



Future Offshore Wind Power Sites -2025

The Committee for Future
Offshore Wind Power Sites
April 2007

Preface

As part of the Danish Government's 2025 Energy Strategy submitted on 17 June 2005 it was decided that the Offshore Wind Turbine Action Plan of 1997 should be updated. Since 1997, the basis for selecting potential areas has changed significantly, among other things as a result of the designation of a number of new nature protected areas in Danish waters and because of the rise in shipping traffic. Moreover the engineering/economic options for installing offshore wind turbines at greater depths have widened as wind turbines have increased in size. The fact that today's wind turbines are significantly higher has a visual impact depending on their distance from the shore.

Thus the objective of updating is to reassess where the future expansion of offshore wind farms may take place based on the experience of recent years.

The updating is being performed in conjunction with the Government's decision to install two offshore wind farms each of 200 MW with a view to the continued expansion of offshore wind power.

An expansion of offshore wind power can contribute to an environmental sound expansion of the electricity sector, ensuring long-term security of energy supply, diversifying energy supplies over more sources and continue to promote the development of wind power technology.

In January 2007, the Government submitted its proposal "A Visionary Danish Energy Policy", the long-term visions of which include "*the share of renewable energy must be increased to at least 30% of gross energy demand by 2025*" and obtaining "*the least costs development of renewable energy*". The Government's vision is for Denmark to entirely free itself from the use of fossil fuels - coal, oil and natural gas - in order to enhance the reliability of energy supplies and counteract the greenhouse effect with its enormous human, natural and economic consequences. Among the means of achieving that vision are more vigorous efforts to promote renewable energy, including wind and bio energy.

As a result of the Government's decision to find suitable sites for the future construction of offshore wind farms, at the end of 2005 the Ministry of Energy and Transport requested the Danish Energy Authority to appoint a committee with associated reference group. The work of the committee is to contribute to a future-oriented strategy capable of constituting the basis for continued growth in the sector, - where economic efficiency and streamlining administrative procedures is obtained through enhanced balancing of sea-use interests. The aim is to obtain energy at stable and competitive prices while safeguarding reliability of supply and environmental interests.

The committee has assessed society's interests in relation to grid transmission conditions, navigation, nature, landscape, raw material exploitation etc. The committee has also assessed options for connecting large scale offshore wind farms to the national grid, including examining the engineering, economic and planning options for on-shore connection of the power and the consequences for the underlying grid of the various potential areas for construction. At the same time the committee described scenarios for technological development of wind turbines capable of installation at greater water depths. The committee attached importance to a planned and coordinated expansion of wind power and the transmission grid with a view to obtaining the greatest possible economic benefits.

The report charts a number of possible offshore areas where offshore wind power could be built to an overall capacity of some 4,600 MW. Offshore wind power with a capacity of 4600 MW could generate approximately 18 TWh, or just over 8% of total energy consumption in Denmark. This corresponds to approximately 50% of Danish electricity consumption. A number of factors have been taken into consideration for all the sites identified. Thus in the short term not all sites will be economically attractive, nor will all sites be equally suitable where, for instance, the interests of nature or landscape are concerned.

Meetings were held on 12 October 2006 at which relevant authorities and interested parties were informed of the work of the committee. In addition, the committee held discussion meetings on 4 December 2006 and 2 February 2007 to give authorities, industry associations and other interested parties, including NGOs, an opportunity to discuss findings with the committee members and obtain an insight into their work. At the same time, the committee had opportunities to integrate the opinions of the wind turbine industry and others in its work.

Charting efforts have been submitted to strategic environmental assessment in accordance with the provisions of the Danish Act on Environmental Impact Assessment of Plans and Programmes relative to overall Danish objectives in the environmental area. Among other things, this involves limiting emissions of greenhouse gases, reducing contamination caused by farming, reducing the transport sector's contribution to the greenhouse effect and reducing the loss of biodiversity.

The report with its annexes, which may be viewed at www.ens.dk, has been sent for public hearing, the deadline for replies being 19 June 2007. Replies received will be included in future work identifying suitable sites.

1. Summary and recommendation

The location of large scale wind farms offshore has triggered a need to balance the many and varying sea-use interests. Overall, the sea around us has gradually become the object of planning - a phenomenon also observed outside Denmark. Until now, offshore wind turbines have been regarded as a new activity in competition with more traditional uses of the sea's resources and possibilities, such as fishing and shipping. Therefore, finding new areas for the location of offshore wind farms underlines the need for a strategic planning at sea.

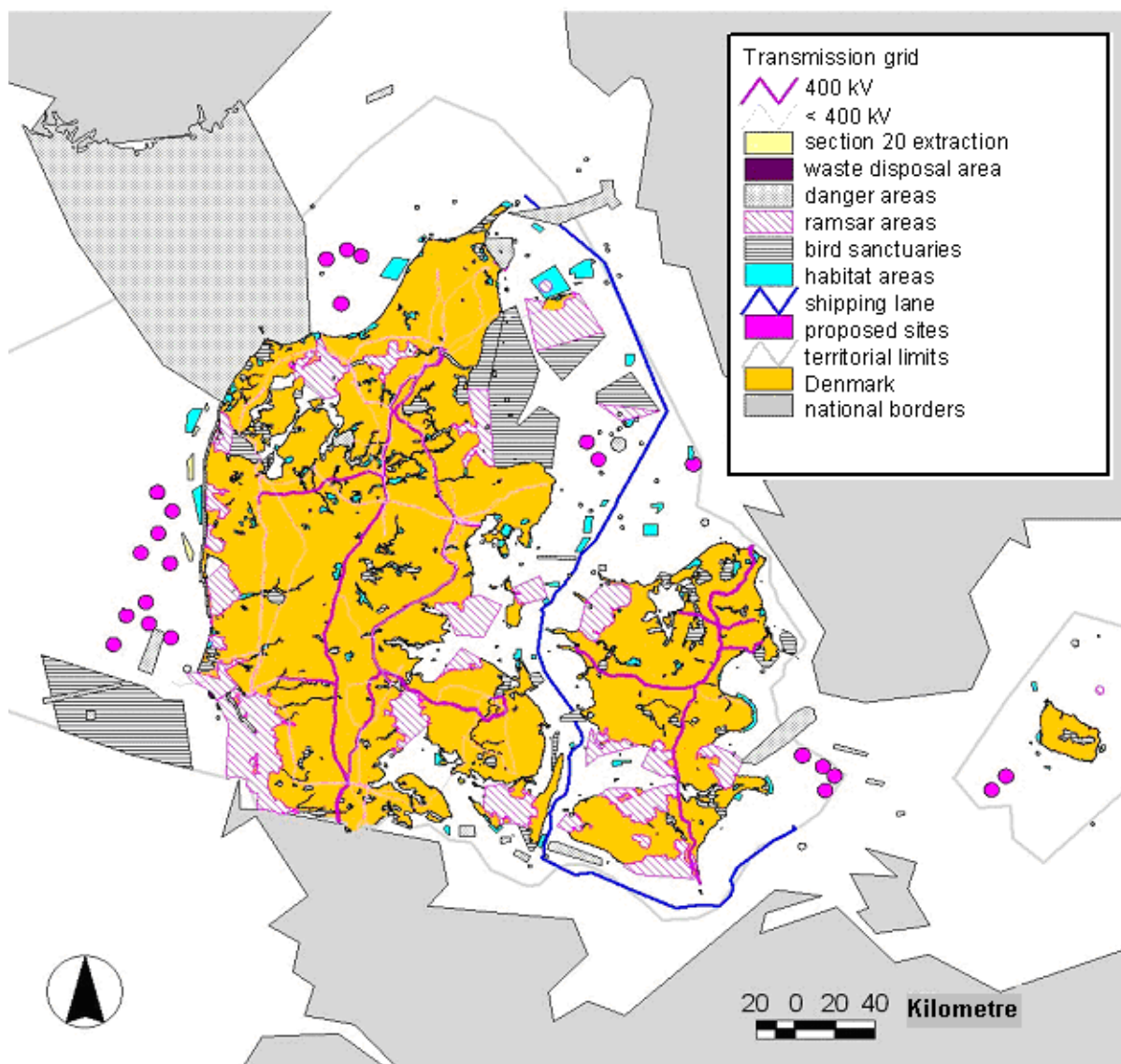
This need is further highlighted by the draft proposal for an overall EU maritime strategy, which the Commission has sent for consultation until July 2007. Under the strategy the maritime sectors must, for instance, arrange their activities with a view to achieving the objectives for good environmental conditions at sea by 2021.

The recommendations of the committee on a prioritised sequence of sites

The committee has examined in detail 23 specific possible sites each of 44 square kilometres to an overall area of 1012 square kilometres divided between 7 offshore areas (see map below).

Taking into consideration the costs involved, the committee recommends that that any forthcoming expansion of offshore wind farm construction should take place in a prioritised order. As, when selecting potential areas the majority of interests were taken into consideration, the recommendations for following a particular sequence in constructing sites are primarily based on the economic consequences regarding the additional costs for installation relative to water depths, grid connection, the expansion of the onshore transmission grid and the expected energy production.

The committee recommends that the first farms be constructed at Djursland-Anholt in the Kattegat and Horns Rev in the North Sea. However, the prioritisation of Horns Rev depends on the closer evaluation of the nature conservation interests. From the economic standpoint an expansion in Jammerbugten off the coast at Ringkøbing in the North Sea would be almost identical. Finally, the committee recommends sites at Store Middelgrund in the Kattegat and Kriegers Flak and Rønne Banke in the Baltic Sea.



The report also discusses a number of areas; of which several have been designated previously, which the committee does not immediately believe to be suited to the installation of large scale offshore wind farms, as long as more suitable sites are available.

The economic estimates made are summarised below. The purpose of the economic estimates is solely to act as a decision-making tool for prioritising the sequence of future offshore wind farm sites by distinguishing between water depths, distances from shore and possible grid connection solutions. The estimates are based on a large number of assumptions. If the assumptions change, this will have an impact on the overall economic assessment of future offshore wind power deployment.

List of sites, mean values for the areas							
	Installed capacity	GRID cost	Construction cost	Overall investment	Wind resources	Full-load hours (5 MW turbine)	Overall investment p.a.
	MW	DKKm/MW	DKKm/MW	DKKm/MW	m/s	hours	DKK/kWh
Djursland	2*200	3.3	12.7	16.0	9.7	4008	3.98
Horns Rev	5*200	4.4	12.8	17.2	10.2	4279	4.01
Jammerbugt	4*200	4.9	13.3	18.2	9.8	4097	4.42
Ringkøbing	5*200	4.2	15.3	19.5	10.3	4298	4.52
Store Middelgrund	200	3.3	16.1	19.4	9.7	4032	4.80
Kriegers Flak	4*200	5.6	14.9	20.5	9.7	4044	5.10
Rønne Banke	2*200	4.3	18.1	22.4	9.8	4056	5.50

List of sites, mean values for the areas. For a description of the assumptions made, refer to sections 4 (Wind Turbine Finances), 6 (Grid Conditions) and 8 (Expansion in Stages). Mean values can not just be added as some of the Grid Costs would be doubled counted for.

Assuming complete construction of all the recommended farms, the analysis shows an overall investment level for the areas of between DKK 16 and 22 million per installed MW including grid connection and grid reinforcement onshore, of which investment in the actual installations amounts to DKK 13-18 million per MW for water depths between 10 and 40 metres.

The costs of grid expansion vary between just over DKK 3 million per MW at Djursland-Anholt and almost DKK 6 million per MW at Kriegers Flak.

Because wind conditions and thus production output have a considerable impact on overall project finances, these are important parameters to be included in economic evaluation. Allowing for the various wind conditions (full-load hours), the average overall investment in construction and grid connection for the areas varies between almost DKK 4/kWh and DKK 5.5/kWh p.a.

Long-term site assessment

The committee recommends that an expansion of large scale offshore wind farms should follow an order of priority. A general “open door approach” involving construction starting on all areas at once could result in an undesirable uncoordinated expansion sequence with the consequent bringing forward of or faulty investment in the transmission grid.

However, the Danish Electricity Supply Act provides for the granting of licences for offshore wind turbines following such an open door approach outside the designated areas. The committee recommends that the derived investments in the transmission grid should, where necessary, be included in the economic evaluation in each case.

In order to ensure that the necessary transmission installations are ready for commissioning at the time the offshore wind turbines enter operations, a long-term localisation plan must be drafted for the expansion of offshore wind power. Coordination between central, regional and local authorities when implementing a localisation plan is crucial to streamlining administrative procedures.

In general it is deemed that the most appropriate approach is to continue the construction of offshore wind farms at the same site until the capacity of the transmission grid has been fully exploited. Only then should the next expansion of the transmission grid start. A planned construction of more farms at one and the same site will enable the optimisation of grid connection. Here one could compare a collection ring for several farms with a number of parallel sea cables from each park. The advantage of a collection ring would be to obtain redundancy with the result that free capacity due to wind turbines breaking down or undergoing maintenance can be utilised by the other wind farms. Moreover, a common grid connection for several offshore wind farms based on high voltage direct current (HVDC-VSC) would be a possible alternative.

The long-term and coordinated planning of offshore wind turbine construction will provide the best technological and economic solution. If the grid connection to each individual farm must be optimised, the total costs of such work would be higher than for a planned overall transmission grid.

The system services costs are expected to increase considerably as wind turbine construction proceeds. However, we must stress that the system operating conditions must be examined in greater detail once a specific wind power localisation plan has been drawn up.

International coordination

Both in the Baltic and in the Kattegat (and perhaps also in the North Sea), there are border areas where various countries' offshore wind farm sites are in such close proximity to each other that coordination between the transmission system operators in each country and the authorities of each country would be a natural consequence. Coordination with neighbouring countries might be of great significance to the exploitation of the areas and the solutions chosen. In some cases, such as at Kriegers Flak, other circumstances such as the underpinning of efficient electricity markets by using connections to offshore wind turbines in commerce between countries may be of crucial importance. Through co-ownership of the connections Energinet.dk can ensure that these are made available on equal terms to all players in the market. The recommended order of priority may be affected should a Swedish-German-Danish partnership for joint connection and landing be chosen for Kriegers Flak.

Weighing up interests and assumptions

The committee has assessed opportunities for prioritising the suitability of potential areas relative to each other.

From the financial point of view, offshore wind turbines should be placed in areas which are relatively close to land and in relatively shallow waters from the standpoint of cost-effective installation of foundations and cable grids. Based on landscape considerations it can be argued that offshore wind turbines should be placed so far out at sea that they are not clearly visible from the coast. Moreover, there are other factors such as shipping lanes, including ferry routes, raw material extraction, fishing and nature conservation areas, together with general nature conservation interests which must be considered. Therefore, decision making has to balance economic factors, wind conditions, connection opportunities to the national grid, nature and the landscape.

Economics

Below is given some of the key economic assumptions used to prioritising the suitability of potential areas. Only investments costs are included - thus excluding e.g. transportation from suitable harbour when installing and operating an offshore wind power plant.

Foundation costs in relation to water dept per MW			
<i>Water depth</i>	10 m	20 m	40 m
(DKKm)	3	4.6	10-13

As the above table shows, when assessing the economic impact of locating offshore wind turbines at various depths, foundation costs rise considerably as depths increase. Likewise, a 20% cost increase for a transformer platform can be expected going from 10m to 35m water dept.

Sea cable costs in relation to distance to shore for a 200 MW unit excluding transformer platform		
<i>Distance to shore</i>	15 km	50 km
(DKKm)	125	330

As the above table shows, an assessment of the financial consequences of increasing the mean distance from 15 km to 50 km from the landing point to the junction station in the offshore wind farm more than doubles the costs for the landing cable using a 150 kV or a 132 kV cable.

Energy production in relation to wind speed		
Wind speed	9.4 m/s	10.3 m/s
Energy production (full-load hours)	3900	4300

As the above table shows, a change in the mean wind speed considerably alters wind farm full-load hours and thus has a great impact on wind farm operating finances.

Wind conditions

Wind conditions at all the sites studied were good. The best wind conditions are on the west coast of Jutland where at a height of 100 metres wind speeds may be expected to be 0.6 m/s higher than the average wind speed in coastal waters, equivalent to approximately 7% greater energy output.

Nature considerations

When locating offshore wind turbines regard must be paid to nature, and Denmark has obligations under the habitats and birds directives. Due regard must be paid both to the areas designated in Natura 2000 (habitats and bird sanctuaries) and to general species protection prescribed by the directive. The appointment of habitat areas at sea has as yet not been completed and it is expected that additional assessments will be needed in the light of the obligations imposed by the directives. However, at present it is unclear which specific areas will be designated. The results of forthcoming studies will be used to document where relevant nature types and species are located and will thus affect the future assessment of the areas identified for wind turbine expansion by the committee.

Environmental monitoring programme for Horns Rev and Nysted offshore wind farms

In the environmental monitoring programme for the Horns Rev and Nysted offshore wind farms a number of circumstances relating to the impact on the various biological communities have been studied. The overall conclusion was that given the current state of knowledge it may be stated that these two offshore wind farms have no material impact on nature. Nevertheless, it was also established that general conclusion could not be drawn from these studies, as on some points the results differed between the two sites. In conjunction with the monitoring programme it was stressed that it is important to locate the farms correctly relative to nature in order to avoid undesirable impact. The scope of magnitude of the impact was defined. However, there is still a need for more knowledge, for example concerning whether the cumulative effects of a major expansion of offshore wind farms could have consequences for the marine environment.

Visibility

It is estimated that depending on visibility conditions large scale offshore wind farms will be visible from a distance of 20 km for 125 m high turbines and 34 km for 260 m high turbines. Thus, turbine height greatly affects visibility. In calm conditions visibility across the sea is extremely good, but due to changing weather conditions visibility will be partially or substantially reduced most days of the year; there are only few days each year when visibility exceeds 19 km.

The need for specific evaluations

When planning the detail location and design of offshore wind farms it is assumed that navigation safety, options for fishing, raw material extraction and nature conservation interests etc will be specifically evaluated. For example, it may be expected that in general a ship collision risk analysis will be required as part of the EIA report (environmental impact assessment). In the preceding planning stage, area and time coordination must be carried out so as to combine preinvestigation activities in the best possible way and so that one interest/activity does not automatically exclude the other.

Test turbines

The location of test turbines at sea must be viewed in the light of the recommendations in the “Report of the Cross-ministerial Work Group on Onshore Test Wind Turbines”, The Danish Energy Authority 2007. The two studies have been constantly coordinated. During the process, adjustments have been made to demarcation between the work group and the committee so as to allow the task of finding suitable sites to be performed in the best possible way. The location of the so called series 0 test turbines onshore or near shore (offshore close to the coast) to a great extent complies with the same requirements. Therefore with regard for final demarcation, the location of test turbines onshore or near shore has been assigned to the cross-ministerial work group on onshore test turbines, whilst the location of other offshore test turbines has been assigned to the Future Offshore Wind Power Sites Committee.

Besides the location of test turbines in connection with large scale offshore wind farms, Omø Stålgunde has been designated as a sample area for the visualisation of the location of a small number of test turbines. One question that needs answering is whether test sites must be made permanent so that wind turbines can be dismantled after the completion of tests to make way for new tests with other turbines.

The committee has discussed the possibility of installing test turbines next to the existing offshore wind turbines south of Samsø. The committee are hesitant regarding landscape conditions, and consequently has called for closer evaluation before making a final decision.

The composition of the committee

- The Danish Energy Authority with regard for the Federal sovereignty jurisdiction over territorial waters and of the exclusive economic zone as concerns the exploitation of wind energy. Thus the Authority is the planning authority and is responsible for approving offshore wind turbines.
- Energinet.dk with responsibility for planning and construction of the electricity transmission grid and for ensuring open and equal access to all the players in the energy market.

- Risø with its specialist knowledge of wind power and the establishment for criteria for wind power test areas.
- The Danish Maritime Authority with responsibility for navigational safety and safety at sea.
- The Danish national Forest and Nature Agency with responsibility for seascape, nature conservation and raw material extraction.