Grid connection of near shore wind farms

methods, preconditions and results

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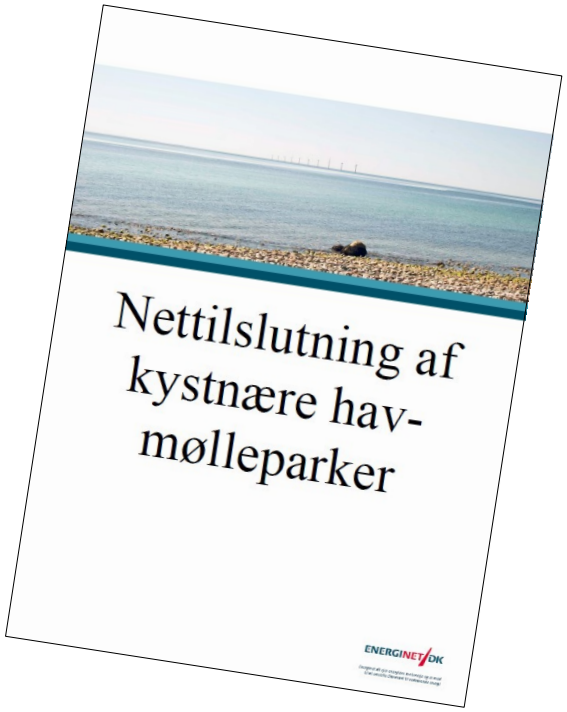
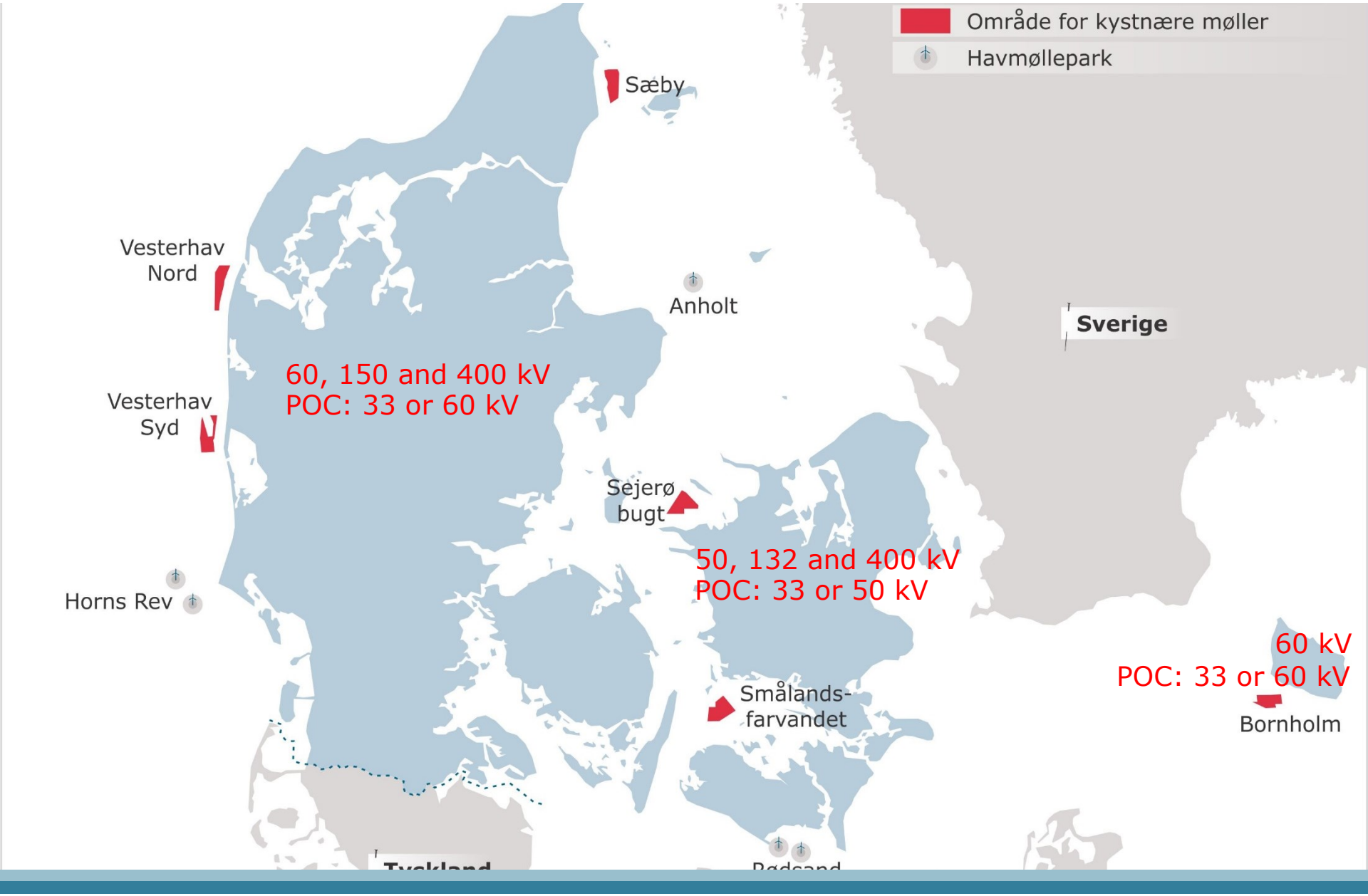
Topics

- Methods
- Preconditions
- Technical and socio-economic analysis




Område for kystnære møller
Havmøllepark
Sæby
Vesterhav Nord
Anholt
Sverige
60, 150 and 400 kV
POC: 33 or 60 kV
Vesterhav Syd
Sejerø bugt
50, 132 and 400 kV
POC: 33 or 50 kV
Horns Rev
60 kV
POC: 33 or 60 kV
Smålands-farvandet
Bornholm
Tyskland
Rødsand

Methods

- Standard concepts
- Grid analysis
- Construction costs
- Calculation of grid losses
- Estimated costs for operation and maintenance
- Allocation of costs

Standard concepts

Analysis of the optimal connection method onshore is based on four general standard concepts that covers different voltage levels and principles.

	Concept 1	Concept 2	Concept 3	Concept 4
Description	New onshore XX/33 kV substation close to coast	33 kV export cables connected to existing substation		50-60 kV export cables connected to existing 50-60 kV substation
Connection point	132-150 kV (SC 1a) or 50-60 kV (SC 1b)	132-150 kV (SC 2)	50-60 kV (SC 3)	50-60 kV (SC 4)
Export cables	33 kV	33 kV	33 kV	50-60 kV

The four standard concepts are assessed socio-economically and technically for all possible combinations of the size of wind farms (50, 100, 150 and 200 MW) and geographical location.

Grid analysis

The necessary development of the 132-150 kV grid is determined by load flow calculations stage 2020, and the analysis is based on the analysis assumptions of Energinet.dk from 2013.

The results of the load flow analysis has been used as inputs to the EIA for each location.

The analysis contains wind farms at 200 MW in all areas except the location at Bornholm that due to the ampacity in the submarine cable between Sweden and Bornholm is reduced to 50 MW.

Construction costs

The CAPEX on shore are generally based on standard unit prices.

For components in the 132 kV, 150 kV and 400 kV grid the costs are based on previously completed projects while the costs of components in the 33 kV, 50 kV and 60 kV grid are based partly on the dialogue with the grid companies and based partly on prices from reinforcements due to connection of wind farms on shore.

Calculation of grid losses

The calculation and estimation of the grid losses due to the near shore wind farms are based on a historical production profile from other offshore wind farms.

These profiles from existing offshore wind farms are used:

- "Horns Rev 2" profile is used to "Vesterhav Syd" and "Vesterhav Nord"
- "Anholt" profile is used to "Sæby" and "Sejerø Bugt"
- "Rødsand 2" profile is used to "Smålandsfarvandet" and "Bornholm"

The profiles has been selected from mid 2013 to mid 2014.


Område for kystnære møller
Havmøllepark
Sæby
Vesterhav Nord
Anholt
Sverige
Vesterhav Syd
Sejerø bugt
Horns Rev
Smålands-farvandet
Bornholm

Calculation of grid losses

The capitalized grid losses from the 33 kV or the 60 kV export cables are included in the total cost of connectivity.

The grid losses are included from the edge of the wind farms in the park corridor and up to the point of connection (POC) on shore.

The internal grid losses in the inter-array cables are not included because the layout of the wind farms and the internal cross sections of the inter-array cables are not known at this time.

Estimated costs of operation and maintenance

The OPEX in the total project are not known in detail for now, instead there has been used a fixed percentage of 3 % of the total CAPEX in each area.

Allocation of costs

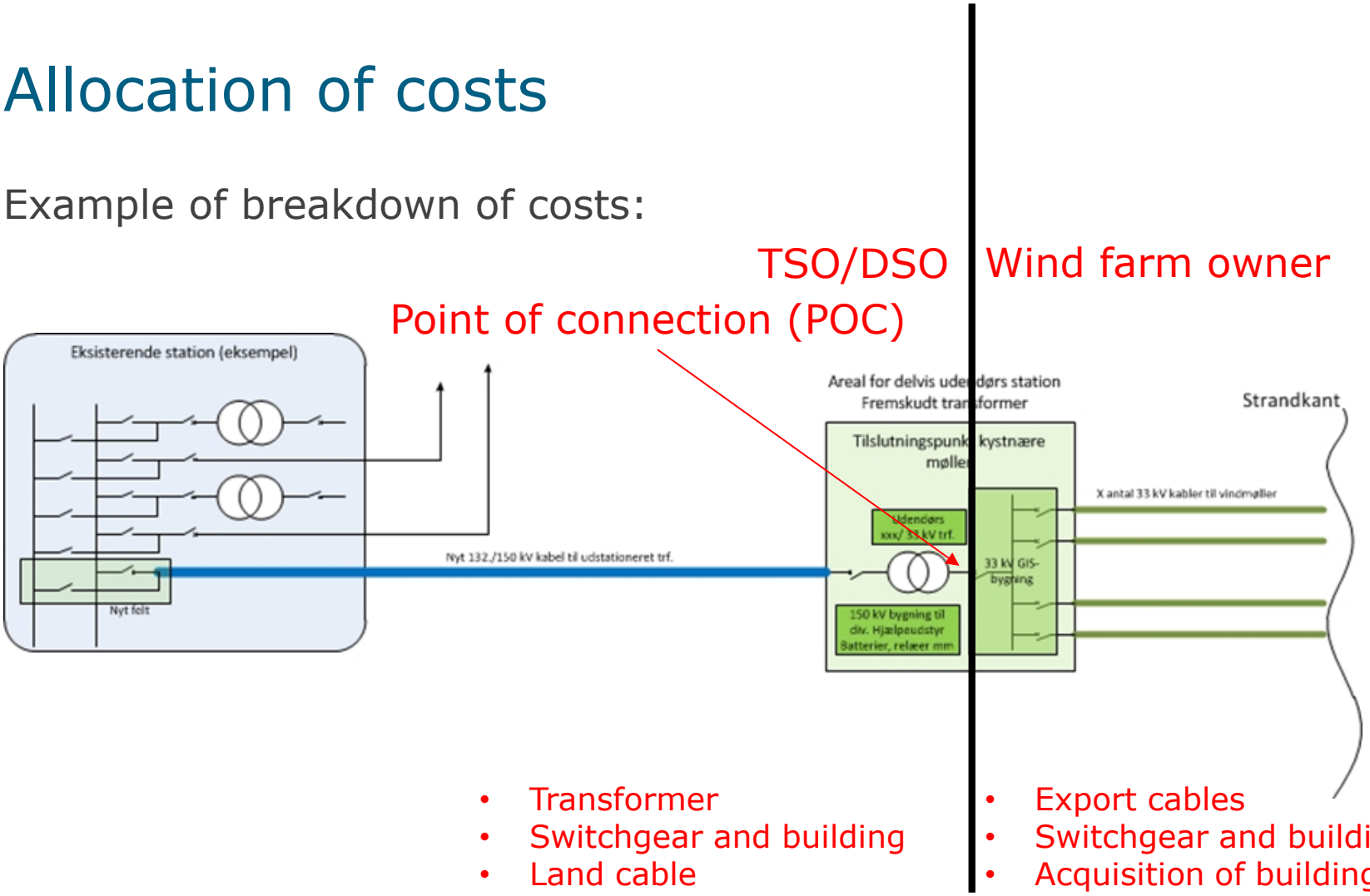
All the costs at sea, including export cables etc. falls to the wind farm owner.

In addition, the Danish Energy Association, DEA has presented a proposal for a breakdown of costs onshore from the coastal line to the POC, which means that CAPEX belonging to the export cables onshore and any distribution system or switchgears between the wind farm and the POC also falls to the wind farm owner including the associated OPEX.

The grid losses due to the wind farm until the POC shall be included in the OPEX and falls to the wind farm owner.

Allocation of costs

Example of breakdown of costs:



- Transformer
- Switchgear and building
- Land cable
- OPEX including grid losses

- Export cables
- Switchgear and building
- Acquisition of building plot
- OPEX including grid losses

Preconditions

- Dimensioning criteria
- Economical preconditions
- Export cables
- 33 kV substation onshore
- Construction costs

Dimensioning criteria

When integrating renewable energy in the grid above 100 kV, the grid is not designed to be n-1 secure i.e. failure of a single component can disconnect the wind farm.

When a substation above 100 kV is connected with more than one overhead line or underground cable to other substations, it is the aim in a n-1 situation that the wind farm can produce at full speed in 40 hours.

Economical preconditions

- Year of interest: 2020
- Real rate of interest: 4 %
- Time horizon: 25 years for the wind farm and 40 years for reinforcements onshore

The capitalized grid losses is calculated for the time horizon.

The costs is calculated in fixed 2014 prices.

Export cables

Cross sections on export cables and inter-array cables should be chosen from a loss economical condition, that means the ampacity and the number of export cables are expected to vary from area to area.

It is not expected that more than a maximum of six export cables is necessary to connect a 200 MW wind farm.

It is assumed that the supply of a wind turbine is either 33 kV or 50 to 60 kV. 33 kV is standard while 50-60 kV is not that widespread yet.

Export cables

To calculate the number of 33 kV export cables there's assumed an ampacity of approximately 36 MW each cable, while the assumed ampacity of a 60 kV cable is approximately 75 MW. At the 50 kV level the expected ampacity is approximately 58 MW each cable.

The wind turbines must be able to deliver and consume reactive power corresponding to power factor 0,95.

To calculate the costs onshore the export cables have been based on a 630 mm^2 Al-PEX buried in a close trifoil formation in its own trench.
The EIA is based on 3,5 meters between the trenches (C-C).

33 kV substation onshore

It is assumed the wind farm is connected in the POC through a 33 kV circuit-breaker switchgear (gas insulated switchgear) if the voltage of the export cables is 33 kV.

The switchgear in the calculation of costs is based on a single-busbar with circuit-breakers towards the export cables and transformer, and a bus-sectionalizer to split up the busbar when the wind farm is larger than 100 MW.

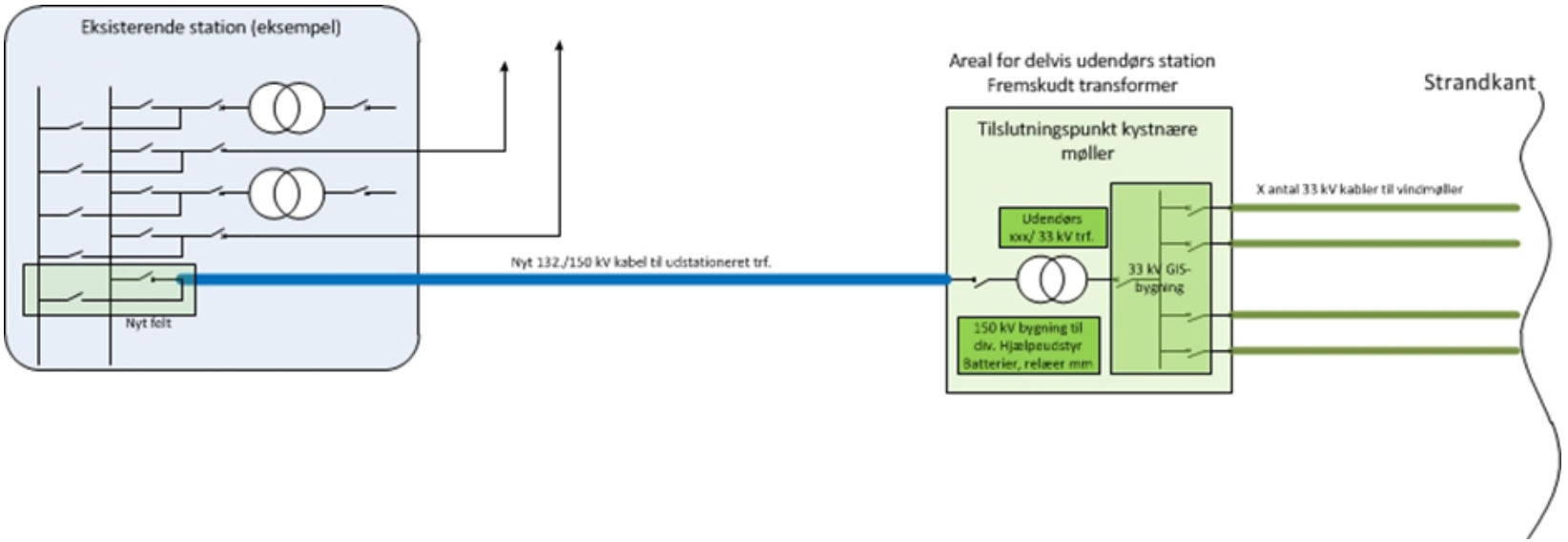
Switchgear	I_r [kA]	P_r [MW]
Busbar	4,00	217
CB – Export cables	1,25	67
CB – Transformer	2,50	135
CB – bus-sectionalizer	2,50	135

Construction costs

Standard concept 1:

- New substation in the areas marked in the EIA either 132-150 kV or 50-60 kV with the necessary XX/33 kV transformer
- 33 kV export cables from shore to POC in the new substation
- 33 kV switchgear in its own building
- Connection from existing grid (50, 60, 132 or 150 kV underground cable)
- Acquisition of building plot
- NPV of reinforcements in the transmission grid
- SC 1 is not applicable on “Bornholm”

Construction costs – SC1a and SC1b



Construction costs

Standard concept 2:

- 33 kV export cables from shore to POC
- POC is in existing 132-150 kV substations *or* where permission is granted to build a new substation in the areas marked in the EIA
- 33 kV switchgear in its own building
- New 132-150/33 kV transformer connected to the existing substation
- NPV of reinforcements in the transmission grid
- SC 2 is not applicable on “Sejerø Bugt”

Construction costs – SC2 and SC3

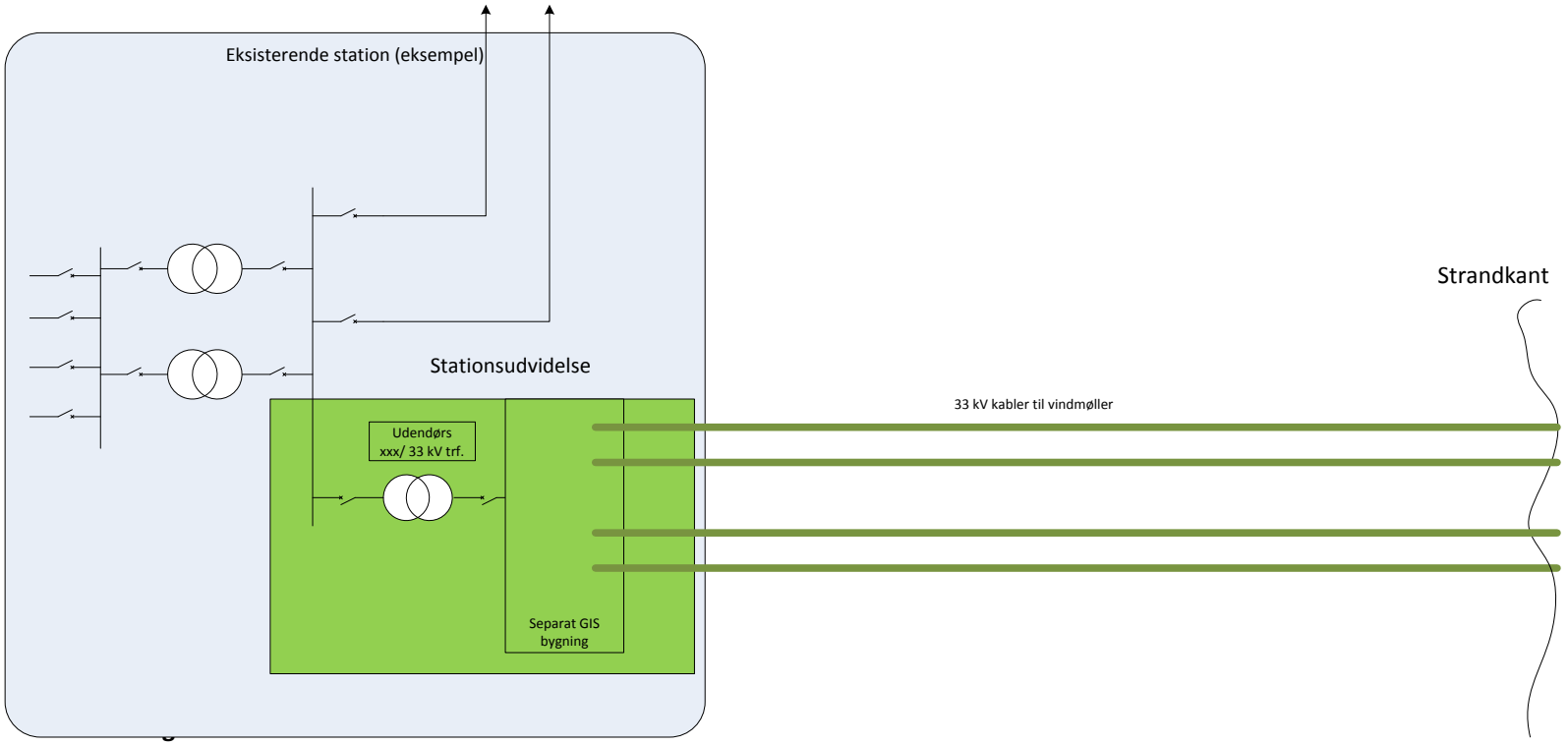


Photo of offshore wind farm Samsø, by Sweco Architects A/S

Construction costs

Standard concept 3:

- 33 kV export cables from shore to POC
- POC is in existing 50-60 kV substation located on a 132-150 kV substation *or* where permission is granted to build a new substation in the areas marked in the EIA
- 33 kV switchgear in its own building
- One or two 50-60/33 kV transformers connected to the existing substation
- NPV of reinforcements in the transmission grid

Construction costs

Standard concept 3:

- SC 3 is based on connecting 50 MW up to 100 MW in "Vesterhav Syd", "Vesterhav Nord" and "Sæby" while only 50 MW is connected in "Sejerø Bugt" and "Bornholm"
- SC 3 is not applicable on "Smålandsfarvandet" due to space limitations near the 50 kV substation

Construction costs

Standard concept 4:

- 50-60 kV export cables from shore to POC
- POC is in existing 50-60 kV substation located on a 132-150 kV substation *or* where permission is granted to build a new substation in the areas marked in the EIA
- Connection of the export cables in the existing substation
- NPV of reinforcements in the transmission grid

Construction costs

Standard concept 4:

- SC 4 is based on connecting 50 MW up to 100 MW in "Vesterhav Syd", "Vesterhav Nord", "Sæby" and "Sejerø Bugt" while only 50 MW is connected on "Bornholm"
- It is only possible to connect "Smålandsfarvandet" to one 50 kV circuit-breaker in the nearby substation

Technical and socio-economic analysis

- Vesterhav Syd
- Vesterhav Nord
- Sæby
- Sejerø Bugt
- Smålandsfarvandet
- Bornholm

Vesterhav Syd

Vesterhav Syd

- POC in “Holmsland” or “Tyvmose” is no longer an option due to the Danish Nature Agency that has prohibited new substations of any kind in that area
- The nearest POC is “Søndervig” (7,3/9,8 km from shore)
- Large investments in the 150 kV grid

	50 MW M. DKK	100 MW M. DKK	150 MW M. DKK	200 MW M. DKK
SC 1a	125	209	**258**	**283**
SC 1b	78	194		
SC 2	116	240	367	431
SC 3	110	240		
SC 4	**56**	**160**		

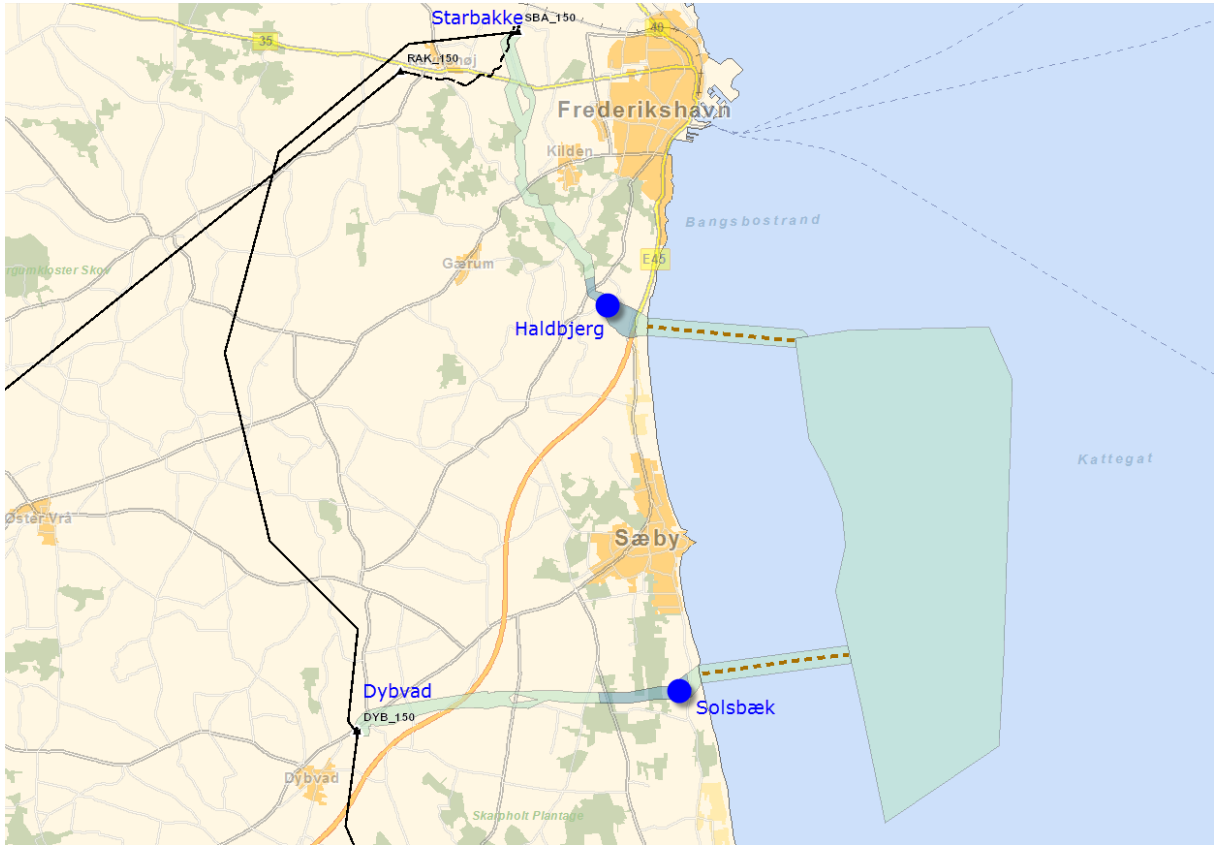
Vesterhav Nord

Vesterhav Nord

- POC is either “Ferring”, “Vejlby” or “Lomborg”
- “Ferring” is the socio-economic choice
- Large investments in the 150 kV grid

	50 MW M. DKK	100 MW M. DKK	150 MW M. DKK	200 MW M. DKK
SC 1a	148	163	**195**	**206**
SC 1b	111	151		
SC 2	120	167	234	268
SC 3	126	181		
SC 4	**96**	**127**		

Sæby

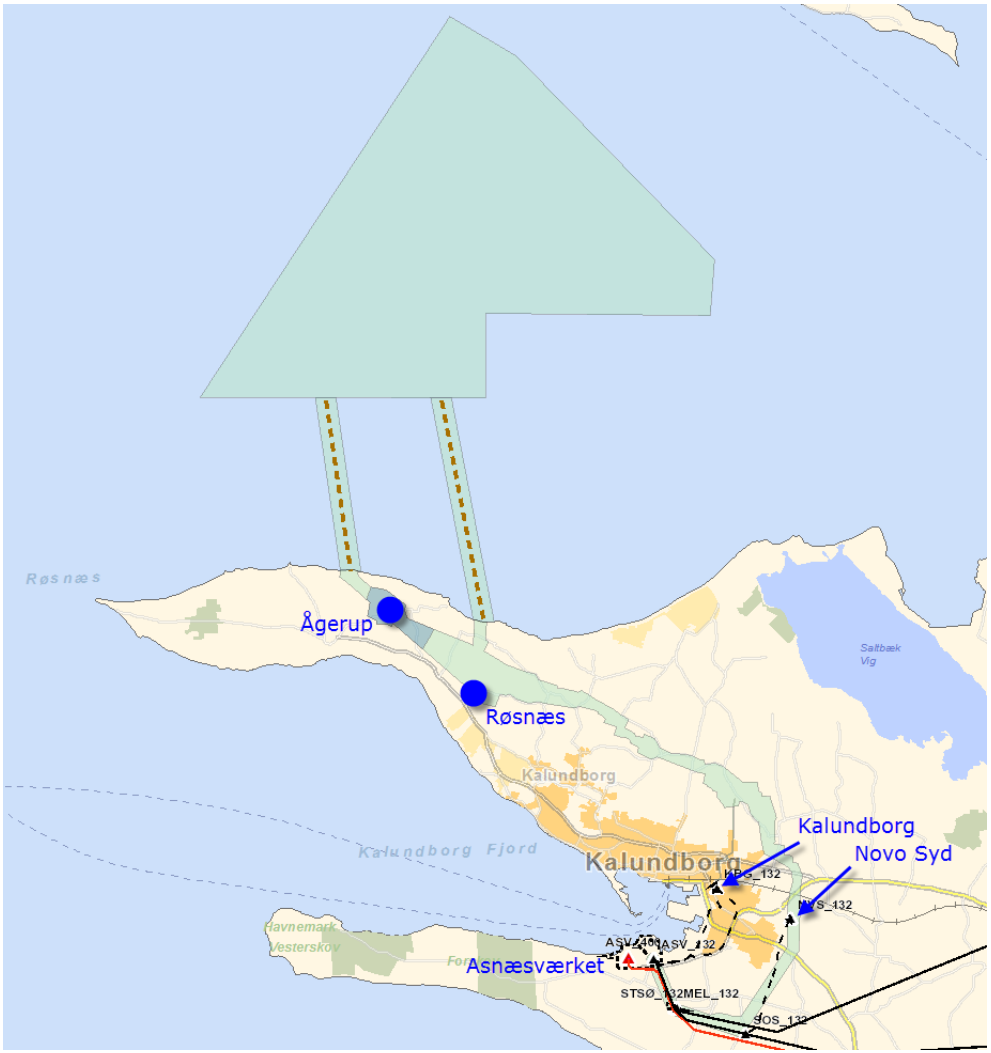

Starbakke
SBA_150
RAK_150
Frederikshavn
Kilden
Bangsbostrand
Gærum
E45
Haldbjerg
Kattegat
Sæby
Dybvad
DYB_150
Solsbæk
Dybvad
Skarpholt Plantage

Sæby

- POC is either "Solsbæk", "Dybvad", "Haldbjerg", or "Starbakke"
- "Solsbæk" is the socio-economic choice
- No further investments in the 150 kV grid

	50 MW M. DKK	100 MW M. DKK	150 MW M. DKK	200 MW M. DKK
SC 1a	94	108	**126**	**137**
SC 1b	43	79		
SC 2	66	110	173	205
SC 3	58	107		
SC 4	**28**	**55**		

Sejerø Bugt

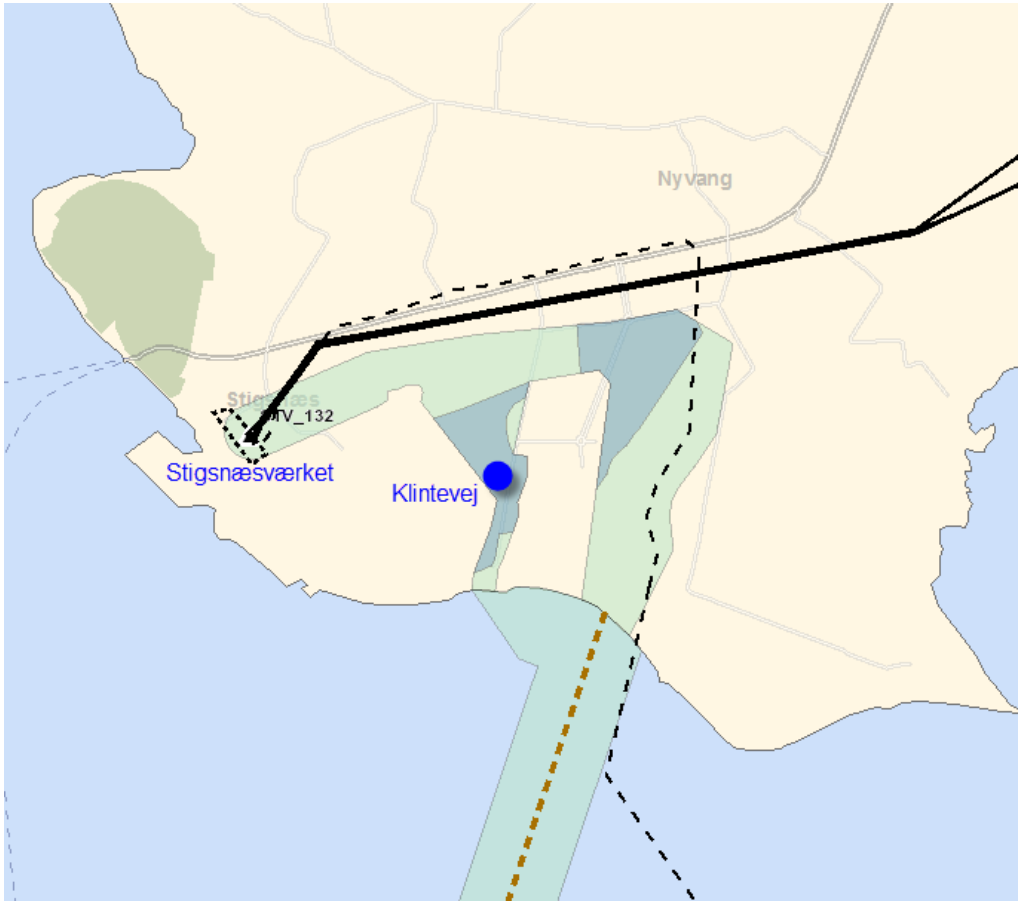

Røsnæs
Ågerup
Røsnæs
Kalundborg
Kalundborg Fjord
Kalundborg
Kalundborg
Novo Syd
Asnæsværket
Saltbæk
Vig

Sejerø Bugt

- POC is either "Ågerup" or "Røsnæs"
- "Røsnæs" is the socio-economic choice up to 100 MW while "Ågerup" is the choice above 100 MW
- No further investments in the 132 kV grid

	50 MW M. DKK	100 MW M. DKK	150 MW M. DKK	200 MW M. DKK
SC 1a	114	**136**	**173**	**187**
SC 1b				
SC 2				
SC 3	44			
SC 4	**39**			

Smålandsfarvandet



Smålandsfarvandet

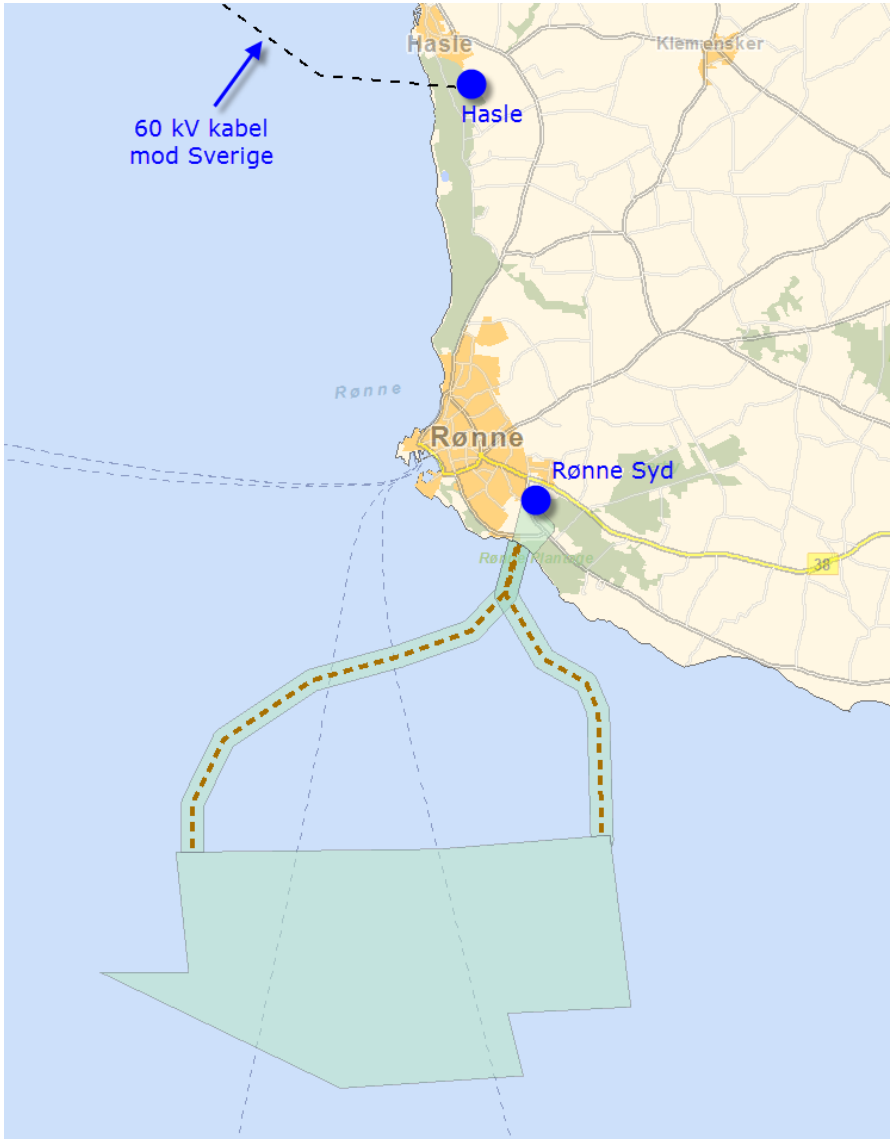
- POC is either "Klintevej" or "Stigsnæsværket"
- "Klintevej" is the socio-economic choice
- No further investments in the 132 kV grid

	50 MW M. DKK	100 MW M. DKK	150 MW M. DKK	200 MW M. DKK
SC 1a	63	82	105	129
SC 1b	34	61		
SC 2	37	59	**91**	**118**
SC 3				
SC 4	**15**	**27**		

Bornholm

- POC is "Rønne Syd"
- No further investments in the 60 kV grid

	50 MW M. DKK
SC 3	25
SC 4	**8**



Questions?