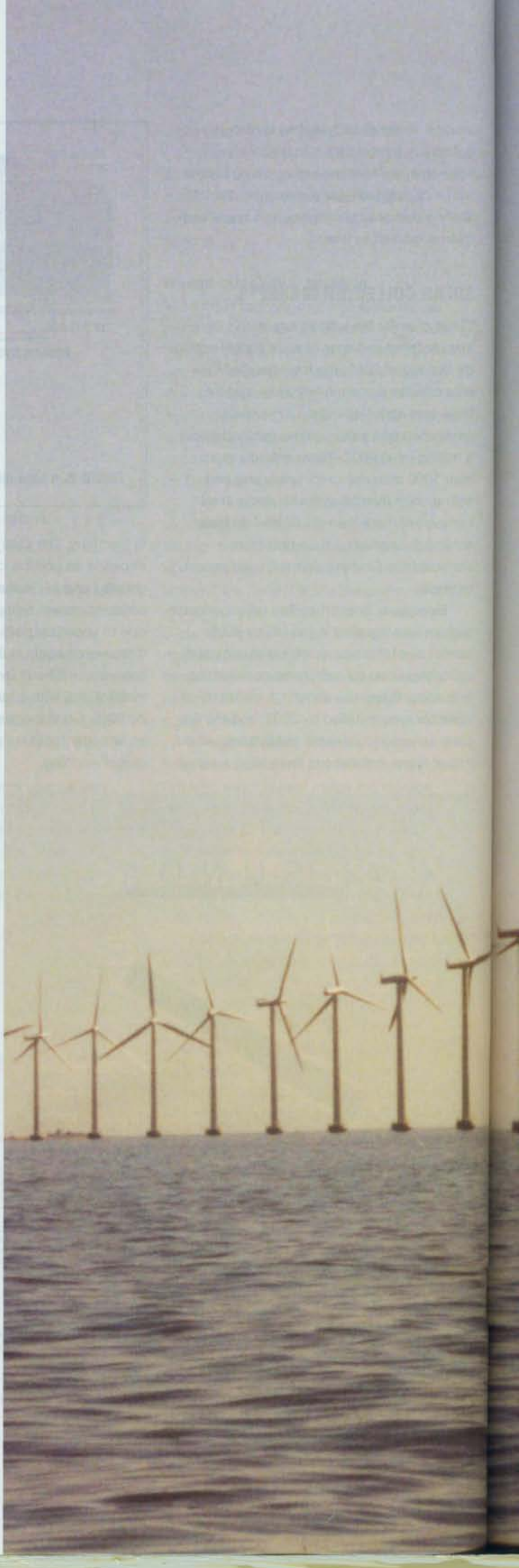
Public opinion is one of the factors driving offshore wind development far out to sea – with all the extra costs that involves. Here, Hans Bjerregaard argues that the industry should set its sites nearer the shore, and presents guidelines on how this can be done. He also presents some of the real costs of establishing nearshore wind farms, based on Danish experience, compared with those further out to sea.

Offshore wind resources are broadly divided into two categories: nearshore – those up to 6 km, and those further out to sea. Most existing offshore wind farms fall into the first category, but new projects, and many longer-term plans, are based at more distant sites. In some countries or areas – notably Germany's North Sea – environmental considerations mean that most or all development will be much further offshore.

At the present stage, offshore wind energy utilization cannot compete economically when there are good onshore sites – therefore, in regions that have abundant sources of good onshore locations for wind turbines, there is basically no need to establish offshore wind farms. Yet there are good reasons for developing offshore wind energy potential in some regions. Some of the most important are that:

- the onshore wind energy potential is in many regions limited due to physical, planning or public acceptance factors, and the available potential has been largely utilized
- exploitation of onshore wind energy potential can be constrained by extra costs related to factors such as weak grids or difficult terrain (such as mountains) – especially when the best sites have been utilized
- offshore sites offer potentially large-scale projects that may be better suited to the larger energy companies, while this may not be the case for onshore sites.

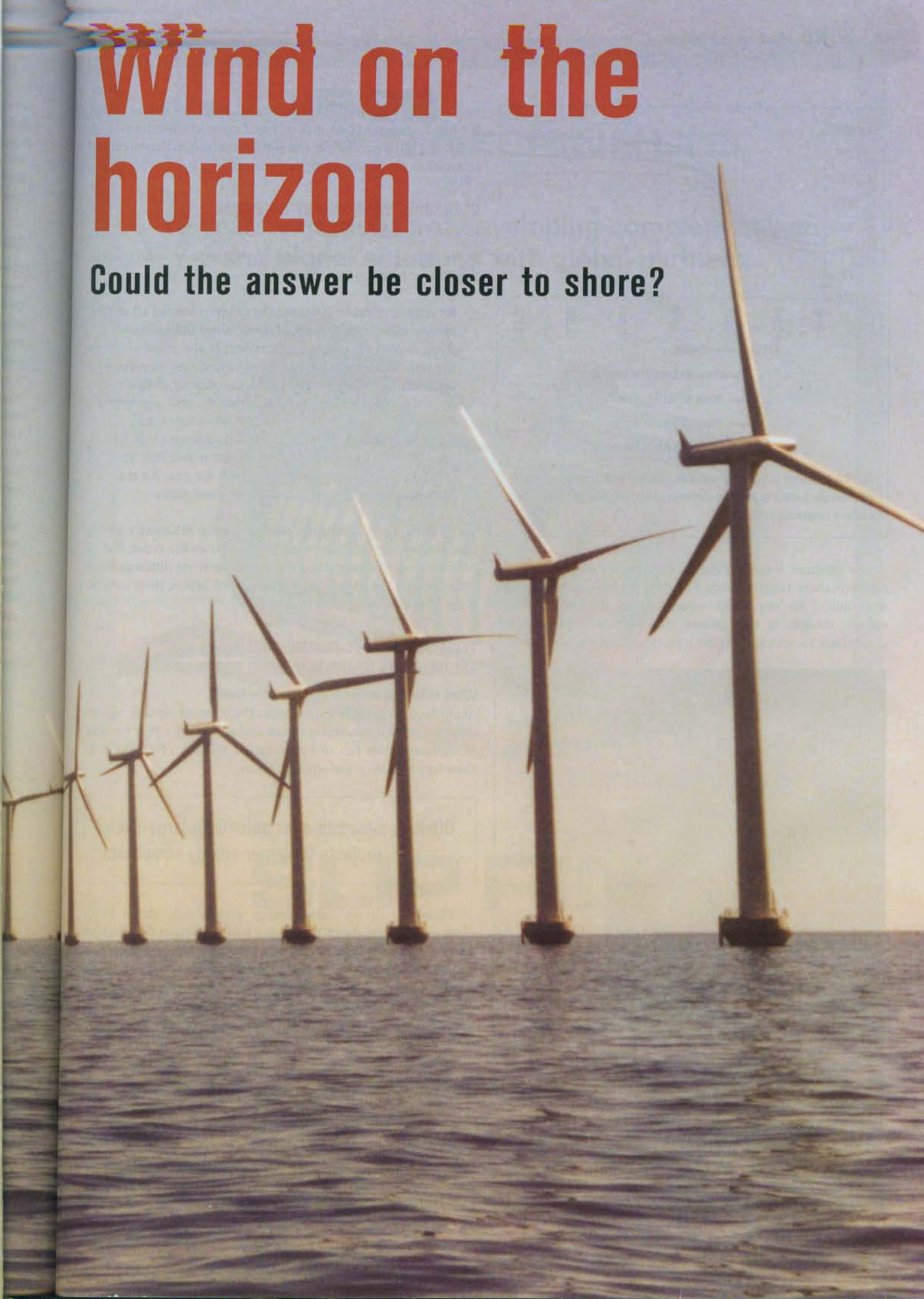
Any combination of these reasons can be sufficient motivation for the establishment of an offshore wind farm.



Getting a sense of perspective – while Copenhagen embraced the Middelgrunden wind farm, situated in the city harbour, most offshore developments are being driven beyond the horizon

Wind on the horizon

Could the answer be closer to shore?



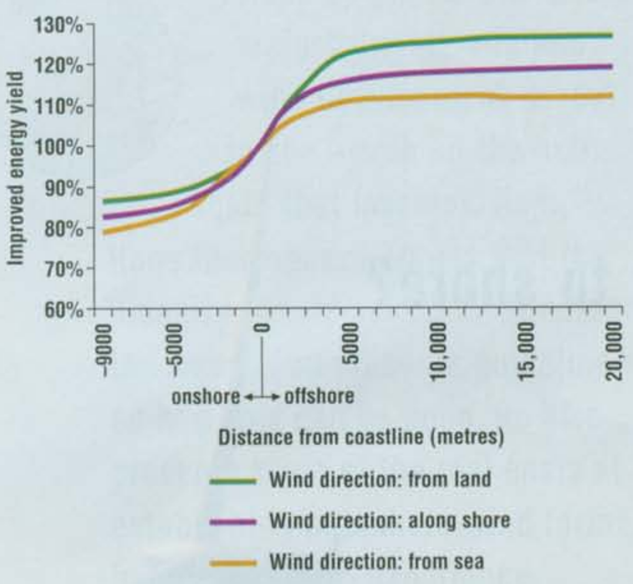


FIGURE 1. Change in energy production with distance from coastline; the example turbine is 3 MW in size with a hub height of 80 metres, and onshore roughness is class 2

As offshore wind utilization has a shorter history than onshore, there is still greater potential for improvement of its economics. An important disadvantage of offshore wind energy, though, is the greater risk presented by offshore conditions. Factors such as the type of seabed, the potential for bad weather during the construction period or the potential for extra operation and maintenance costs contribute to that increased risk. As extra experience is gained, these risks can be reduced, but will not disappear entirely.

NEARSHORE WIND ENERGY POTENTIAL IS READY TO BE UTILIZED

There are several reasons why the nearshore wind energy resource is ready to be tapped:

- for economic reasons, sea depths of up to around 10 metres are the most attractive for offshore wind utilization – these depths are most common near to the coast
- the grid connection cost is an important cost element in establishing offshore wind farms; the shorter distance from the coastline means lower costs for grid connection
- for co-operatively or locally owned wind farms, an offshore wind farm's location close to the area that the owners live can be a positive socio-economic factor, creating a physical connection; this is the case for the Middelgrunden and Samsø offshore wind parks.

Yet in a number of countries there is a great reluctance to the establishment of offshore wind parks near to the coast, due to concerns over planning and the reactions from different local stakeholders. Yet, as will be demonstrated below, there can be ways of overcoming such resistance.

TECHNICAL AND ECONOMIC GUIDELINES FOR ESTABLISHING NEARSHORE WIND PARKS

Wind resource assessment – micro level

According to Danish experience, the cost of setting up an offshore wind measurement mast and gathering a year's worth of measurements has to be budgeted at least €100,000. It is therefore a relatively costly operation.

> **Offshore sites can offer potentially large-scale projects for larger energy companies**

Figure 1 shows how energy production varies with distance from the shore. Based on a wind direction distribution whereby some 60% of the energy production comes from the prevailing wind direction (such as in Denmark, where 60% of the wind is westerly or south-westerly), there will typically be a decrease of 12%–28% at sites near the shore, depending on the orientation of the coastline relative to the prevailing wind direction. At a distance of more than 5 km, there will be almost no reduction. If the wind direction is more uniform (in the case of the Greek island of Crete, for example, where almost 100% of the energy comes from the north-west), the sensitivity of the coastline orientation will be higher. If there are mountains or rough terrain, the decrease in relation to distance will change.

Water depths and foundation costs

So far, water depths outside the 2–30-metre range have not been considered appropriate for offshore wind farms.

At depths of less than 2 metres, there will be problems with accessibility by boat (though specially designed vehicles might provide an alternative for transportation of the equipment to site). Depths greater than 30 metres have so far been thought of as too expensive - but there is no exact upper limit. Even floating wind turbines are being considered for much greater water depths.

Three types of wind turbine foundations are normally considered:

- gravity foundations (2-20 metres)
- monopile (5-30 metres)
- jacket (15-30 metres).

According to experience gained in Denmark:

- the price basis for a water depth of 8 metres is €250-300/kW, including installation (typical foundation costs on land are €40-50/kW, so there is an

approximately sevenfold increase)
- the cost increase per metre of additional water depth is roughly 2%
- the foundation costs represent 20%–25% of the total project costs
- the foundation costs can vary considerably with seabed conditions and weather conditions (such as high waves, tides or ice).

Grid connection

Grid connection cost can vary greatly. One of the main factors is the location of the nearest connection point on land is that it is 'strong enough' to take the feed-in power from the wind farm. It will often be necessary to upgrade the grid onshore, and maybe even install a new, land-based substation. The costs for grid connection can therefore be anywhere between zero and millions of Euros.

Guidelines for the connection from the shore to the wind farm offshore are given in the following sections.

Offshore wind energy utilization cannot compete economically when there are good onshore sites

Cable roll-out and wash-down

Costs range from €15–70/metre, depending on the seabed conditions and the need to 'wash down' the cable effectively to cover it with the sand found on the seabed, in order to protect it. Where the seabed is rocky, wash-down is of course not possible, and other cover arrangements might be needed. Yet this stage may not actually be needed if there is no sea traffic in the region.

Internal cables between wind turbines

For connections between the wind turbines, 30–33 kV cable is normally used. This is the typical transformer size in offshore wind turbines (though onshore, 10–20 kV is usual for wind). The reason for not using higher voltage in the wind turbines is mainly that the space required for higher voltage is much higher, and such an arrangement will not fit onto standard

BELOW Sea view: public acceptance is an important factor for wind farms very close to the shore CHRISTIAN KJAER FACING PAGE Constructed in the tough conditions of the North Sea, Nysted wind farm is typical of the recent trend for situating turbines further offshore NYSTED HAVMOELLEPARK

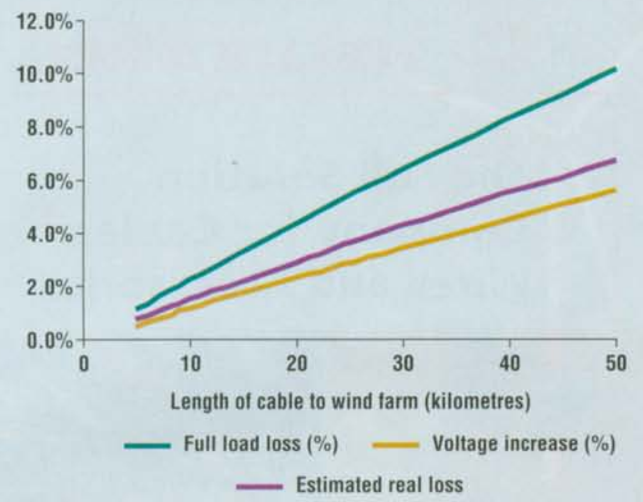


FIGURE 2. Loss and voltage at full load, different cable lengths, 30 MW; 30 kV; 3 x 300 mm² copper cable. Losses of about 2% or above will normally make it feasible to increase the voltage

tower sizes. Manufacturers are working on solutions for this.

The cost of 150 mm² copper interconnection cables is approximately €85/metre. These are normally large enough for the internal connection (though, depending on the connection layout, larger cables might be used for a part of the connection). The cost of cable wash-down may be added here, also.

Offshore transformer station

For larger wind farms, needing a connection to land with voltage higher than 33 kV (that is, of more than about 40 MW capacity), an offshore transformer arrangement will be needed. The cost of this is considerable. For the Danish large offshore projects, the cost of a 150/32 kV - 180 MW transformer is approximately €8 million (DKK 60 million), including foundation and installation costs.

Grid losses and voltage increase

Not only are the costs important, but the losses and voltage increase can also be deciding factors in choosing the right voltage level and cable dimensions.

Figure 2 shows an example of losses in relation to cable length. It shows that the loss is 0.13% per kilometre, plus 0.2% of cable length for the connecting cable between land and the offshore wind farm. For instance, in the case of a 10 km connection it will be 1.3% + 0.2% = 1.5%. There will additionally be losses in the internal cable connection within the wind farm. The voltage increase at 50 km cable length is below 6%, so this should cause no problems.

Costs of offshore wind turbines

Extra costs may also occur. The Horns Rev offshore project, which used Vestas 2 MW turbines, had the following 'add-ons':

- helio-platform (for helicopter landing)
- stationary tool box in each wind turbine generator
- improved tower surface
- nacelle with heaters and temperature regulators

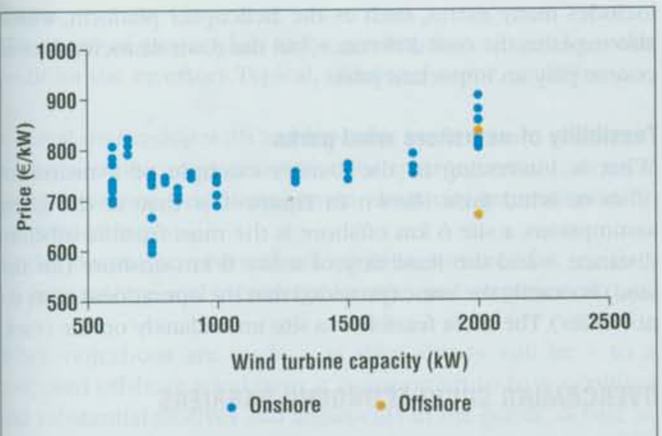


FIGURE 3. Examples of wind turbine prices, mainly for onshore applications. Source: Danish wind turbine catalogue 2001 (EMD)

- extra platforms in tower (for grid connection and handy room, where repair people can stay if there is a storm)
- containers for waste
- three-day survival kit for service personnel
- 150-tonne tower (110 tonnes is standard) to adapt to monopile foundation)
- two flight marking lamps on nacelle
- red paint on blade tips.

In this case, there were extra costs of around 10% of the investment in the turbine. In other offshore projects, the helicopter platform is not needed.

2 MW turbines at the Horns Rev wind farm VESTAS

Wind turbine prices vary quite considerably. Figure 3 shows a recent overview of Danish wind turbine generators (WTG survey, November 2001) and two offshore examples. The low turbine price offshore is from Middelgrunden, using a 2 MW Bonus turbine with 76-metre rotor. The other offshore

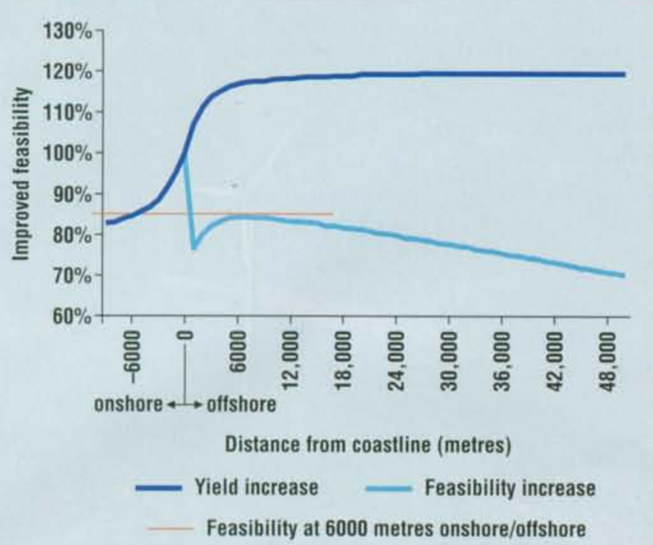


FIGURE 4. Feasibility for an example turbine, 3 MW in size with a hub height of 80 metres, onshore roughness is class 2, with the main wind along shore. Feasibility is based on yield loss and cost increase. At 6 km offshore, feasibility is approximately the same as 6 km onshore – and the 'ideal' distance offshore in this example

wind farm is Horns Rev, using 2 MW Vestas turbines of 80-metre rotor diameter (and 10% more swept area). It should be realistic for a feasibility study to conclude a price level around €850/kW. Note that the Horns Rev solution also includes many extras, such as the helicopter platform, which also explains the cost difference, but the rotor diameter does of course play an important part.

Feasibility of nearshore wind parks

What is interesting in the Danish example of a nearshore offshore wind farm shown in Figure 4 is that, at the given assumptions, a site 6 km offshore is the most feasible offshore distance – and the feasibility of a site 6 km onshore (on flat land) is exactly the same (provided that the operational costs do not differ). The most feasible is a site immediately on the coast.

OVERCOMING SOCIO-ECONOMIC BARRIERS

At many levels – political, planning, financing and development – there may be some scepticism about making use of nearshore wind energy potential, as potential barriers are seen as being too great and the risks too high.

In Denmark, there are six nearshore wind farms, and only two at greater distance from the coast. Three of the coastal wind parks were established in 2002 and 2003. The nearshore Middelgrunden Offshore Wind Park, out of the harbour of Copenhagen, is the first megawatt-turbine offshore wind farm, and as such has been the reference for the new generation of offshore wind farms. Furthermore, Sweden, the Netherlands and the UK have all established nearshore wind farms. In several cases, it has therefore been possible to overcome the barriers.

The most important factors in overcoming the barriers are described in the following sections.

Scope

The scope of project has to be greater than simply to make profit for the investors. Typical, additional scope could be:

- local ownership with local income generation
- sustainable energy generation for environmental reasons (for instance, prioritizing green electricity generation in political ways)
- demonstrating new technology of importance for national/regional income generation and employment.

When objections are made - as they always will be - to a proposed offshore wind farm, it is important to have qualified and substantial motives and arguments in the public debate in favour of the wind farm, otherwise the proposal is likely to be rejected at the planning level.

Ownership

Local ownership or co-ownership can be important for acceptance of a proposed nearshore wind park. This is the case for the Middelgrunden, Samsø and Roenland nearshore wind projects in Denmark. The local ownership can as examples take place through:

- public co-operative ownership - with a greater number of, typically small, co-operative owners (Middelgrunden, Samsø and Roenland)
- local municipality (Samsø)
- local private investors (Samsø and Roenland)
- local, publicly owned utility (Middelgrunden).

Siting

The Samsø wind farm in Denmark is situated off a stretch of coast with a low population density SAMSØ HAVVIND

Several nearshore wind parks are sited as a part of or near to working locations such as a harbour, industrial plant or similar. This type of site can improve the public acceptance - as at Roenland, Middelgrunden and Frederikshavn. The potential disadvantage can be that, in harbours, the wind parks are very visible to many people, which may reduce the level of public acceptance, as at Grenaa, a new, Danish nearshore wind park to be established in 2004.

Another possibility is placing the offshore wind park in an area with either few or no inhabitants whose views would be affected by the wind farm, as at Samsø, in Denmark.

Screening checklist

As a tool for evaluating the potential barriers for establishing, nearshore wind parks, a software-based screening checklist has been developed.

SEAWIND

This article is based on SEAWIND, an EU Altener project providing background and guidelines for establishing nearshore wind farms. The guidelines for establishing

Utgrunden wind farm, off the Swedish coast GE WIND

nearshore wind parks were developed by partners from Denmark, Germany, Spain and France, as a result of a EU SEAWIND Altener-project carried out in 2002–2003 (No.1003/2001).

As background, the project used the experiences gained at established nearshore wind parks in the EU, especially the Middelgrunden and Samsø projects, in parallel with its development of the guidelines. The main responsible partner for developing the technical/economic guidelines was EMD, Denmark - a consultancy specializing in software for the planning and economic evaluation of wind energy - and for the organizational, planning and financing guidelines, Green Globe Energy, Denmark - a consultancy responsible for these and management matters at Samsø.

Regional case studies were carried out in 3 EU regions, with regional partners testing the guidelines at the regional level. These cases were:

- Rousillon-Lanquedoc, France, with the test of a nearshore 72 MW offshore wind park at Aigues Mortes, 4 km from the coastline; the regional partner is ARCHIMEDES, a sustainable energy consultancy company based in the region
- Catalonia, Spain, where a 52.5 MW nearshore wind park at the Ebro Delta was tested; the regional partner is ICAEN, the Catalan authority responsible for wind energy planning in Catalonia
- the Butendiek 240 MW Offshore Wind Park in the North Sea 35 km west of Sylt, for which the partner is Butendiek GmbH; this case is not nearshore, but included anyway so as to use the experience from a large co-operative offshore wind energy project.

The guidelines were also tested in cases in the regions of Yorkshire and the north-west in the UK, and on the south-east coast of Ireland, in co-operation with regional partners.

Software development for offshore optimization

The WindPRO software tool (www.windpro.com) has been improved in several ways to better support offshore development. While WindPRO is a general tool for project development, it can already handle the most important issues for offshore development such as wind farm layout design, energy calculation, economy calculation and environmental documentation (noise, flicker, ZVI, photomontage and animation). But some need for improvement with the offshore aspect has been identified. The most important aspects are:

- more advanced park layout design (arc layout and parallel rows in radials)
- optimization of 'regular pattern layouts', including water depth considerations.

RECOMMENDATIONS

To promote the exploitation of the EU's nearshore wind potential, it is proposed that the EU Commission carries out overall registration of nearshore wind energy potential, using the results from the SEAWIND study presented here, in co-operation with national and regional authorities.

Co-operation should be established with interested regional authorities in developing a 'European Atlas of the Potential for Near Coastal Offshore Wind Energy'. The Atlas should be based on the following:

- registration of physical elements such as sea depth, wind resources and grid connection possibilities in representative European regions
- testing the socio-economic model developed in the SEAWIND project in several regions, to evaluate the real potential, taking into account socio-economic factors.

Hans Bjerregaard is Partner in Green Globe Energy I/S, Denmark, and was director for Samsø Offshore Wind Park Ltd during its construction phase.
e-mail: hansb@post8.tele.dk
web: www.greenglobe.dk