate of the offshore wind farms' production duration curve.

In some cases, the grid analyses identified a need for reinforcements in the underlying transmission grid in order to be able to move power from the local area in situations where the area is unable to consume all the power produced. The costs of such reinforcements are included either as direct costs or as costs incurred for the acceleration of already planned investments.

Based on the location of the six locations for the erection of near-shore wind farms, one or two landing points have been defined for each location. The landing points are defined on the basis of the shortest possible cable route, taking into account the nature, environment and other conditions at sea and on land.

For each location and for all combinations of landing points and wind farm sizes, it has been calculated which of the four standard concepts represent the most cost-effective connection solution while at the same time fulfilling Energinet.dk's Grid dimensioning criteria. These calculations and descriptions of points of connection, cable lengths and other reinforcements for each of the six selected locations can be found in Appendix 2. In this section, the results of the calculations are exclusively presented as a brief description of the recommended optimum solution for each location.
Because the calculations do not include construction costs regarding the parts located at sea and up to the shore, there may be cases where another landing point or another of the four standard concepts is more suitable than the one suggested when considering the project as a whole. In such cases, the costs of other standard concepts can be found in Appendix 2.

The map sections in the following sections show the possible locations of the wind farms. The maps also indicate the new possible onshore and offshore cable routes included in the environmental impact assessments.

5.1 General – sections 5.2 to 0

In the following sections, the construction costs are calculated and allocated according to the descriptions in section 3.6 Cost allocation.

For estimation purposes, the operating and maintenance costs are fixed at 3% of the fixed asset investment. The grid company and the turbine owner pay their own operating and maintenance costs. The calculated operating and maintenance costs in the tables are therefore only intended as a guide.

As mentioned in section 3.4, the grid loss costs are calculated from the edge of the offshore wind farm up to the first onshore transformation point. Hence, it should be noted that the part of the grid loss originating from the offshore wind farm's internal grid has not been calculated and will therefore constitute a substantial part of the total transmission losses. The reason why the transmission loss of the internal grid in the offshore wind farm has not been calculated is that the erection pattern and thus the laying of the cables and their cross-sections are unknown at the present time.

Based on the Danish Energy Agency's proposed cost allocation, the following assumes that the turbine owner is required to pay for transmission losses up to the point of connection on land. The cost allocation between the turbine owner and the grid company/Energinet.dk will therefore depend on where permission for the establishment of the point of connection can be obtained.

If permission for the establishment of a deployed substation near the shore can be obtained, the point of connection on the bushings of the transformer will be on the side with the same voltage level as the export cables. If permission for the establishment of a deployed substation can be obtained, but the current wind farm size dictates that the export cables should be routed up to the existing grid instead of establishing a near-shore transformation point, the point of connection will still be where the deployed substation could have been established. This ensures the same cost allocation regardless of wind farm size.

The connection solutions for the individual wind farm sizes recommended from a socio-economic perspective are all proposed on the basis of the costs of establishing the onshore facilities, transmission loss costs and operating and maintenance costs. No account is taken of the costs relating to the offshore facilities as these are not known in advance. If a wind turbine erector recommends using another selected and examined landing point than the recommended one with the lowest socio-economic costs on land, it is recommended to include the costs at sea to ensure that the lowest possible socio-economic costs for the total facility can be achieved.

5.2 North Sea South

The possibility of connecting near-shore wind turbines to the grid in the North Sea just north of Hvide Sande, bordered to the north by a wedge-shaped area, has been examined; see the map section shown in Figure 1.

The two selected landing points are shown on the map, and the possibility of establishing a deployed substation near Holmsland, Tyvmose or the existing 60 kV Søndervig substation has been examined. In any case, the connection to the existing grid will have to take place via cables north of Ringkøbing Fjord to the 150 kV Lem Kær substation.

In order to be able to utilise the wind turbines' capacity, the existing transmission grid must be reinforced. For 100, 150 and 200 MW wind farms, a 150 kV cable must be laid between Lem Kær and Stoustrup, incl. a conversion of the 150 kV facility in Stoustrup into a double busbar facility[3]. The cable must be compensated by a 40 Mvar reactor, which in most cases will be placed in Stoustrup. In some cases, the best solution will, however, be to place the reactor in Lem Kær as this would allow for overall optimisation of the installed reactors. Both the cable connection, substation conversion and reactor installation will take place earlier than the already planned activities described in the Network Development Plan 2013.

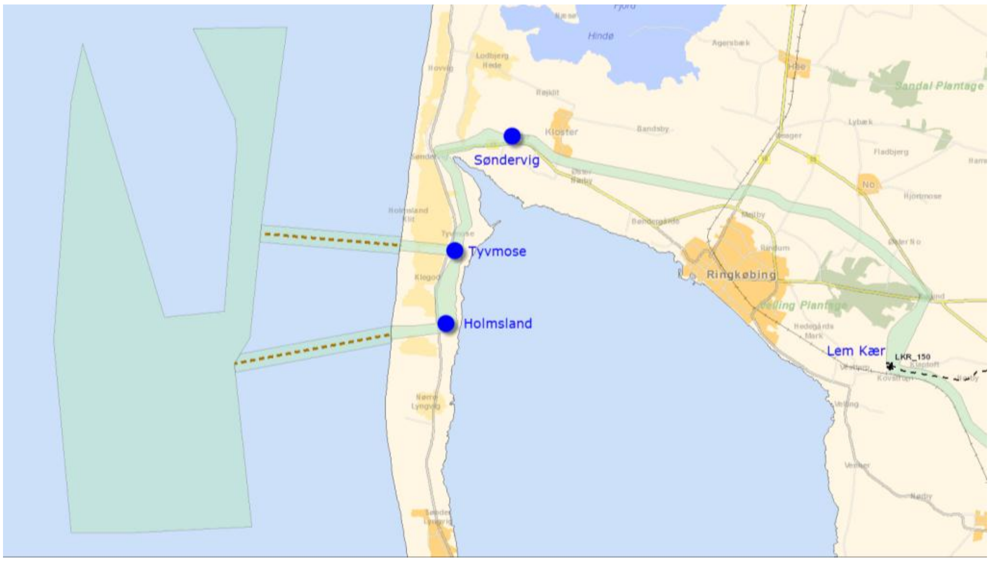


Figure 1: North Sea South

3 Municipal plans for the establishment of additional onshore wind power turbines near Lem Kær may require reinforcements to be made for wind farms below 50 MW as well.

5.2.1 Connection depending on wind farm size

5.2.1.1 50 MW (standard concept 4)

For 50 MW wind farms and from a socio-economic perspective, the connection should be made via the northern landing point near Tyvmose. The connection should be made using 60 kV cables laid from the offshore wind farm along the route shown, past Søndervig and all the way to Lem Kær, where they are connected to the existing 60 kV facility.

5.2.1.2 100 MW (standard concept 4)

For 100 MW wind farms and from a socio-economic perspective, the connection should be made via the northern landing point near Tyvmose. The connection should be made using 60 kV cables laid from the offshore wind farm along the route shown, past Søndervig and all the way to Lem Kær, where they are connected to the existing 60 kV facility. A total of two 40 Mvar reactors will be installed at Lem Kær and Stoustrup, of which the latter is intended for the compensation of the 150 kV cable between Lem Kær and Stoustrup, which results in earlier deployment than stated in the Network Development Plan 2013.

5.2.1.3 150-200 MW (standard concept 1a)

For 150 and 200 MW wind farms and from a socio-economic perspective, the connection should be made via the northern landing point near Tyvmose. The connection should be made using 33 kV cables laid from the offshore wind farm to an advanced 150/33 kV substation located near Tyvmose and connected to Lem Kær by means of a 150 kV cable. A total of three 40 Mvar reactors will be installed at Tyvmose, Lem Kær and Stoustrup, of which the latter is intended for the compensation of the 150 kV cable between Lem Kær and Stoustrup which results in earlier deployment than stated in the Network Development Plan 2013.

5.2.1.4 Common factors for all wind farm sizes

The wind farm's point of connection and thus cost allocation will depend on whether permission can be obtained for the establishment of a deployed transformation point. The cost allocation between the turbine owner and the grid company/Energinet.dk is shown in the tables below based on a point of connection at either Holmsland, Tyvmose or Søndervig.

5.2.2 Cost allocation with the point of connection located at Holmsland:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and maintenance [DKK million]	Transmission loss [DKK million]
50	61	Energinet.dk	0.0	0.0	3.6
		Grid company	36.2	1.1	14.5
		Turbine owner	2.2	0.1	3.7
100	170	Energinet.dk	46.8	1.4	6.7
		Grid company	72.4	2.2	29.0
		Turbine owner	4.4	0.1	7.4
150	227	Energinet.dk	161.3	4.8	9.0
		Grid company	0.0	0.0	0.0
		Turbine owner	18.2	0.5	33.1
200	240	Energinet.dk	163.3	4.9	11.8
		Grid company	0.0	0.0	0.0
		Turbine owner	20.5	0.6	39.3

5.2.3 Cost allocation with the point of connection located at Tyvmose:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construc-tion costs [DKK million]	Operation and maintenance [DKK million]	Transmis-sion loss [DKK million]
50	**56**	Energinet.dk	0.0	0.0	3.6
		Grid company	32.6	1.0	13.0
		Turbine owner	2.3	0.1	3.4
100	**160**	Energinet.dk	46.8	1.4	6.6
		Grid company	65.2	2.0	26.1
		Turbine owner	4.7	0.1	6.8
150	**218**	Energinet.dk	154.8	4.6	9.0
		Grid company	0.0	0.0	-
		Turbine owner	18.8	0.6	30.6
200	**232**	Energinet.dk	156.8	4.7	11.8
		Grid company	0.0	0.0	0.0
		Turbine owner	21.3	0.6	36.3

5.2.4 Cost allocation with the point of connection located at Søndervig:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmis-sion loss [DKK million]
50	**56**	Energinet.dk	0.0	0.0	3.6
		Grid company	25.0	0.7	9.9
		Turbine owner	10.0	0.3	6.6
100	**160**	Energinet.dk	46.8	1.4	6.6
		Grid company	49.9	1.5	19.7
		Turbine owner	20.0	0.6	13.2
150	258	Energinet.dk	130.5	3.9	8.9
		Grid company	0.0	0.0	0.0
		Turbine owner	54.4	1.6	58.3
200	283	Energinet.dk	132.5	4.0	11.6
		Grid company	0.0	0.0	0.0
		Turbine owner	64.0	1.9	69.2

It should be noted that the above costs are based on an outdoor 150 kV facility for connection of the 150/33 kV transformer being established for 150 MW and 200 MW wind farms. If, as a result of public authority requirements, an indoor facility must be established instead due to the substation's close proximity to the holiday home area and Ringkøbing Fjord, the costs will increase by approx. DKK 14-16 million.

The descriptions and costs of the other connection solutions are stated in Appendix 2.

5.3 North Sea North

The possibility of grid connection of near-shore wind turbines in an area beginning south of Thyborøn and continuing down along the coast to Ferring has been examined. A map section of the area is shown in Figure 2.

Two possible landing points have been chosen as shown on the map. At the northern landing point, the possibility of establishing a deployed substation near Vejlby has been examined, while at the southern landing point the possibility of establishing a deployed substation near Ferring has been examined. For both landing points, the connection of the offshore wind farm to the existing transmission grid is to take place in a new 150 kV Lomborg substation located east of the existing Ramme substation as this substation cannot be further expanded. The Lomborg substation is connected to the existing 150 kV cable between Ramme and Struer.

Figure 2: North Sea North

In order to be able to utilise the power produced by the wind turbines, it is necessary to lay a 150 kV cable between the new Lomborg substation and Idomlund for all the wind farm sizes examined. This connection must be compensated by a 70 Mvar reactor at Idomlund. For 150 MW and 200 MW wind farms, an additional 150 kV cable must be laid between Idomlund and Herning which will have to be compensated by a 100 Mvar variable reactor at Herning[4] and a 100 Mvar variable reactor at Idomlund.

The 150 kV Idomlund-Lomborg connection is included in Network Development Plan 2013, so the costs of this connection and the related reactor are included in the analyses as accelerated investments.

5.3.1 Connection depending on wind farm size

5.3.1.1 50-100 MW (standard concept 4)

For 50 and 100 MW wind farms and from a socio-economic perspective, the connection should be made via the southern landing point. The connection should be made using 60 kV cables laid from the offshore wind farm along the route shown, past Ferring and all the way up to the new Lomborg substation. Lomborg must be established as a 150/60 kV substation connected to the existing 150 kV cable between Ramme and Struer.

5.3.1.2 150-200 MW (standard concept 1a)

For 150 and 200 MW wind farms and from a socio-economic perspective, the connection should be made via the southern landing point. The connection should be made using 33 kV cables laid from the offshore wind farm to a deployed 150/33 kV substation located near Ferring and connected to Lomborg by means of a 150 kV cable. Lomborg is connected to the existing 150 kV cable between Ramme and Struer, and a 40 Mvar reactor is installed at Ferring and Lomborg.

5.3.1.3 Common factors for all wind farm sizes

The wind farm's point of connection and thus cost allocation will depend on whether permission can be obtained for the establishment of a deployed transformation point. The cost allocation between the turbine owner and the grid company/Energinet.dk is shown in the tables below based on a point of connection at either Ferring or Vejlby.

[4] The existing 50 Mvar reactor at Herning is replaced by the variable reactor.

5.3.2 Cost allocation with the point of connection located at Ferring:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and maintenance [DKK million]	Transmission loss [DKK million]
50	**96**	Energinet.dk	63.2	1.9	3.5
		Grid company	16.3	0.5	5.9
		Turbine owner	1.5	0.0	3.1
100	**127**	Energinet.dk	64.8	1.9	6.4
		Grid company	31.4	0.9	11.7
		Turbine owner	3.0	0.1	6.2
150	**-195**	Energinet.dk	138.8	4.2	9.0
		Grid company	0.0	0.0	0.0
		Turbine owner	15.0	0.5	27.1
200	**206**	Energinet.dk	140.8	4.2	11.8
		Grid company	0.0	0.0	0.0
		Turbine owner	16.7	0.5	32.1

5.3.3 Cost allocation with the point of connection located at Vejlby:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and maintenance [DKK million]	Transmission loss [DKK million]
50	-106	Energinet.dk	63.2	1.9	3.5
		Grid company	24.1	0.7	9.3
		Turbine owner	0.7	0.0	2.8
100	147	Energinet.dk	64.8	1.9	6.5
		Grid company	47.0	1.4	18.6
		Turbine owner	1.4	0.0	5.7
150	219	Energinet.dk	168.7	5.1	9.0
		Grid company	0.0	0.0	0.0
		Turbine owner	11.2	0.3	24.6
200	229	Energinet.dk	170.7	5.1	11.8
		Grid company	0.0	0.0	0.0
		Turbine owner	12.2	0.4	29.1

The descriptions and costs of the other connection solutions are stated in Appendix 2.

5.4 Dependencies between North Sea South and North Sea North

The North Sea South and North Sea North locations are so close to one another that the infeed of power generated by one location affects the conditions for the other location. This is due to large amounts of power being generated by wind turbines in this area, resulting in occasional surplus power which must be transmitted via the transmission grid.

This requires reinforcements of the existing transmission grid, which are not only related to the establishment of an offshore wind farm in one location, but also determined by the combination of the power infeed at North Sea South and North Sea North. This is shown in the table below to which the costs specified in sections 5.2 and 0 should be added:

South / North	0 MW	50 MW	100 MW	150 MW	200 MW
0 MW	-	-	-	150 kV cable HER-IDU	150 kV cable HER-IDU
50 MW	-	-	-	150 kV cable HER-IDU	IDU KT52 and 150 kV cable HER-IDU
100 MW	-	-	-	IDU KT52	IDU KT52 and 150 kV cable HER-IDU
150 MW	-	150 kV cable HER-IDU	IDU KT52	IDU KT52 and 150 kV cable HER-IDU	IDU KT52 and 150 kV cable HER-IDU
200 MW	150 kV cable HER-IDU	IDU KT52	IDU KT52 and 150 kV cable HER-IDU	IDU KT52 and 150 kV cable HER-IDU	

The following abbreviations are used in the table above: HER = 150 kV substation at Herning, IDU = 400/150 kV substation at Idomlund, IDU KT52 = 400/150 kV transformer 2 at Idomlund.

The 150 kV cable connection between Herning-Idomlund, including the related 100 Mvar variable reactor at Herning, is included in Network Development Plan 2013 for establishment in 2021 and must therefore be included in the financial calculations as an expense brought forward from 2021 to 2019. The expense is calculated at DKK 11 million in 2014 prices.

The cost of connecting the 400/150 kV transformer 2 in the 400 kV substation at Idomlund has been calculated at DKK 33 million.

The above reinforcement may become necessary for some of the combinations where no reinforcement need is specified if more power is connected on land than assumed in the projections.

The costs are borne by Energinet.dk as part of the costs incurred for the necessary expansion of the transmission grid resulting from the integration of renewable energy.

5.5 Sæby

The location selected for the erection of near-shore wind turbines off the coast of Sæby can be seen from the map section in Figure 3.

Landing points have been appointed in the northern and southern part of the location as the central part of the location is located off the coast of Sæby where landing is deemed inexpedient due to the proximity to Sæby. The possibility for establishing deployed substations at Haldbjerg or Solsbæk have been examined for the two landing points.

The connection to the existing transmission grid can thus be made to the 150 kV Starbakke substation west of Frederikshavn, or to the 150 kV Dybvad substation south-west of Sæby.

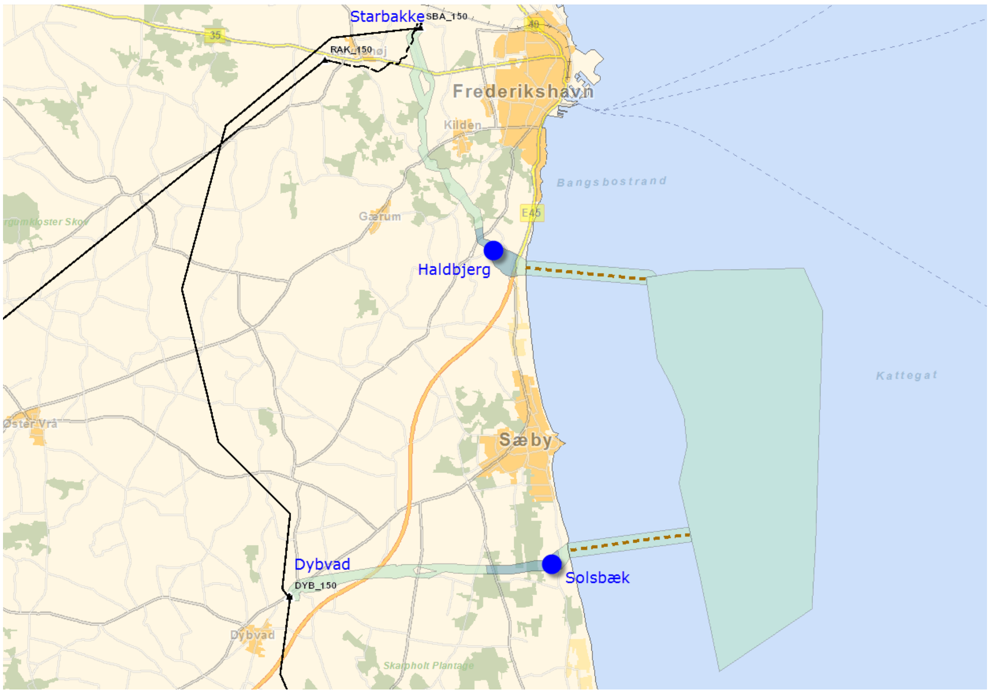


Figure 3: Sæby

5.5.1 Connection depending on wind farm size

5.5.1.1 50-100 MW (standard concept 4)

For 50 and 100 MW wind farms and from a socio-economic perspective, the connection should be made via the southern landing point. The connection should be made using a 60 kV cable laid from the offshore wind farm along the route shown, past Solsbæk and all the way up to the 60 kV Dybvad substation.

5.5.1.2 150-200 MW (standard concept 1a)

For 150 and 200 MW wind farms and from a socio-economic perspective, the connection should be made via the southern landing point. The connection should be made using 33 kV cables laid from the offshore wind farm to a deployed 150/33 kV substation located near Solsbæk and connected to Dybvad by means of a 150 kV cable. Dybvad is converted into a double busbar facility, and a 40 Mvar reactor is installed.

5.5.1.3 Common factors for all wind farm sizes

The wind farm's point of connection and thus cost allocation will depend on whether permission can be obtained for the establishment of a deployed transformation point. The cost allocation between the turbine owner and the grid company/Energinet.dk is shown in the tables below based on a point of connection at either Solsbæk or Haldbjerg.

5.5.2 Cost allocation with the point of connection located at Solsbæk:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and maintenance [DKK million]	Transmission loss [DKK million]
50	**28**	Energinet.dk	0.0	0.0	3.4
		Grid company	14.8	0.4	5.5
		Turbine owner	1.1	0.0	2.8
100	**55**	Energinet.dk	0.0	0.0	6.2
		Grid company	29.6	0.9	10.9
		Turbine owner	2.2	0.1	5.5
150	**126**	Energinet.dk	77.5	2.3	8.6
		Grid company	0.0	0.0	0.0
		Turbine owner	13.1	0.4	24.3
200	**137**	Energinet.dk	79.5	2.4	11.3
		Grid company	0.0	0.0	0.0
		Turbine owner	14.4	0.4	28.8

5.5.3 Cost allocation with the point of connection located at Haldbjerg:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Trans-mission loss [DKK million]
50	29	Energinet.dk	0.0	0.0	3.4
		Grid company	13.4	0.4	4.9
		Turbine owner	2.9	0.1	3.5
100	57	Energinet.dk	0.0	0.0	6.2
		Grid company	30.4	0.9	9.8
		Turbine owner	2.3	0.1	7.0
150	136	Energinet.dk	73.0	2.2	8.6
		Grid company	0.0	0.0	0.0
		Turbine owner	21.4	0.6	30.5
200	150	Energinet.dk	75.0	2.3	11.3
		Grid company	0.0	0.0	0.0
		Turbine owner	24.3	0.7	36.1

The descriptions and costs of the other connection solutions are stated in Appendix 2.

5.6 Sejerø Bay

The possibility of connecting near-shore wind farms to the grid from a triangular area north of Kalundborg has been examined as shown on the map section in Figure 4.

The two selected landing points are shown on the map, and the possibility of establishing a deployed substation at Ågerup or the existing 50 kV Røsnæs substation has been examined. Both landing points have been examined for connection to the existing transmission grid in the 132 kV substation at Asnæs Power Station and in the 50 kV Røsnæs substation.

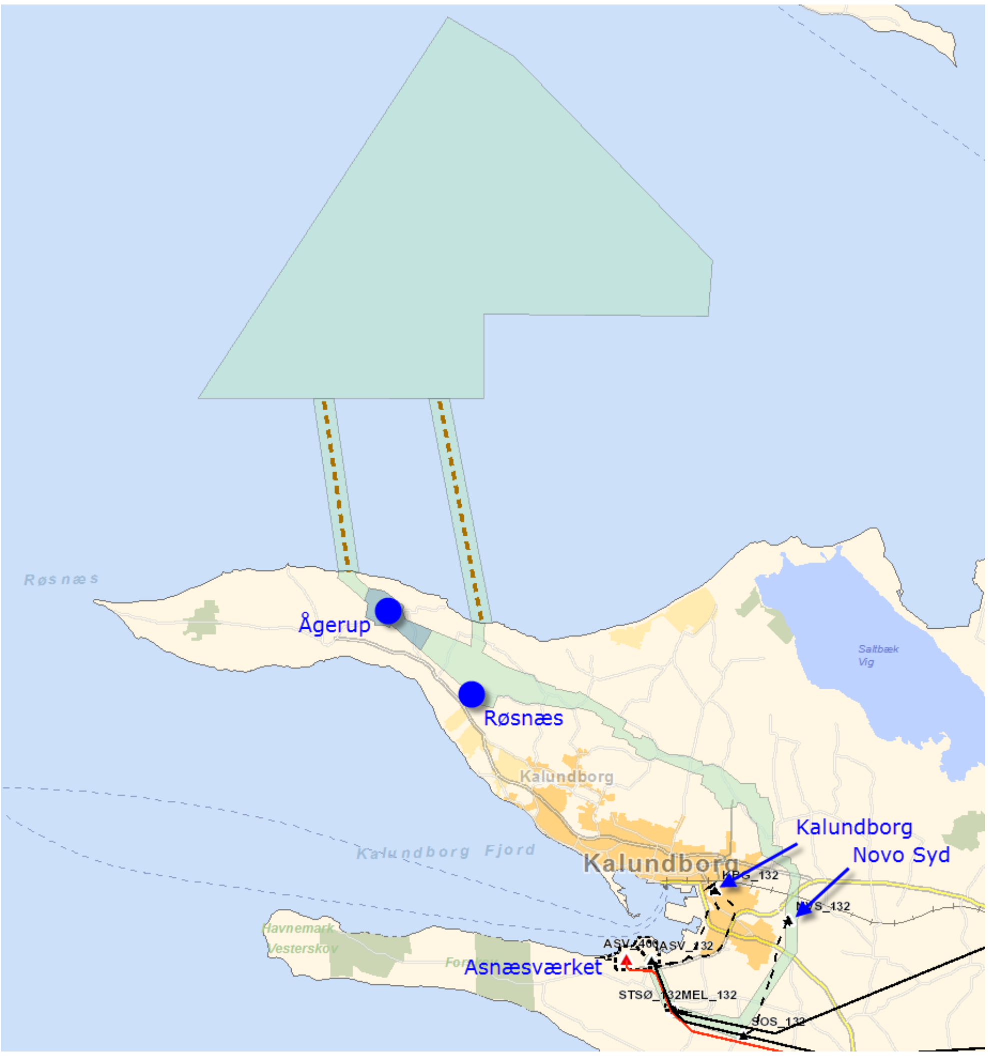


Figure 4: Sejerø Bay

5.6.1 Connection depending on wind farm size

5.6.1.1 50 MW (standard concept 4)

For 50 MW wind farms and from a socio-economic perspective, the connection should be made via the eastern landing point. The connection should be made using a 50 kV cable routed from the offshore wind farm to the existing 50 kV Røsnæs substation.

A 50 kV cable is installed from Røsnæs to Kalundborg as a replacement for the existing 50 kV overhead line between Røsnæs and Kalundborg which is today is partially built as an underground cable.

5.6.1.2 100 MW (standard concept 1a)

For 100 MW wind farms and from a socio-economic perspective, the connection should be made via the eastern landing point. The connection should be made using 33 kV cables laid from the offshore wind farm to a deployed 132/33 kV substation located near the existing 50 kV Røsnæs substation and connected to the 132 kV substation at Asnæs Power Station by means of a 132 kV cable.

5.6.1.3 150-200 MW (standard concept 1a)

For 150 and 200 MW wind farms and from a socio-economic perspective, the connection should be made via the western landing point. The connection should be made using 33 kV cables laid from the offshore wind farm to a deployed 132/33 kV substation located near Ågerup and connected to the 132 kV substation at Asnæs Power Station by means of a 132 kV cable.

For 150 and 200 MW wind farms, a 40 Mvar reactor will be installed at Ågerup in order to compensate the cable.

5.6.1.4 Common factors for all wind farm sizes

The wind farm's point of connection and thus cost allocation will depend on whether permission can be obtained for the establishment of a deployed transformation point. The cost allocation between the turbine owner and the grid company/Energinet.dk is shown in the tables below based on a point of connection at either Ågerup or Røsnæs.

5.6.2 Cost allocation with the point of connection located at Ågerup:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmission loss [DKK million]
		Energinet.dk	0.0	0.0	3.4
50	41	Grid company	20.3	0.6	4.6
		Turbine owner	2.5	0.1	9.8
		Energinet.dk	95.0	2.9	6.2
100	137	Grid company	0.0	0.0	0.0
		Turbine owner	12.9	0.4	20.0
		Energinet.dk	107.2	3.2	9.1
150	**173**	Grid company	0.0	0.0	0.0
		Turbine owner	19.5	0.6	33.7
		Energinet.dk	109.2	3.3	11.9
200	**187**	Grid company	0.0	0.0	0.0
		Turbine owner	22.1	0.7	39.9

5.6.3 Cost allocation with the point of connection located at Røsnæs:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmission loss [DKK million]
50	**39**	Energinet.dk	0.0	0.0	3.4
		Grid company	16.2	0.5	9.3
		Turbine owner	2.7	0.1	6.7
100	**136**	Energinet.dk	88.0	2.6	6.2
		Grid company	0.0	0.0	0.0
		Turbine owner	13.7	0.4	24.9
150	176	Energinet.dk	100.2	3.0	9.0
		Grid company	0.0	0.0	0.0
		Turbine owner	20.8	0.6	42.0
200	191	Energinet.dk	102.2	3.1	11.9
		Grid company	0.0	0.0	0.0
		Turbine owner	23.2	0.7	49.8

The descriptions and costs of the other connection solutions are stated in Appendix 2.

5.7 Coastal waters off Småland

The location selected for the erection of near-shore wind farms in the coastal waters off Småland is south of Stigsnæs Power Station and is shown on the map section in Figure 5.

Two landing points have been defined for this location. At the western landing point, the possibility of establishing a deployed substation near Klintevej is examined. At the eastern landing point, the cables are routed along a longer route straight to Stigsnæs Power Station. For both solutions, the connection to the existing transmission grid must be made in the 132 kV substation at Stigsnæs Power Station.

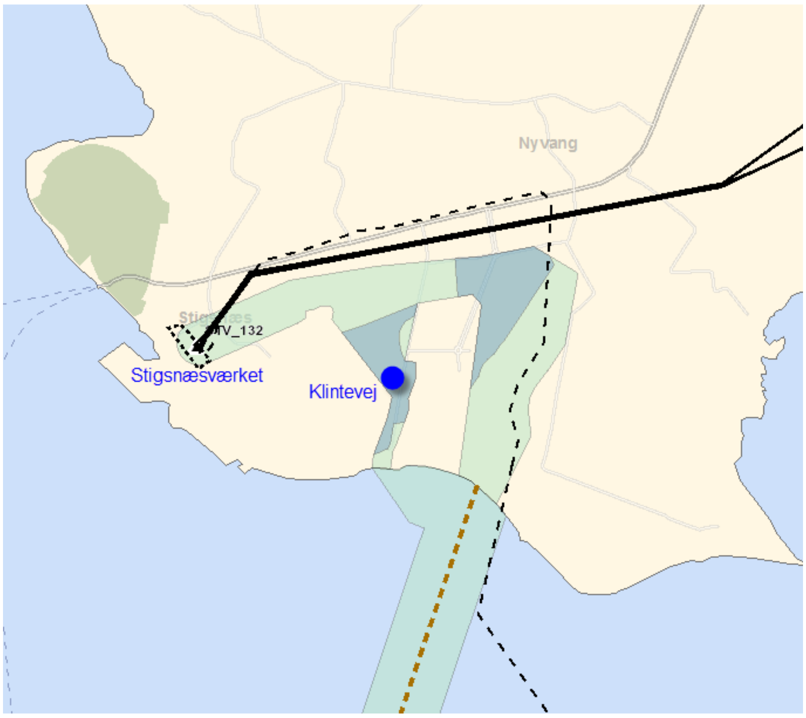


Figure 5: Coastal waters off Småland

5.7.1 Connection depending on wind farm size

5.7.1.1 50-100 MW (standard concept 4)

For 50 MW and 100 MW wind farms and from a socio-economic perspective, the connection should be made via the western landing point using a 50 kV cable laid from the offshore wind farm along the route shown all the way up to the 50 kV substation at Stigsnæs Power Station.

5.7.1.2 150-200 MW (standard concept 2)

For 150 MW and 200 MW wind farms and from a socio-economic perspective, the connection should be made via the western landing point using 33 kV cables laid from the offshore wind farm along the route shown all the way up to the 132 kV substation at Stigsnæs Power Station.

For a 200 MW wind farm, a 40 Mvar reactor is installed at the 132 kV substation at Stigsnæs Power Station.

5.7.1.3 Common factors for all wind farm sizes

The wind farm's point of connection and thus cost allocation will depend on whether permission can be obtained for the establishment of a deployed transformation point. The cost allocation between the turbine owner and the grid company/Energinet.dk is shown in the tables below based on a point of connection at either Klintevej or Stigsnæs Power Station.

5.7.2 Cost allocation with the point of connection located at Stigsnæs Power Station:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmis-sion loss [DKK million]
		Energinet.dk	0.0	0.0	2.9
50	18	Grid company	1.3	0.0	0.0
		Turbine owner	5.6	0.2	8.4
		Energinet.dk	0.0	0.0	5.3
100	32	Grid company	1.3	0.0	0.0
		Turbine owner	11.2	0.3	14.3
		Energinet.dk	14.6	0.4	7.4
150	-106	Grid company	0.0	0.0	0.0
		Turbine owner	32.4	1.0	50.4
		Energinet.dk	27.4	0.8	9.7
200	137	Grid company	0.0	0.0	0.0
		Turbine owner	37.9	1.1	59.7

5.7.3 Cost allocation with the point of connection located at Klintevej:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmis-sion loss [DKK million]
		Energinet.dk	0.0	0.0	2.9
50	15	Grid company	3.7	0.1	1.2
		Turbine owner	1.1	0.0	6.3
		Energinet.dk	0.0	0.0	5.3
100	27	Grid company	6.2	0.2	2.0
		Turbine owner	2.2	0.1	10.6
		Energinet.dk	14.6	0.4	7.4
150	91	Grid company	11.6	0.3	7.1
		Turbine owner	11.3	0.3	37.6
		Energinet.dk	27.4	0.8	9.7
200	118	Grid company	13.9	0.4	8.4
		Turbine owner	12.6	0.4	44.6

The descriptions and costs of the other connection solutions are stated in Appendix 2.

5.8 Bornholm

The selected location off the coast of Bornholm is shown on the map section in Figure 6.

In connection with the establishment of a near-shore wind farm of the coast of Rønne for connection to the existing 60 kV grid on Bornholm, it was agreed with the Danish Energy Agency on 23 January 2014 to only examine the possibility of connecting a 50 MW wind farm to the grid. This is because a larger wind farm would require a new cable to be laid between Bornholm and Sweden as the amount of surplus of power at times will exceed the transferring capability of the existing connection. There is not deemed to be sufficient time to install a new cable between Bornholm and Sweden before the commissioning of the wind farm due to the expected long case handling time and subsequent long installation period. A landing point south of Rønne has been defined as shown on the map.

Figure 6: Bornholm

5.8.1 Connection of 50 MW

5.8.1.1 50 MW (standard concept 4)

For a 50 MW wind farm and from a socio-economic perspective, the connection should be made via the landing point and the eastern wind farm corridor using a 60 kV cable laid from the offshore wind farm along the route shown all the way up to the 60 kV Rønne South substation.

5.8.2 Cost allocation with the point of connection located at Rønne South via the eastern corridor:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmission loss [DKK million]
50	**8**	Grid company	1.3	0.0	0.0
		Turbine owner	1.9	0.1	4.8

5.8.3 Cost allocation with the point of connection located at Rønne South via the eastern corridor:

Wind farm size [MW]	Total costs [DKK million]	Cost bearer	Construction costs [DKK million]	Operation and main-tenance [DKK million]	Transmission loss [DKK million]
50	10	Grid company	1.3	0.0	0.0
		Turbine owner	1.9	0.1	6.8

The descriptions and costs of the other connection solutions are stated in Appendix 2.

6. Total losses in the transmission system

Calculations have been made of the total extra transmission losses that 350 MW installed capacity from near-shore wind turbines may produce in the overall power system in Jutland and/or on Zealand and Funen. The calculations are based on the combinations of installed capacity that may result in the greatest overall losses and may therefore be regarded as worst-case calculations. The transmission losses are capitalised over a period of 25 years.

No transmission loss has been calculated for the overall 60 kV grid on Bornholm as the transmission losses resulting from the connection of a 50 MW wind farm on Bornholm are not comparable with the transmission losses in the worst-case calculations for Jutland/Funen and Zealand.
The tables can be used to compare different combinations as the grid losses differ depending on the size of the wind farms and where they are connected.

The table below shows the capitalised transmission losses for Jutland/Funen for the combinations resulting in the largest loss increases:

North Sea South [MW]	200	200	200	200	150	150	150	150	150
North Sea North [MW]	150	100	50	0	200	150	100	50	0
Sæby [MW]	0	50	100	150	0	50	100	150	200
Cap. transmission loss [DKK million]	221	200	-195	204	205	186	183	196	191

North Sea South [MW]	100	100	100	100	50	50	50	0	0
North Sea North [MW]	200	150	100	50	200	150	100	200	150
Sæby [MW]	50	100	150	200	100	150	200	150	200
Cap. transmission loss [DKK million]	172	171	184	172	172	197	174	149	157

It appears from the above table that there may be extra transmission losses in the Jutland/Funen power system corresponding to as much as DKK 221 million if 350 MW near-shore wind farms are established in the selected locations. The largest transmission losses occur in connection with the erection of 200 MW offshore wind turbines in North Sea South and 150 MW offshore wind turbines in North Sea North. This is natural, given that large amounts of power at the location are already being transported in the transmission grid as the transmission loss is determined by the square of the current, ie i^2 x r.

At the same time, the combination with the lowest cost is calculated at DKK 149 million, not using North Sea South but dividing production between North Sea North and Sæby.

The capitalised value of the additional transmission losses in the Zealand power system appears from the table below:

Sejerø Bay	200	150
Coastal waters off Småland [MW]	150	200
Cap. transmission loss [DKK million]	188	231

As shown above, additional transmission losses may occur in the Zealand power system equivalent to a capitalised value of DKK 231 million. This is the result of the establishment of 150 MW in Sejerø Bay and 200 MW in the coastal waters off Småland.

The calculation of the transmission losses is subject to some uncertainty as they are calculated on the basis of the first full year of operation (2020). No account is thus taken of the development in the transmission grid in the years ahead, nor of any power generated by future wind farms, including new large offshore wind farms.

In the event of an expansion of the transmission grid, the individual cables will also be optimised in relation to transmission losses, thereby reducing the transmission losses. The transmission loss costs shown should therefore be seen as a guide.

When the final wind farm sizes and their location are known, new grid loss calculations may be performed to better reflect the expected transmission losses.

7. Loss of production

A number of assessments have been performed of the costs resulting from a production loss in the event of a breakdown of all or some parts of the connection facility from the seashore up to the point in the existing grid to which the offshore wind farms are to be connected. The calculation of the costs resulting from the loss of production is based on the error probability that a given component is not available and a specific outage time for it, which influences the amount of power that cannot be supplied to the grid by the wind farm.
The costs resulting from the loss of production are calculated for all six locations, for the different connection solutions at the individual locations and for all four wind farm sizes from 50 MW to 200 MW. Only onshore facilities are included.

The main conclusions concern whether the connection facility should be designed as a single bar facility with one transformer connected or as a double busbar facility with two transformers connected. If choosing one design over another makes more socio-economic sense, the most economical design is recommended.

Connection facility	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Purchasing of strategic backup transformer	50-60/33 kV	132-150/50-60 kV 132-150/33 kV	132-150/50-60 kV 132-150/33 kV	132-150/50-60 kV 132-150/33 kV
Is it profitable to connect the backup transformer during normal operation?	Yes – towards 33 kV GIS	Yes – towards 50-60 kV GIS Yes – towards 33 kV GIS	Yes – towards 50-60 kV GIS Yes – towards 33 kV GIS	Yes – towards 50-60 kV GIS Yes – towards 33 kV GIS
33 kV GIS – connection of one transformer 33 kV GIS – connection of two transformers	Not profitable Added guarantee	Not profitable Added guarantee	Not profitable Added guarantee	Not profitable Added guarantee
50-60 kV GIS – connection of one transformer 50-60 kV GIS – connection of two transformers	Simple connection Added guarantee	Simple connection Added guarantee	Simple connection Added guarantee	Not profitable Added guarantee
50-60 kV AIS – connection of one transformer 50-60 kV AIS – connection of two transformers	Simple connection Added guarantee	Simple connection Not profitable	Simple connection Not profitable	Simple connection Not profitable
132-150 kV GIS – connection of one transformer 132-150 kV GIS – connection of two transformers	Simple connection Not profitable	Simple connection Added guarantee	Simple connection Added guarantee	Simple connection Added guarantee
132-150 kV AIS – connection of one transformer 132-150 kV AIS – connection of two transformers	Simple connection Not profitable	Simple connection Added guarantee	Simple connection Added guarantee	Simple connection Added guarantee

It appears from the table that it is profitable to purchase one or more backup transformers regardless of the wind farm size selected.

Furthermore, it appears that it is profitable to connect the backup transformer during normal operation for all wind farm sizes as long as the export cables from the wind farm are landed at 33 kV or 50-60 kV and as long as the 50-60 kV cables are terminated in a 50-60 kV GIS. For a 50-60 kV AIS, it is not profitable to connect two transformers during normal operation, which is why this is indicated as being 'Not profitable'.

Because it is profitable to connect two transformers against the 33kV GIS, this makes more socio-economic sense than connecting only one transformer as the costs resulting from the loss of production are higher than the fixed asset investment, which is why connecting one transformer is indicated as being 'Not profitable'.

In principle, a 50 MW wind farm can be connected via a 132-150/33kV transformer, but the above table shows that it is not profitable to purchase a backup transformer for storage as the associated costs are higher than the costs resulting from the loss of production. The total fixed asset investments resulting from the connection of 33 kV towards either 50-60 kV or towards 132-150 kV will therefore determine which solution is the most economical.

8. Added guarantee for the sale of generated power

The analyses described in section 5 are all conducted on the basis of Energinet.dk's Grid dimensioning criteria[5] that specify which conditions the grid connection of production facilities must fulfil. If a connection with an added guarantee for the transmission of the generated power is desired, this can be achieved by installing an additional 132-150/33 kV transformer or 50-60/33 kV transformer in cases where the landing cables operate at 33 kV. This will make the landing solution itself n-1 secure in relation to long-term transformer breakdowns. At the same time, a double busbar facility is established at the substation instead of a single busbar facility for improved flexibility.

If it is decided to transmit power using 50-60 kV cables, the connection is made according to the standard concepts described in

[5] Energinet.dk's Grid dimensioning criteria (in Danish) from May 2013 can be found at www.Energinet.dk.

Appendix 1 to an existing 132-150 kV substation. At the existing substations relating to the six near-shore locations, two 132-150/50-60 kV transformers are connected with the exception of Stigsnæs Power Station. Stigsnæs can be expanded with an additional 132/50 kV transformer, if this solution is chosen. If the substation's existing 132/50 kV transformer is disconnected, the near-shore wind farm will also be disconnected as excessive momentary voltage jumps will otherwise occur in the 50 kV subtransmission grid.

The above does not consider who should bear the cost of the improved security as the tender conditions are not known, nor who is liable for loss of production.

The costs of the improved security for the solutions specified range from DKK 18 million to 23 million depending on the wind farm size, location and the connection solution chosen. The costs of the solutions specified in section 5 are shown in the table below:

	50 MW	100 MW	150 MW	200 MW
North Sea South			DKK 21 million	DKK 23 million
North Sea North			DKK 21 million	DKK 23 million
Sæby			DKK 21 million	DKK 23 million
Sejerø Bay		DKK 18 million	DKK 21 million	DKK 23 million
Coastal waters off Småland			DKK 18 million	DKK 23 million
Bornholm				

9. Appendix 1

This appendix describes the four standard concepts used in the assessment of the technically/financially optimum connection solutions for each of the six geographical locations selected. Technically, the four standard concepts can be implemented at all locations, but the financial aspects of each concept will depend on external circumstances such as distance and the design of existing substations.

9.1 Standard concept 1 – deployed 132-150/33 kV transformer (1a) or a deployed 50-60/33 kV transformer (1b) located close to the seashore

A substation is established near the landing point where the 33 kV connections from the offshore wind farms are connected, and transformation to either 132-150 kV (1a) or 50-60 kV (1b) level is carried out. The substation is used solely for the connection of the offshore wind farm in question, and the transformer can thus be considered to be deployed from the substation in the existing transmission grid to which the 50-60-132-150 kV cable is connected. The principle is outlined in Figure 7 for a 132-150 kV connection.

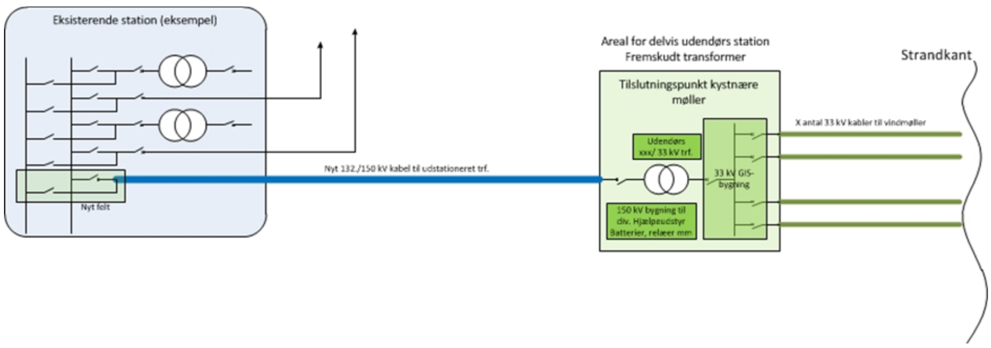


Figure 7

Given that the 50-60 kV grid is not designed to transport large volumes of power, standard concept 1b with an advanced 50-60/33 kV substation only examines the possibility of connecting offshore wind farms of up to 100 MW.

The deployed transformer is established with a 132-150 kV AIS circuit breaker, outdoor transformer, building measuring 8 x 13 metres (W x L) for a 33 kV GIS and miscellaneous auxiliary equipment. The substation building must contain two batteries, simple substation control, remote control, fibre installation and a relay cubicle for the cable and transformer. Separate cubicles/boards for the cable and transformer with tripping of the common circuit breaker in front of the transformer are assumed.

In the existing substation, a standard line bay for the deployed transformer for the production facility is established.

The same applies to connection to a 50-60 kV substation. The deployed transformer is fitted with a 50 kV or a 60 kV AIS circuit breaker. The rest is principally the same.

The space requirement will be approx. 6,000 m2.

9.2 Standard concept 2 – 33 kV landing facility for connection in existing 132-150 kV substation

From the new near-shore wind farm, 33 kV cables are routed straight to an existing 132-150 kV substation in the transmission grid. Typically, the substation closest to the landing point will be chosen, but another substation may be more suitable due to technical conditions.

The existing substation is expanded with the required number of 132-150/33kV transformers, and switchgears are installed for the connection of 33 kV cables. In some cases, it may be necessary to increase the existing substation area.

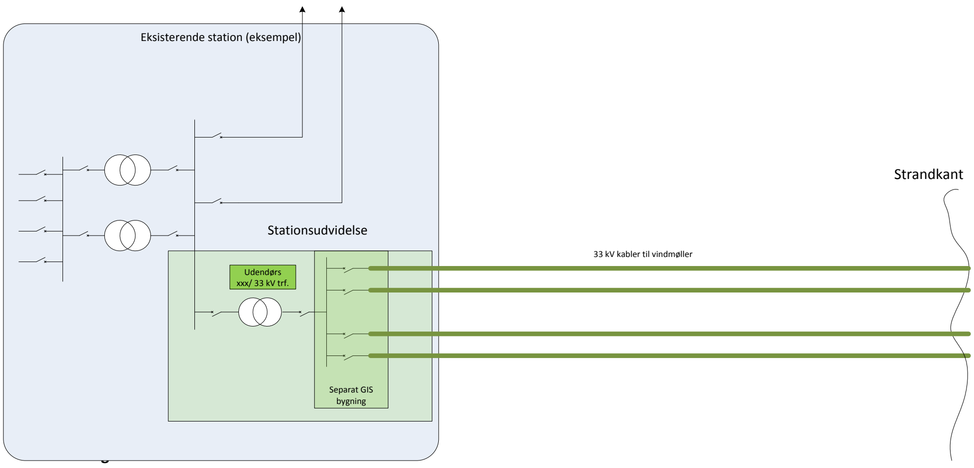


Figure 8

A small building for the 33kV GIS is erected, and auxiliary equipment, communication facilities, substation control etc. are established as extensions of existing facilities. The existing substation battery, rectifier, inverter etc. are expanded to include the 33 kV facility.
A standard transformer bay for connection of a transformer with an oil collection device must be established in the existing substation.

The space requirement of the existing substation is calculated individually.

9.3 Standard concept 3 – 33 kV landing facility for connection in existing 50-60 kV substation

In principle, this solution is identical to solution 2, but the connection is made in an existing 50-60 kV substation in the existing grid, which influences the volume of power that can be absorbed from the offshore wind farm. Standard concept 3 therefore only examines the possibility of connecting offshore wind farms of up to 100 MW.

9.4 Standard concept 4 – 50-60 kV landing facility for connection in existing 50-60 kV substation

If the erector of the wind turbine chooses to establish a 50 or 60 landing facility, this requires the addition of one or more 50-60 kV bays in the nearest 50 or 60 kV substation. There may be situations where the 50 or 60 kV grid cannot handle the power and where the power should instead be carried straight to the nearest 150/60 kV substation as a 60 kV generator cable. This may be if the grid is already fully or partially placed underground, or if the distances are disproportionately long, and large production is already installed.

10.Appendix 2

This appendix reviews the specific connection options for each of the six selected locations on the basis of the four standard concepts. The appendix contains a general description of how the four standard concepts could be implemented in each of the six locations depending on the wind farm size.

For standard concepts 1a and 2, analyses have been carried out for the connection of 50, 100, 150 and 200 MW offshore wind farms. As standard concepts 1b, 3 and 4 involve connection to the 50-60 kV grid, analyses have only been carried out for 50 MW and 100 MW wind farms as it for technical reasons would not be expedient to connect larger production facilities at these voltage levels.

The table below shows the possibilities examined.

	50 MW	100 MW	150 MW	200 MW
Standard concept 1a				
Standard concept 1b			Not relevant	Not relevant
Standard concept 2				
Standard concept 3			Not relevant	Not relevant
Standard concept 4			Not relevant	Not relevant

10.1 North Sea South

In connection with the installation of near-shore wind turbines in the North Sea South location north of Hvide Sande, the connection to the transmission grid must be made in the 150 kV Lem Kær substation via cables north of Ringkøbing Fjord.

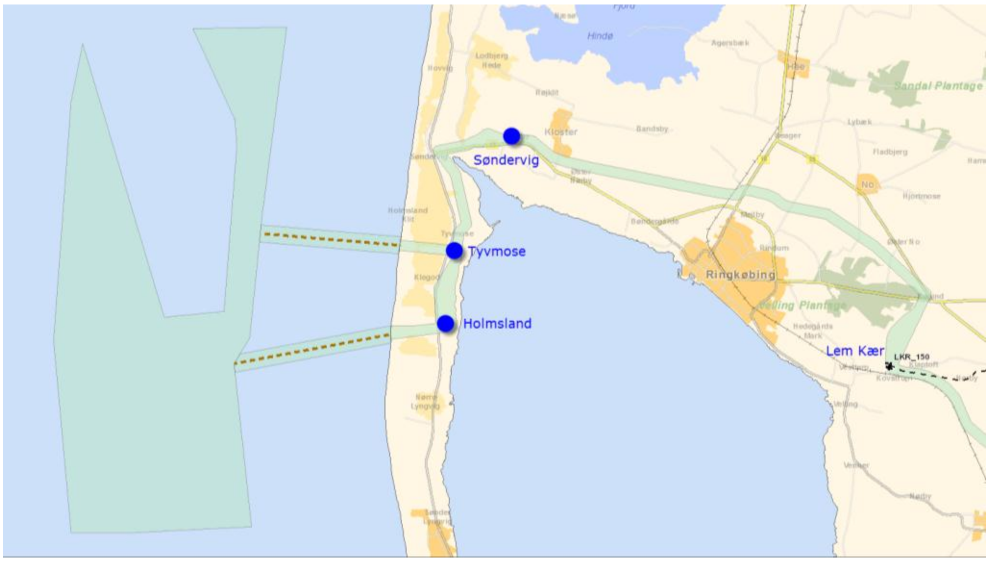


Figure 9

A southern and a northern landing point have been determined, which allows a deployed substation to be established near Holmsland and Tyvmose, respectively. In addition, a deployed substation may be established at the existing 60 kV Søndervig substation.

When connecting 100, 150 and 200 MW capacity at Lem Kær, the underlying 150 kV grid must be reinforced with a new 150 kV connection between Lem Kær and Stoustrup. This section and the required compensation and rebuilding of the Stoustrup substation are included in the Network Development Plan as a replacement for the existing 150 kV overhead line between Stoustrup and Videbæk. The section and the resulting costs are therefore included in the financial calculations as a 12-year acceleration from the planned establishment in 2030. In connection with the acceleration, it has been decided not to remove the overhead line between Stoustrup and Videbæk as the 150 kV grid will not have reached a sufficient level of development in 2020. Consequently, the overhead line will not be removed until the 150 kV cable between Herning and Videbæk is laid.

10.1.1 Connection at Lem Kær 150 kV via Holmsland

10.1.1.1 Standard concept 1

The deployed substation is placed near Holmsland, which is about 1.5 km from the landing point. 33 kV cables are laid from the offshore wind farm to the deployed substation.

Standard concept 1a:
A 150 kV cable is laid from the deployed substation near Holmsland to Lem Kær. At 100, 150 and 200 MW connected capacity, a total of three 40 Mvar reactors are installed at Lem Kær, Stoustrup and Holmsland for compensation of the cables, of which the Stoustrup reactor is triggered by the 150 kV connection between Lem Kær and Stoustrup. The Lem Kær substation is expanded with up to three bays for the connection of cables and reactors.

In cases where the cable between Lem Kær and Stoustrup is required, the 150 kV substation at Stoustrup is expanded with two bays and converted into a double busbar facility.

Standard concept 1b:
One or two 60 kV cables are laid from the deployed substation near Holmsland to Lem Kær substation. For cable compensation purposes, a 40 Mvar reactor is installed at Lem Kær and Stoustrup. The existing 60 kV facility at Lem Kær is also expanded with the necessary new bays.

At 150 kV level, both Lem Kær and Stoustrup are expanded with bays for connection of reactors and the cable connection between the two substations.

10.1.1.2 Standard concept 2

33 kV cables from the offshore wind farm are routed via the southern landing point and Holmsland to the existing substation at Lem Kær where transformation to 150 kV is established at the substation site as described in

Appendix 1, section 9.2. For compensation purposes, 40 Mvar reactors are installed at Lem Kær and Stoustrup. The existing 150 kV facility at Lem Kær must be expanded with new 150 kV bays for connection of the required number of 150/33 kV transformers, reactors and cables towards Stoustrup.

The 150 kV Stoustrup substation is also expanded with two bays and converted into a double busbar facility in cases where the cable between Lem Kær and Stoustrup is required.

10.1.1.3 Standard concept 3

33 kV cables from the offshore wind farm are routed via the southern landing point and Holmsland all the way up to the existing 60 kV substation at Lem Kær where transformation to 60 kV is established as described in

Appendix 1, section 9.3. For cable compensation purposes, 40 Mvar reactors are installed at Lem Kær and Stoustrup. The existing 60 kV substation is expanded with the required number of bays, and at 150 kV level at Lem Kær two new bays are established for the reactor and cable towards Stoustrup.

The 150 kV Stoustrup substation is also expanded with two bays and converted into a double busbar facility in cases where the cable between Lem Kær and Stoustrup is required.

10.1.1.4 Standard concept 4

60 kV cables from the offshore wind farm are routed via the southern landing point and Holmsland to Lem Kær and connected in the existing 60 kV facility. For cable compensation purposes, 40 Mvar reactors are installed at Lem Kær and Stoustrup. The existing 60 kV facility at Lem Kær must also be expanded with one or two new bays depending on the wind farm size, and at 150 kV level at Lem Kær two new bays are established for the reactor and cable towards Stoustrup.

The 150 kV Stoustrup substation is also expanded with two bays and converted into a double busbar facility in cases where the cable between Lem Kær and Stoustrup is required.

10.1.2 Connection at Lem Kær 150 kV via Tyvmose

The four standard concepts for connection at Lem Kær via the northern landing point and Tyvmose will have to be implemented in principally the same way as the connection via the southern landing point and Holmsland described in section 10.1.1.

The distance from the northern landing point to Tyvmose is approx. 1.6 km.

10.1.3 Connection at Lem Kær 150 kV via Søndervig

The four standard concepts for connection at Lem Kær via the northern landing point and Søndervig will have to be implemented in principally the same way as the connection via the southern landing point and Holmsland described in section 10.1.1. However, it will be possible to replace the two 40 Mvar reactors at Lem Kær and Stoustrup with one 70 Mvar reactor located at Lem Kær.

The area of the existing 60 kV substation at Søndervig is expanded as needed for the establishment of a deployed transformer at the other locations.

The distance from the northern landing point to Søndervig is approx. 6.7 km.

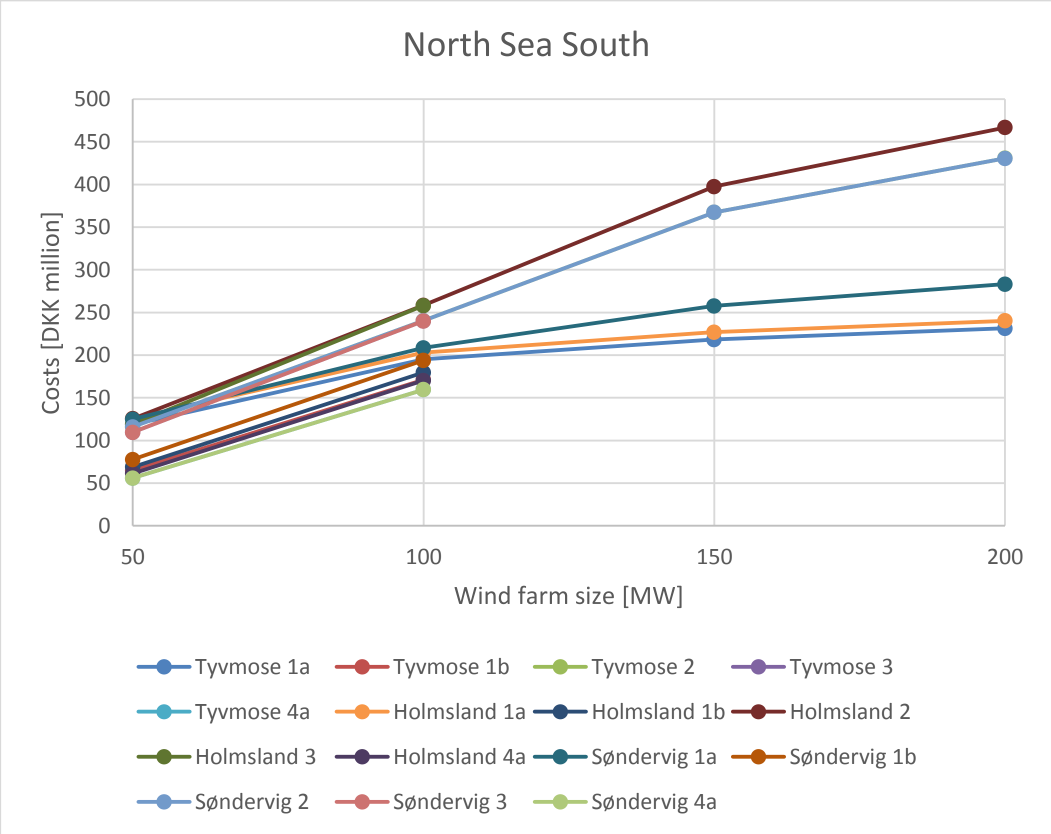
10.1.4 Distances

The following distances are used for the calculation of costs relating to the establishment of a near-shore wind farm at North Sea South:

Målepunkt A	Målepunkt B	Tracelængde i km	Tillæg	Total km
Sydlig parkkorridor	Land	4,6	1,05	4,9
Nordlig parkkorridor	Land	4,1	1,05	4,3
Sydligt ilandføringspunkt	Søndervig	9,0	1,10	9,8
Søndervig	Lem Kær	15,7	1,10	17,3
Nordligt ilandføringspunkt	Søndervig	6,7	1,10	7,3
Søndervig	Lem Kær	15,7	1,10	17,3
Sydligt ilandføringspunkt	Holmsland	1,5	1,10	1,6
Holmsland	Lem Kær	23,2	1,10	25,5
Nordligt ilandføringspunkt	Tyvmose	1,6	1,10	1,7
Tyvmose	Lem Kær	20,8	1,10	22,9
Lem Kær	Stoustrup	24,7	1,10	27,2

10.1.5 Costs

The total costs of the four standard concepts can be seen from the diagram below. As can be seen, whether the connection is made via Holmsland, Tyvmose or Søndervig has no major impact on costs due to the small differences between the geographical distances.



The costs in the diagram above are shown in the table below where the most cost-effective connection methods from a socio-economic perspective are highlighted in bold:

	Method	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Tyvmose (northern)	Standard concept 1a	119	-195	**218**	**231**
	Standard concept 1b	65	171		
	Standard concept 2	116	240	367	431
	Standard concept 3	110	240		
	Standard concept 4	**56**	**160**		
Holmsland (southern)	Standard concept 1a	126	203	227	240
	Standard concept 1b	69	180		
	Standard concept 2	126	258	398	467
	Standard concept 3	119	258		
	Standard concept 4	61	170		
Søndervig (via northern)	Standard concept 1a	125	209	258	283
	Standard concept 1b	78	194		
	Standard concept 2	116	240	367	431
	Standard concept 3	110	240		
	Standard concept 4	**56**	**160**		

Solutions are indicated for 50 MW and 100 MW which have the same level of cost as Tyvmose and Søndervig due to the solutions being based on connection at Lem Kær. It is thus only standard concept 1 which is different as the wind farm is connected in a deployed substation near either Tyvmose or Søndervig.

10.2 North Sea North

In connection with the establishment of the near-shore wind turbines at North Sea North off the coast of Harboøre, the connection to the transmission grid must be made in a new 150 kV Lomborg substation east of the existing Ramme substation. This is necessary as Ramme cannot be further expanded. The new Lomborg substation is connected to the existing 150 kV cable between Ramme and Struer.

Figure 10

The location of North Sea North relative to Lomborg offers the possibility of a southern and a northern landing point with the option of establishing a deployed substation at Ferring or Vejlby.

In order to be able to utilise the capacity provided by the connection of offshore wind turbines at North Sea North, the underlying transmission grid must be reinforced with a new 150 kV cable connection from the new Lomborg substation to Idomlund. This section and related substation conversions and establishment of a 70 Mvar reactor at Idomlund are part of Network Development Plan 2013 and are therefore included in the financial calculations as an 8-year acceleration from the planned establishment in 2026.

10.2.1 Connection in a new Lomborg substation via Ferring

10.2.1.1 Standard concept 1

The deployed substation is placed near Ferring, which is about 1.0 km from the landing point. 33 kV cables are laid from the offshore wind farm to the deployed substation.

Standard concept 1a:
From the deployed substation near Ferring, a 150 kV cable is laid to the new Lomborg substation which is connected to the Ramme-Struer cable. In addition to the 70 Mvar reactor for compensation of the Idomlund-Lomborg cable, a 40 Mvar reactor must be installed at Lomborg for 100, 150 and 200 MW wind farms, and for 150 and 200 MW wind farms a 40 Mvar reactor must also be installed at Ferring.

The new substation at Lomborg must be established with three line bays (one for the offshore wind farm and two for the existing cable towards Ramme and Struer, respectively) and possibly a reactor bay, depending on the wind farm size.

Standard concept 1b:
One or two 60 kV cables are laid from the deployed substation near Ferring to the new Lomborg substation. 150/60 kV transformation must be established at Lomborg, so as to allow the substation to be connected to the existing 150 kV cable between Ramme and Struer.

The new substation at Lomborg is established with one transformer bay and two 150 kV line bays towards Ramme and Struer, respectively.

10.2.1.2 Standard concept 2

33 kV cables from the offshore wind farm are routed all the way up to the new substation at Lomborg where transformation to 150 kV is established as described in

Appendix 1, section 9.2, so as to allow the new substation to be connected to the Ramme-Struer cable.

The new substation at Lomborg is established with bays for connecting transformers and cables.

10.2.1.3 Standard concept 3

33 kV cables from the offshore wind farm are routed all the way up to the new substation at Lomborg where transformation to 60 kV is established as described in

Appendix 1, section9.3. Moreover, transformation to 150 kV level is established, so as to allow the substation to be connected to the Ramme-Struer cable.

The new substation at Lomborg is established with bays for connecting transformers and cables.

10.2.1.4 Standard concept 4

60 kV cables from the offshore wind farm are routed all the way up to the new substation at Lomborg where 150/60 kV transformation is established, so as to allow the substation to be connected to the existing 150 kV cable between Ramme and Struer.

The new substation at Lomborg is established with two 150 kV line bays for connection to the Ramme-Struer cable and one transformer bay. Furthermore, one or two 60 kV line bays for connecting the cable connection from the offshore wind farm are established.

10.2.2 Connection in a new Lomborg substation via Vejlby

In principle, the four standard concepts for connection of the offshore wind farm to the transmission grid at a new substation at Lomborg via the northern landing point are identical to those applying to connection via the southern landing point described in section 10.2.1.

The distance from the northern landing point to Vejlby is approx. 0.4 km.

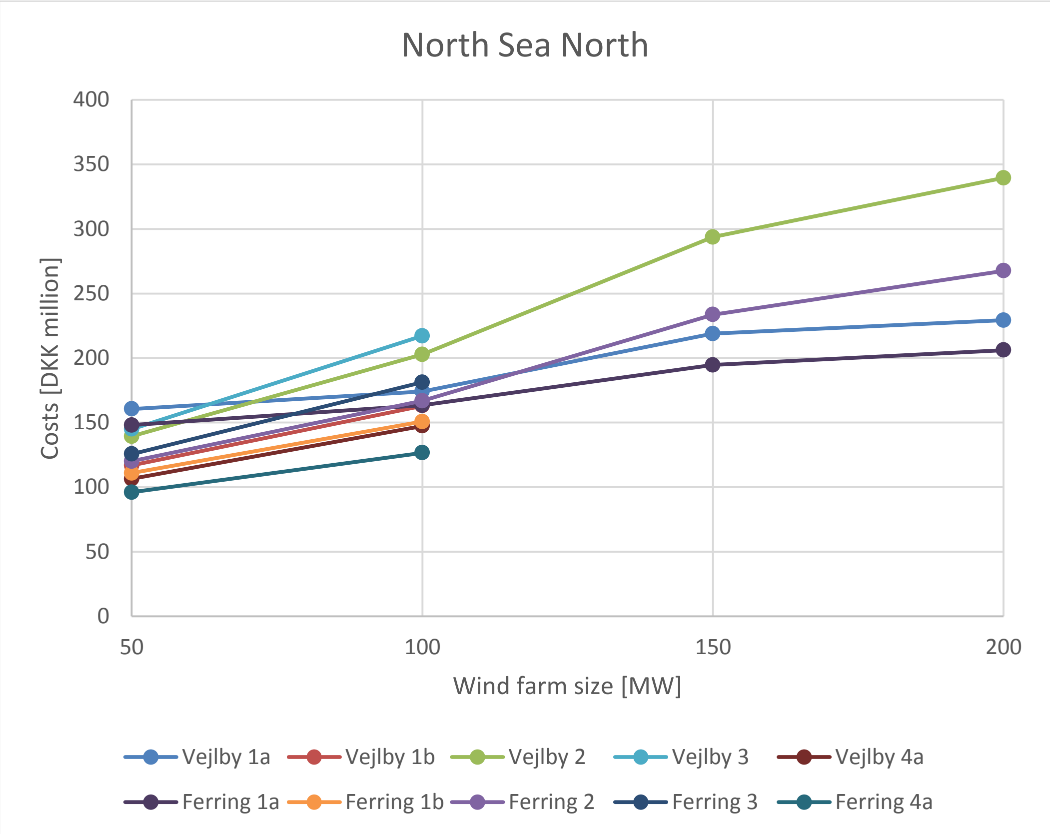
10.2.3 Distances

The following distances are used for the calculation of costs relating to the connection of a near-shore wind farm at North Sea North:

Målepunkt A	Målepunkt B	Tracelængde i km	Tillæg	Total km
Sydlig parkkorridor	Land	4,0	1,05	4,2
Nordlig parkkorridor	Land	4,1	1,05	4,3
Sydligt ilandføringspunkt	Ferring	1,0	1,10	1,1
Ferring	Lomborg	9,2	1,10	10,1
Nordligt ilandføringspunkt	Vejlby	0,4	1,10	0,5
Vejlby	Lomborg	14,9	1,10	16,3
Lomborg	Idomlund	25,0	1,10	27,5
Lomborg	Ramme	2,0	1,00	2,0
Lomborg	Struer	22,6	1,00	22,6
Idomlund	Herning	39,4	1,10	43,4

10.2.4 Costs

The total costs of the four standard concepts for grid connection of an offshore wind farm at North Sea North are shown in the diagram below.



The costs in the diagram above are shown in the table below where the most cost-effective connection methods from a socio-economic perspective are highlighted in bold:

	Method	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Vejlby (northern)	Standard concept 1a	161	174	219	229
	Standard concept 1b	117	163		
	Standard concept 2	139	203	294	340
	Standard concept 3	145	217		
	Standard concept 4	-106	147		
Ferring (southern)	Standard concept 1a	148	163	**-195**	**206**
	Standard concept 1b	111	151		
	Standard concept 2	120	167	234	268
	Standard concept 3	126	181		
	Standard concept 4	**96**	**127**		

10.3 Sæby

If the near-shore wind turbines are erected off the coast of Sæby, there are two possible locations for connection to the existing transmission grid, namely the 150 kV Dybvad substation and the 150 kV Starbakke substation.

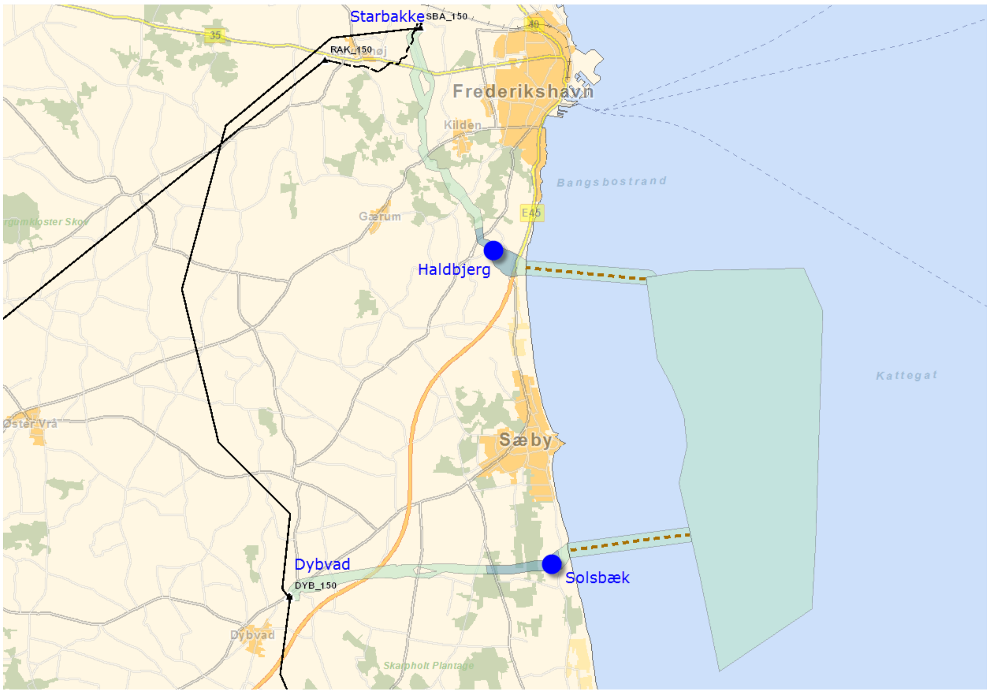


Figure 11

10.3.1 Connection at Dybvad

When establishing a connection to the existing transmission grid at Dybvad, the southern landing point south of Sæby is used. Connection of up to 200 MW production at Dybvad does not require reinforcements of the underlying transmission grid.

10.3.1.1 Standard concept 1

The deployed substation is placed near Solsbæk, which is about 0.7 km from the landing point. 33 kV cables are laid from the offshore wind farm to the deployed substation.

Standard concept 1a:
A 150 kV cable is laid from the deployed substation near Solsbæk to Dybvad, where a 40 Mvar reactor for compensation of the cable is also installed for 100, 150 and 200 MW offshore wind farms. At Dybvad, the existing 150 kV facility must be converted into a double busbar facility and expanded with one or two 150 kV bays depending on the compensation need.

Standard concept 1b:
One or two 60 kV cables are laid from the deployed substation near Solsbæk to Dybvad. Here, the existing 60 kV facility must also be expanded with one or two new bays.

10.3.1.2 Standard concept 2

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing substation at Dybvad where transformation to 150 kV is established at the substation site as described in

Appendix 1, section 9.2. The existing 150 kV facility at Dybvad must be converted into a double busbar facility and expanded with new 150 kV bays for connection of the required number of 150/33 kV transformers.

10.3.1.3 Standard concept 3

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing substation at Dybvad where transformation to 60 kV is established as described in

Appendix 1, section 9.3. The existing 60 kV substation is expanded with the required number of bays.

10.3.1.4 Standard concept 4

60 kV cables from the offshore wind farm are routed via the landing point to Dybvad and terminated in the existing 60 kV facility which must be expanded with one or two new bays beforehand depending on the wind farm size.

10.3.2 Connection at Starbakke

When connecting a near-shore wind farm to the existing transmission grid at Starbakke, a landing point between Frederikshavn and Sæby is used. Connection of up to 200 MW production at Starbakke does not require reinforcements of the underlying transmission grid.

10.3.2.1 Standard concept 1

The deployed substation is placed near Haldbjerg, which is about 1.9 km from the landing point. 33 kV cables are laid from the offshore wind farm to the deployed substation.

Standard concept 1a:
A 150 kV cable is laid from the deployed substation near Haldbjerg to Starbakke, where a 40 Mvar reactor for compensation of the cable must also be installed for 100, 150 and 200 MW offshore wind farms. The switchgear at Starbakke is expanded with two 150 kV bays.

Standard concept 1b:
One or two 60 kV cables are established from the deployed substation near Haldbjerg to Starbakke depending on the wind farm size. Here, the existing 60 kV facility must be expanded with the corresponding number of new bays.

10.3.2.2 Standard concept 2

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing substation at Starbakke where transformation to 150 kV is established as described in

Appendix 1, section 9.2.

10.3.2.3 Standard concept 3

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing substation at Starbakke where transformation to 60 kV is established as described in

Appendix 1, section 9.3.

10.3.2.4 Standard concept 4

60 kV cables from the offshore wind farm are routed via the landing point to Starbakke and terminated in the existing 60 kV facility which must be expanded with one or two new bays beforehand depending on the wind farm size.

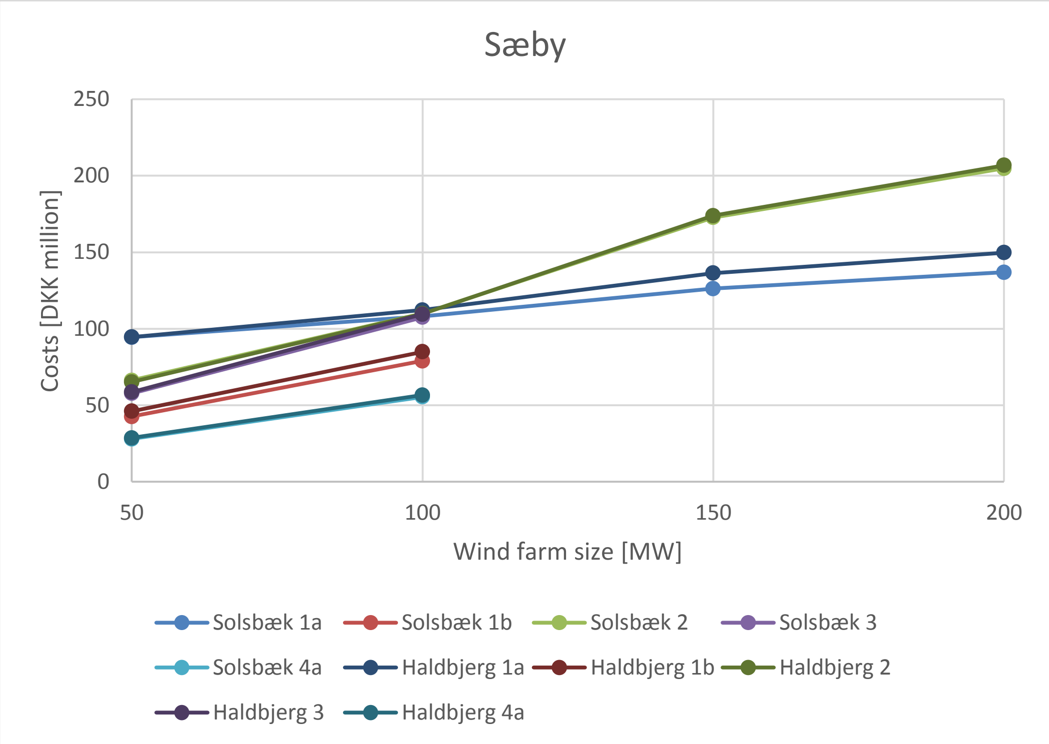
10.3.3 Distances

The following distances are used for the calculation of costs relating to the connection of a near-shore wind farm off the coast of Sæby:

Målepunkt A	Målepunkt B	Tracelængde i km	Tillæg	Total km
Sydlig parkkorridor	Land	4,0	1,05	4,2
Nordlig parkkorridor	Land	4,0	1,05	4,2
Sydligt ilandføringspunkt	Solsbæk	0,7	1,10	0,8
Solsbæk	Dybvad	9,0	1,10	9,9
Sydligt ilandføringspunkt	Dybvad	9,7	1,10	10,7
Nordligt ilandføringspunkt	Haldbjerg	1,9	1,10	2,1
Haldbjerg	Starbakke	8,1	1,10	8,9
Nordligt ilandføringspunkt	Starbakke	10,0	1,10	11,0

10.3.4 Costs

The total costs of the four standard concepts can be seen from the diagram below. As can be seen, the costs of the connection at Dybvad and Starbakke are almost the same as the distance from the landing point to the two existing substations is almost the same.



The costs in the diagram above are shown in the table below where the most cost-effective connection methods from a socio-economic perspective are highlighted in bold:

	Method	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Dybvad/ Solsbæk (Southern)	Standard concept 1a	94	108	**126**	**137**
	Standard concept 1b	43	79		
	Standard concept 2	66	110	173	205
	Standard concept 3	58	107		
	Standard concept 4	**28**	**55**		
Starbakke/ Haldbjerg (Northern)	Standard concept 1a	95	112	136	150
	Standard concept 1b	46	85		
	Standard concept 2	65	110	174	207
	Standard concept 3	59	109		
	Standard concept 4	29	57		

10.4 Sejerø Bay

If near-shore wind turbines are erected in Sejerø Bay, it is possible to connect to the existing grid at either the 132 kV substation at Asnæs Power Station or at the 50 kV Røsnæs substation. Based on the location of the designed area, an eastern and a western landing point has been determined, which allows for the establishment of a deployed substation at Røsnæs or Ågerup.

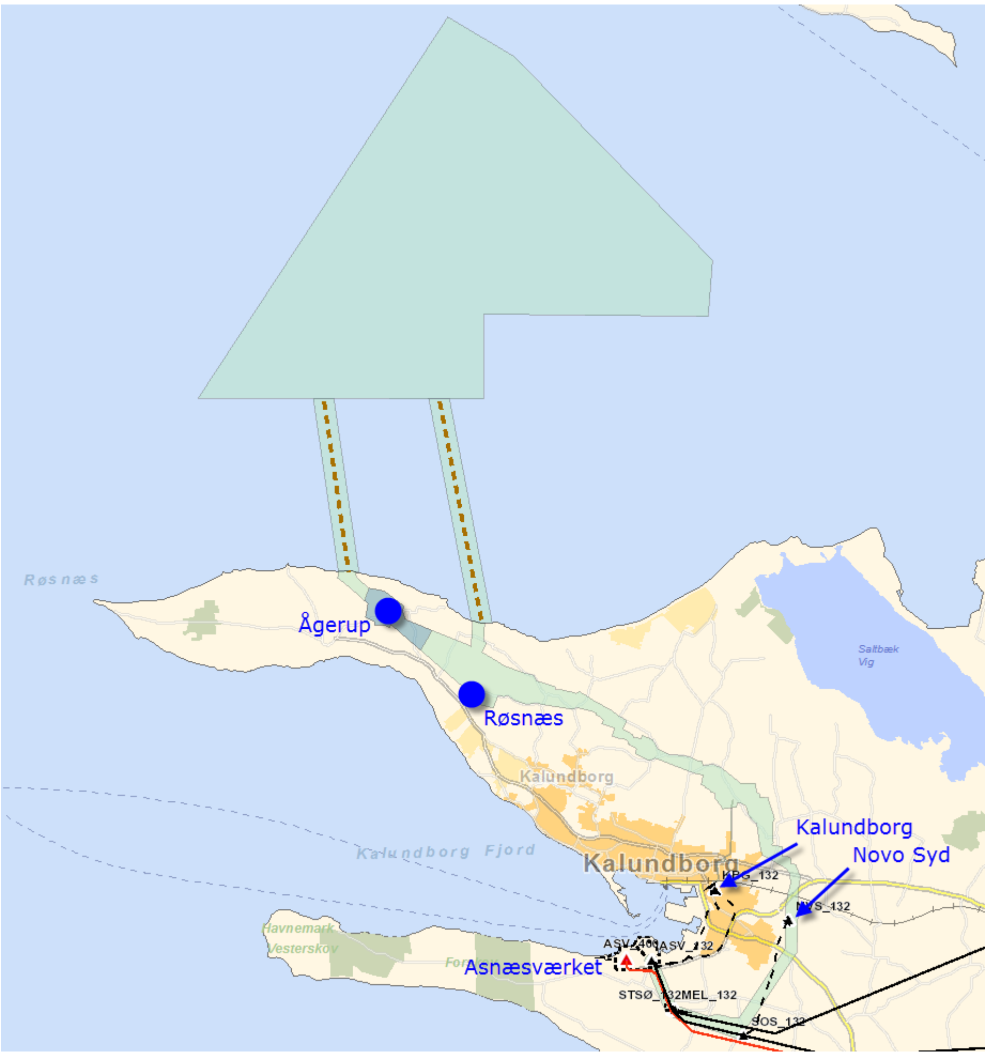


Figure 12

The 132 kV substation at Asnæs Power Station does not offer transformation to lower voltage levels, nor can such transformation be established due to lack of space. Consequently, an offshore wind farm in Sejerø Bay cannot be connected at Asnæs Power Station under standard concepts 1b and 2.

Connection of up to 200 MW production to the 132 kV substation at Asnæs Power Station does not require additional reinforcements of the underlying transmission grid. When establishing a connection to the existing 50 kV substation at Røsnæs, a 50 kV cable to Kalundborg or Novo South must be laid. According to SEAS-NVE, it is only possible to lay a single 50 kV cable to Kalundborg from the north due to the extremely difficult cable route approaching Kalundborg. Standard concepts 3 and 4 therefore only examine the possibility of connecting a 50 MW offshore wind farm.

If it turns out that the route cannot be used due to space limitations, it may be necessary to route the 50 kV cable into Novo South, which is an indoor substation where the cable can be connected to a new 50 kV bay. According to Seas-NVE, if more than 37 MW is connected, any existing 50 kV cable between Novo South and Novo North must be replaced as operational constraints may otherwise occur in the 50 kV grid at Kalundborg. The costs of connecting the wind farm in the 50 kV Novo South substation have not been calculated as the distance to Kalundborg is shorter.

10.4.1 Connection at Asnæs Power Station via Røsnæs

10.4.1.1 Standard concept 1

The deployed substation is placed near the existing 50 kV Røsnæs substation, which is about 1.8 km from the landing point. 33 kV cables are laid from the offshore wind farm to the deployed substation.

Standard concept 1a:
A 132 kV cable is laid from the advanced substation near Røsnæs to the 132 kV substation at Asnæs Power Station, where the existing line bay towards Kamstrup can be rebuilt and reused. For 150 and 200 MW wind farms, a 40 Mvar reactor is installed for compensation of the cable at Røsnæs.

If it is possible to expand Novo South into a complete 132 kV substation, it may be necessary to route the cable past Novo South on the way to Asnæs Power Station. This would make it possible to integrate future cables into the transmission grid as these cannot necessarily be routed into Asnæs Power Station, where space is already limited. The costs of expanding Novo South and connecting the cable in Novo South have not been determined as it is expected that the cable from Røsnæs can be connected in Asnæs Power Station at the present time.

10.4.1.2 Standard concept 3

33 kV cables from the offshore wind farm are routed via the eastern landing point all the way up to the existing 50 kV Røsnæs substation where transformation to 50 kV is established as described in

Appendix 1, section 9.3. The existing 50 kV substation is expanded with the required number of bays, a cable is laid to the 50 kV Kalundborg substation and the existing 50 kV overhead line is removed.

10.4.1.3 Standard concept 4

50 kV cables from the offshore wind farm are routed via the eastern landing point to the 50 kV Røsnæs substation and connected in the existing facility, which must be expanded with a new bay. A cable to the 50 kV Kalundborg substation is laid, and the existing 50 kV overhead line is removed.

10.4.2 Connection at Asnæs Power Station via Ågerup

In principle, the possibilities for connecting the offshore wind farm via Ågerup and the western landing point are the same as those applicable to connection via Røsnæs and the eastern landing point as described in section 10.4.1.

The distance from the western landing point to Ågerup is approx. 1.6 km.

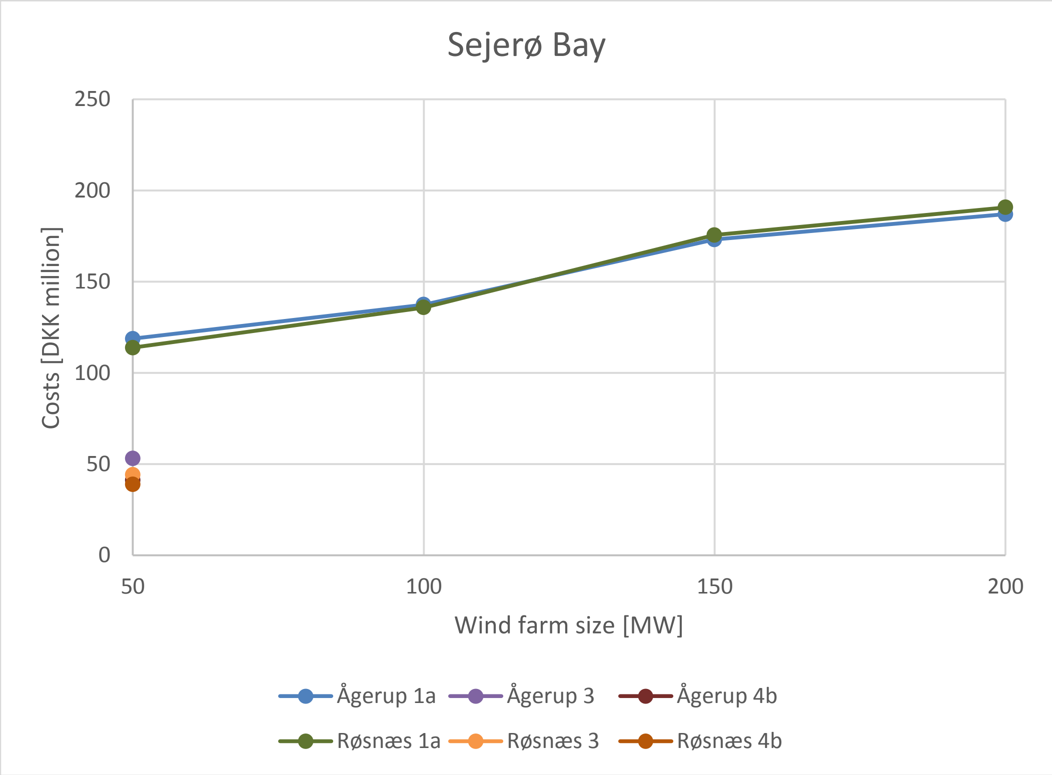
10.4.3 Distances

The following distances are used for the calculation of costs relating to the connection of a near-shore wind farm in Sejerø Bay:

Målepunkt A	Målepunkt B	Tracelængde i km	Tillæg	Total km
Vestlig parkkorridor	Land	4,3	1,05	4,5
Østlig parkkorridor	Land	5,6	1,05	5,9
Ågerup	Vestligt ilandføringspunkt	1,6	1,10	1,8
Ågerup	Novo Syd	13,6	1,10	15,0
Ågerup	Asnæs	19,7	1,10	21,7
Østligt ilandføringspunkt	Røsnæs	1,8	1,10	2,0
Vestligt ilandføringspunkt	Røsnæs	4,4	1,10	4,8
Røsnæs	Kalundborg	9,9	1,10	10,9
Røsnæs	Novo Syd	11,2	1,10	12,3
Røsnæs	Asnæs	17,3	1,10	19,0

10.4.4 Costs

The total costs of the possible standard concepts can be seen from the diagram below.


Sejerø Bay
Costs [DKK million]
250
200
150
100
50
0
50
100
150
200
Wind farm size [MW]
Ågerup 1a
Ågerup 3
Ågerup 4b
Røsnæs 1a
Røsnæs 3
Røsnæs 4b

The costs in the diagram above are shown in the table below where the most cost-effective connection methods from a socio-economic perspective are highlighted in bold:

	Method	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Ågerup (Western)	Standard concept 1a	119	137	**173**	**187**
	Standard concept 1b				
	Standard concept 2				
	Standard concept 3	53			
	Standard concept 4				
Røsnæs (Eastern)	Standard concept 1a	114	**136**	176	191
	Standard concept 1b				
	Standard concept 2				
	Standard concept 3	**44**			
	Standard concept 4				

The above standard concepts 3 and 4 for Ågerup imply connection in the existing Røsnæs substation as the connection is made in an existing substation and because Ågerup does not exist at the moment.

10.5 Coastal waters off Småland

If the near-shore wind turbines are erected in the coastal waters off Småland near Stigsnæs Power Station, the grid connection must be made via a landing point south-east of Stigsnæs Power Station. It is not possible to establish 50/33 kV transformation at the substation site at Stigsnæs Power Station due to lack of space, and consequently an offshore wind farm in the coastal waters off Småland cannot be connected under standard concept no. 3, which is excluded from the analyses.

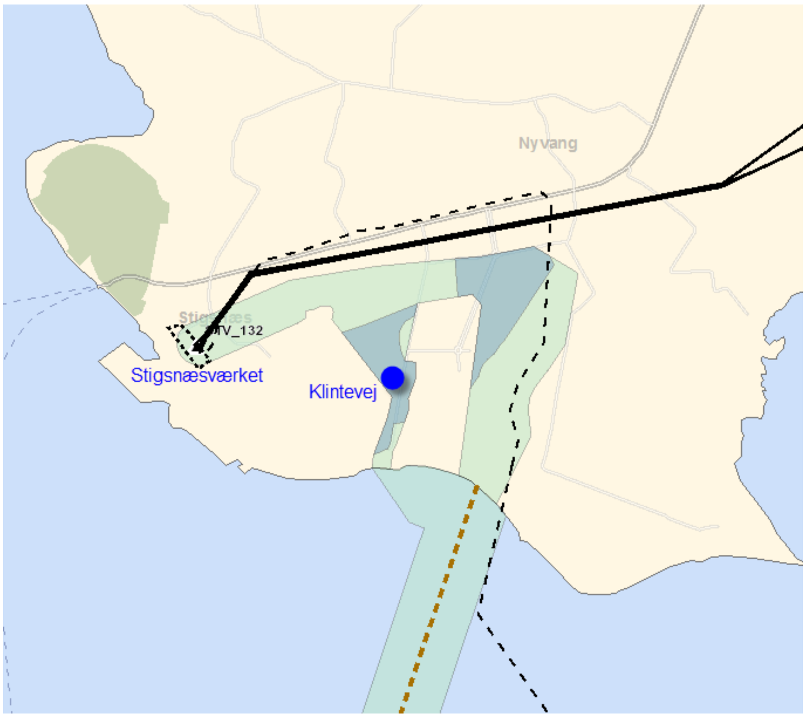


Figure 13

Connection to the 132 kV substation at Stigsnæs Power Station will not require further grid reinforcements.

10.5.1 Connection in Stigsnæs Power Station via the western landing point

10.5.1.1 Standard concept 1

The deployed substation is placed near Klintevej, which is about 0.7 km from the landing point. 33 kV cables are laid from the offshore wind farm to the deployed substation.

Standard concept 1a:
A 132 kV cable is laid from the deployed substation near Klintevej to Stigsnæs Power Station. For a 200 MW wind farm, a 40 Mvar reactor is installed for compensation of the cable at the deployed substation. One or two of the bays from the connection of the preserved power station units are reused at the 132 kV substation at Stigsnæs Power Station.

Standard concept 1b:
One or two 50 kV cables are laid from the deployed substation near Klintevej to the 50 kV substation at Stigsnæs Power Station. The existing 50 kV facility can only be expanded with one new 50 kV bay as it is not possible to further extend the busbar. As a result, the cables must be gathered in the same bay and disconnecting the bay will thus disconnect the entire wind farm.

10.5.1.2 Standard concept 2

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing 132 kV substation at Stigsnæs Power Station where transformation to 132 kV is established at the substation site as described in

Appendix 1, section 9.2. For a 200 MW offshore wind farm, a 40 Mvar reactor for compensation of the cable is installed at Stigsnæs Power Station. One or two of the bays from the connection of the preserved power station units are reused at the 132 kV substation at Stigsnæs Power Station.

10.5.1.3 Standard concept 4

50 kV cables from the offshore wind farm are routed to Stigsnæs Power Station and connected to the existing 50 kV facility, which is expanded with one new bay as there is no space for further expanding the busbar. As a result, the cables must be gathered in the same bay and disconnecting the bay will thus disconnect the entire wind farm.

10.5.2 Connection in Stigsnæs Power Station via the eastern landing point

10.5.2.1 Standard concept 2

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing 132 kV substation at Stigsnæs Power Station where transformation to 132 kV is established at the substation site as described in

Appendix 1, section 9.2. For a 200 MW offshore wind farm, a 40 Mvar reactor for compensation of the cable is installed at Stigsnæs Power Station. One or two of the bays from the connection of the preserved power station units are reused at the 132 kV substation at Stigsnæs Power Station.

10.5.2.2 Standard concept 4

50 kV cables from the offshore wind farm are routed to Stigsnæs Power Station and connected to the existing 50 kV facility, which is expanded with one new bay as there is no space for further expanding the busbar. As a result, the cables must be gathered in the same bay and disconnecting the bay will thus disconnect the entire wind farm.

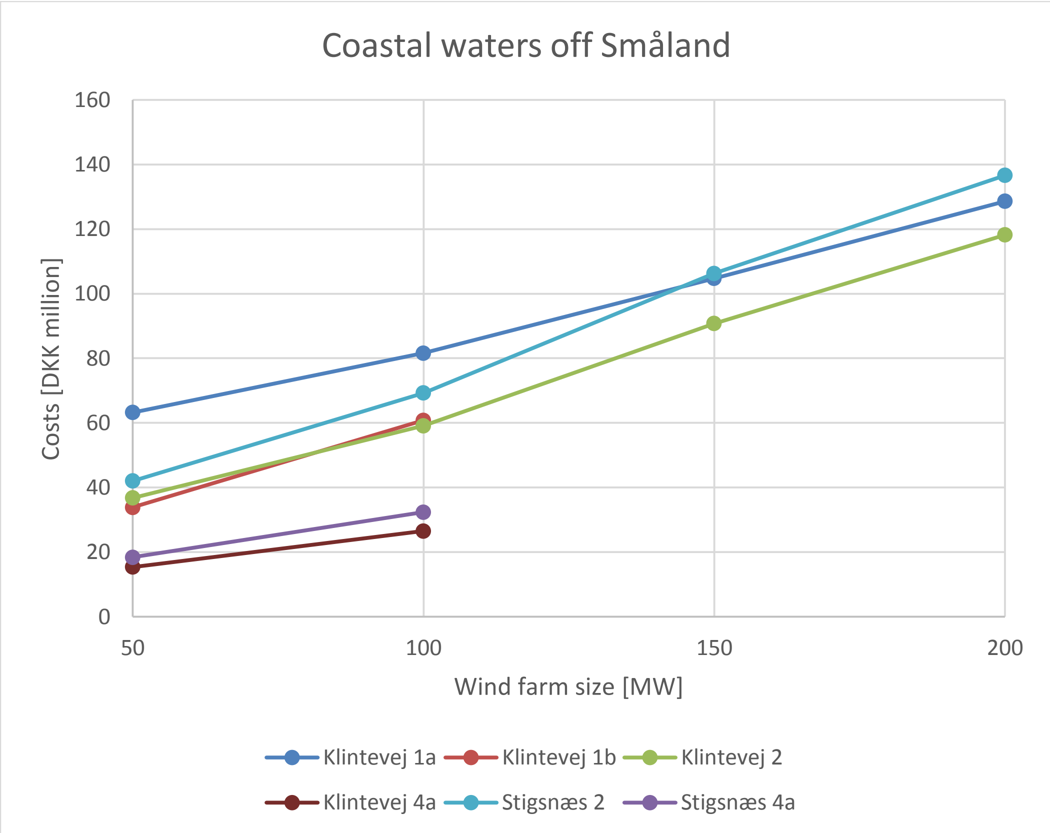
10.5.3 Distances

The following distances are used for the calculation of costs relating to the connection of a near-shore wind farm in the coastal waters off Småland:

Målepunkt A	Målepunkt B	Tracelængde i km	Tillæg	Total km
Parkkorridor	Land	8,4	1,05	8,8
Vestligt ilandføringspunkt	Stigsnæs	2,4	1,10	2,6
Østligt ilandføringspunkt	Stigsnæs	3,7	1,10	4,1
Vestligt ilandføringspunkt	Klintevej	0,7	1,10	0,8
Klintevej	Stigsnæs	1,7	1,10	1,8

10.5.4 Costs

The total costs of the possible standard concepts can be seen from the diagram below.



The costs in the diagram above are shown in the table below where the most cost-effective connection methods from a socio-economic perspective are highlighted in bold:

	Method	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Klintevej (Western)	Standard concept 1a	63	82	105	129
	Standard concept 1b	34	61		
	Standard concept 2	37	59	**91**	**118**
	Standard concept 3				
	Standard concept 4	**15**	**27**		
Stigsnæs (Eastern)	Standard concept 1a				
	Standard concept 1b				
	Standard concept 2	42	69	-106	137
	Standard concept 3				
	Standard concept 4	18	32		

The above standard concept 4 for Klintevej implies connection in the existing substation at Stignæs Power Station as the connection is made in an existing substation and because Klintevej does not exist at the moment.

10.6 Bornholm

According to an agreement with the Danish Energy Agency of 23 January 2014, only the possibilities for connecting a near-shore 50 MW wind farm off the coast of Bornholm are analysed. This is due to the fact that the connection of larger wind farms will require an extension of the transmission capacity from Bornholm to Sweden in order to transport any excess production away from the island. It is not considered possible to complete the installation of a new cable to Sweden by 2020 where the offshore wind turbines must be operational due to the expected long case handling time on the part of the Swedish authorities and subsequent long installation period.

Figure 14

If a near-shore wind farm is erected off the coast of Rønne, the connection to the grid must be made in the 60 kV Rønne South substation. A possible landing point has been determined from where the distance to Rønne South is 1.4 km.

10.6.1 Connection at Rønne South via the western corridor

10.6.1.1 Standard concept 3

33 kV cables from the offshore wind farm are routed via the landing point all the way up to the existing Rønne South substation where transformation to 60 kV is established as described in

Appendix 1, section 9.3.

10.6.1.2 Standard concept 4

A 60 kV cable from the offshore wind farm is routed to Rønne South and connected in the existing 60 kV facility, which is expanded with a new bay.

10.6.2 Connection at Rønne South via the eastern corridor

In principle, the possibilities for connecting the offshore wind farm via the eastern corridor are the same as those applicable to connection via the western corridor. However, the distance from the wind farm to land is significantly shorter.

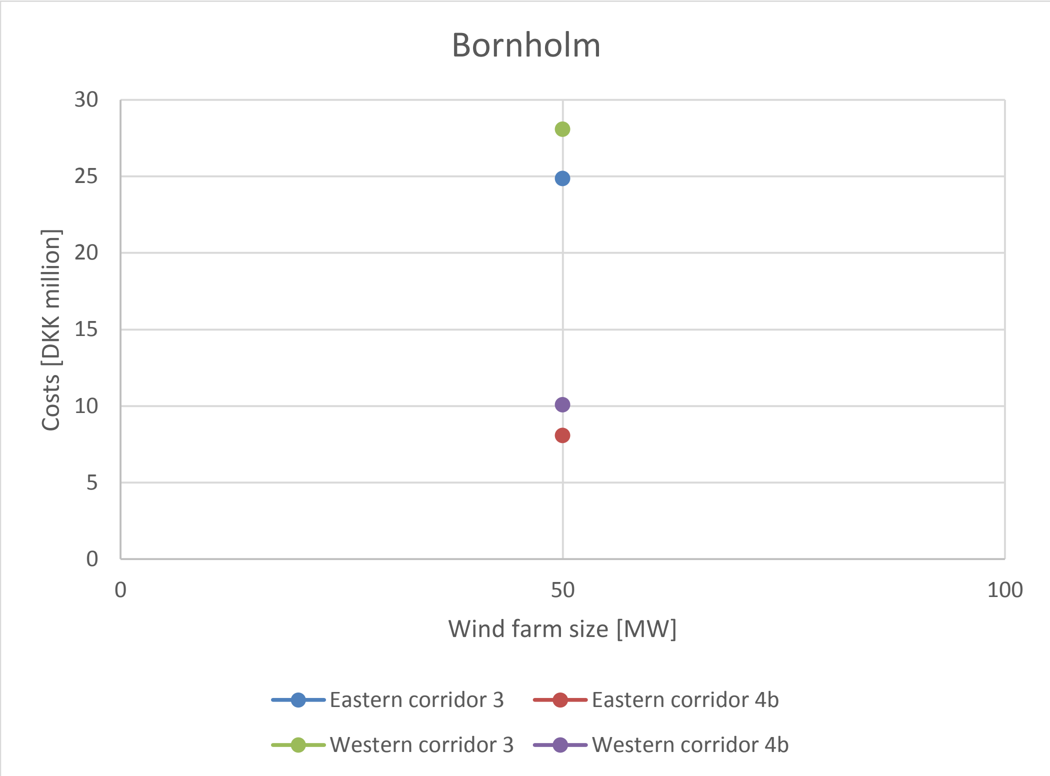
10.6.3 Distances

The following distances are used for the calculation of costs relating to the connection of a near-shore wind farm off the coast of Bornholm:

Målepunkt A	Målepunkt B	Tracelængde i km	Tillæg	Total km
Vestlig parkkorridor	Land	11,0	1,05	11,5
Østlig parkkorridor	Land	7,4	1,05	7,7
Ilandføringspunkt	Rønne Syd	1,2	1,10	1,4

10.6.4 Costs

The total costs of the possible standard concepts can be seen from the diagram below.



The costs in the diagram above are shown in the table below where the most cost-effective connection methods from a socio-economic perspective are highlighted in bold:

	Method	50 [MW]	100 [MW]	150 [MW]	200 [MW]
Rønne South (Western)	Standard concept 3	28			
	Standard concept 4	10			
Rønne South (Eastern)	Standard concept 3	25			
	Standard concept 4	**8**			