“PROSPECTS FOR OFFSHORE WIND ENERGY”

A report written for the EU (Altener contract XVII/4.1030/Z/98-395) by
The British Wind Energy Association (BWEA).

Views or opinions contained within the report are not necessarily those of BWEA, EWEA or the Commission.

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EXECUTIVE SUMMARY

Of all renewable energy technologies, offshore wind energy has possibly the most favourable combination of the key attributes of resource, energy cost and risk. The European offshore wind resource is extremely large, energy costs are cheaper than those of many other renewable technologies (but more expensive than onshore wind), and the risks are low, as the technology has already entered the demonstration phase.

Studies of offshore wind energy have been in progress for around 20 years. As a result the key issues associated with the resource, the offshore environment and the necessary adaptations of wind turbine technology are all well understood. Early studies focused on the use of MW size wind turbines, frequently in large arrays, whereas early demonstration wind farms used modest numbers of specially adapted versions of commercial machines around the 500 kW mark. Although these have operated successfully and some have delivered energy in excess of expectations, they are mostly installed in relatively sheltered waters. The conditions in some of the windier regions, for example the North Sea, will be more hostile.

Several studies of European resources have confirmed that most states have accessible offshore wind energy resources equal to at least 20 % of current consumption, and most have considerably more. Constraints do, however, need to be taken into account including shipping lanes, military activity, dredging concessions and environmentally sensitive areas. Most resource studies classify the resource according to water depth and distance from shore, as the cheaper resources (in modest depths, close to the shore) are likely to be exploited first.

Offshore wind speeds are generally higher than coastal wind speeds. Ten kilometres from the shore, speeds are typically around one m/s higher and there are large areas of the North Sea and Baltic with wind speeds above 8 m/s (at 50m). Turbulence is lower offshore. This reduces the fatigue loads, but wind/wave interactions must be taken into account during design. Wind speeds are inevitably less well characterised than onshore; this is unimportant as far as resource assessments are concerned, but accurate estimates are needed to establish generation costs. Potential offshore operators are currently making measurements and further studies are also underway.

Denmark, Sweden, Belgium, the Netherlands, Germany and the United Kingdom have already built wind turbines in marine environments, either in the sea or on harbour breakwaters. Further activity is planned in most of these states, plus Ireland and Italy. Responding to this interest, several manufacturers are now offering machines specifically for the offshore market, mostly in the range 1.5 to 2 MW in size and with design modifications such as sealed nacelles and special access platforms for maintenance purposes. Larger machines tend to be more economic as the more expensive foundations are at least partially justified by a higher energy yield.

Although it was anticipated that access for maintenance might be a problem early experience from Danish installations is encouraging although, again, experience from some of the more hostile seas is still lacking.

The construction, delivery to site and assembly of the MW size machines demands specialist equipment, suitable ports and careful timetabling to maximise the possibilities of calm weather windows. Another factor which may influence the siting of offshore wind farms -- apart from offshore constraints -- is adequate grid connection capacity, as offshore wind farms are likely to be several tens, or even hundreds, of MW in size. These sizes are necessary to spread the considerable expenses of hiring specialist equipment and so keep energy costs to an acceptable level.

The energy costs from onshore wind farms cannot be established with the same precision as those of onshore installations and depend, in any case, on the institutional framework of the country where they are installed. Very broadly, capital costs are around 30 to 50 % higher than onshore. This is partially offset by higher energy yields of up to around 30%, for near-shore wind farms. Offshore wind farms are, therefore, even more capital intensive than onshore wind farms, so energy cost comparisons are even more sensitive to test discount rates and capital repayment periods. The limited evidence available so far suggests that offshore energy prices may be around 25 to 40 % higher than onshore costs but it must be emphasised that the database is very limited. The full potential of offshore will only be realised, however, if governments promote plans, which enable the economic advantages of wind farms of several tens of MW in size to be exploited.

One of the key attractions of offshore wind energy is the reduced environmental constraints. Reduced noise constraints may result in the use of higher tip speeds (and hence lighter blades, higher aerodynamic efficiency, or both); it is also possible that two-blade machines may become a more attractive proposition. The adverse visual effects are reduced offshore and the advantages of lighter machines at the MW scale, i.e. fewer parts and a lighter rotor, may lead to significant savings in transport and erection costs. Offshore siting will, however, need to take account of electromagnetic and radio communications and also take into account environmentally sensitive areas.

There is no doubt about the technical feasibility of offshore wind energy and Denmark is committed to the installation of around 4000 MW of offshore wind farms by 2030. Elsewhere in Europe, however, plans for offshore wind are generally less advanced. Liberalisation of the European electricity markets has introduced an element of uncertainty into some plans. This is undesirable, as there are tremendous opportunities for job creation in offshore services, construction and, of course, in the manufacture the wind turbines themselves. Firm action by national governments, backed up by clear policies at EU level is needed to ensure that there is no loss of momentum in the development of offshore wind energy.

1 INTRODUCTION

The current interest in wind energy for electricity generation can be traced back to the oil crisis of the 1970's. A number of Government-funded research and development programmes were initiated during this period, particularly in the United States, Denmark, Germany, Sweden, the Netherlands and the United Kingdom. Many of these focused on the development of large machines (with rotor diameters around 50/60 meters, 1 MW power output). The reasoning behind this strategy was that fewer machines would be needed and hence the environmental impact would be minimised. Even at this early stage it was recognised that onshore development might eventually be constrained and that the offshore resource offered good winds and a very large energy potential.

Winds are generated by complex mechanisms involving the rotation of the earth, heat energy from the sun, the cooling effects of the oceans and polar ice caps, temperature gradients between land and sea and the physical effects of mountains and other obstacles. Most coastal and mountain regions are windy while the interiors of large land masses are generally less windy. Some of the windiest regions are to be found in the coastal regions of the Americas, Europe, Asia and Australasia.

Offshore wind has the potential to deliver substantial quantities of energy more cheaply than many other renewable energies, but more expensive than onshore wind. It also has the added attraction that it has minimal environmental effects and, broadly speaking, the best European resources are reasonably well located relative to the centres of electricity demand. Wind speeds are generally higher than onshore and with reduced turbulence. Experience from early installations is already bringing down energy costs and so the prospects for large-scale exploitation of Europe’s large resource at modest cost are becoming increasingly attractive.

Historical summary

Early European offshore wind energy studies, carried out during the late 1970s and early 1980s, generally concentrated on assessments of three key interrelated issues:-

- wind speeds and wind characteristics,
- The magnitude of the energy resource,
- The feasibility and cost of building wind turbines offshore

Most of the studies looked at the feasibility of using machines with ratings in the range two to 5 MW, arranged in clusters of up to a hundred or more machines. Although there were no commercial machines of this type in operation, there were a number of land-based prototypes and experimental machines, and the expectation was that commercial designs would soon follow.

The power outputs from these conceptual wind farms were in a range from about 300 MW upwards and they were capable of producing electrical energy on a similar scale to a conventional power station. Most envisaged sites around 20 km or more offshore

Studies of this kind were carried out in Denmark, the Netherlands, Sweden and the United Kingdom. Elsewhere, the Westinghouse Corporation carried out an extremely detailed study for United States Department of Energy, which looked at both horizontal and vertical-axis designs.

These early studies were possibly ahead of their time. Offshore development, in practice, has proceeded in a more evolutionary manner, initially with relatively small machines sited close to the shore. Nevertheless, they identified many of the key issues involved in the exploitation of offshore wind energy. The increased wind speeds at offshore sites were, and are, a key issue and the importance of water depth and seabed conditions was also recognised. It was clear that adequate information about wave conditions was needed, partly ensure that there were no problems with machine dynamics and partly to ensure that the turbine blades were clear of the waves at all times. The cost of the grid connection to the shore showed up as a significant proportion of the total – typically around 25%.

Several of the studies assumed a minimum water depth would be needed, to ensure adequate clearance for construction vessels. The Danish study, for example, restricted itself to 6 to 20 m depths only. This restriction influenced some early assessments of the total energy resource, but is viewed as less crucial today. Table 1.1 summarises key data for three of the early studies[1].

Table 1.1 Some early offshore studies

	Denmark	Sweden	UK
Date study completed	1983	1979	1980
Turbine diameter/rated power, MW	80/3	90/5	80/3.73
Site mean wind speed, m/s	8.6	9.5	9.3
Number of machines	595/630	70 per year	196
Rated power of wind farm, MW	c. 1800	350 per year	731
Yield from array, TWh	4	0.95 (70 m/cs)	1.6
Water depth, m	10	20	20
Foundation type	Gravity or piled		Gravity or piled

Offshore wind turbines already built

None of the early design studies for offshore wind were translated into actual hardware. The first tentative steps toward the offshore environment began with the construction of wind farms along harbour walls from the 1980s onwards. Examples may be found at Zeebrugge in Belgium, Ebeltoft in Denmark and Blyth harbour in England. These all comprise medium-sized machines, operating in an offshore environment but built on existing structures. The first truly "offshore" wind turbines were built at Helgoland in Germany in 1989, Blekinge in Sweden in 1990 and Vindeby in Denmark in 1991. Later examples followed within the enclosed seas in the Netherlands and off the coasts of Denmark and Sweden. Details of all these installations are shown in table 1.2 and it may be noted that the later examples move significantly further away from shore. However, no wind farms have yet been constructed off the West Coast of Denmark, or the North Sea coasts of England or The Netherlands, where wind and wave conditions are more severe.

Table 1.2 Offshore wind turbines

Location	Date	Turbines/ rating, kW	Output, MW	Water depth, m/ Distance from shore, m	Foundation type
Helgoland, DE	1989-95	1/1200	1.2	5/10	Gravity
Blekinge, SW	1990	1/220	0.22	6/250	Tripod
Vindeby, DK	1991	11/450	4.95	2-5/1500	Box caisson

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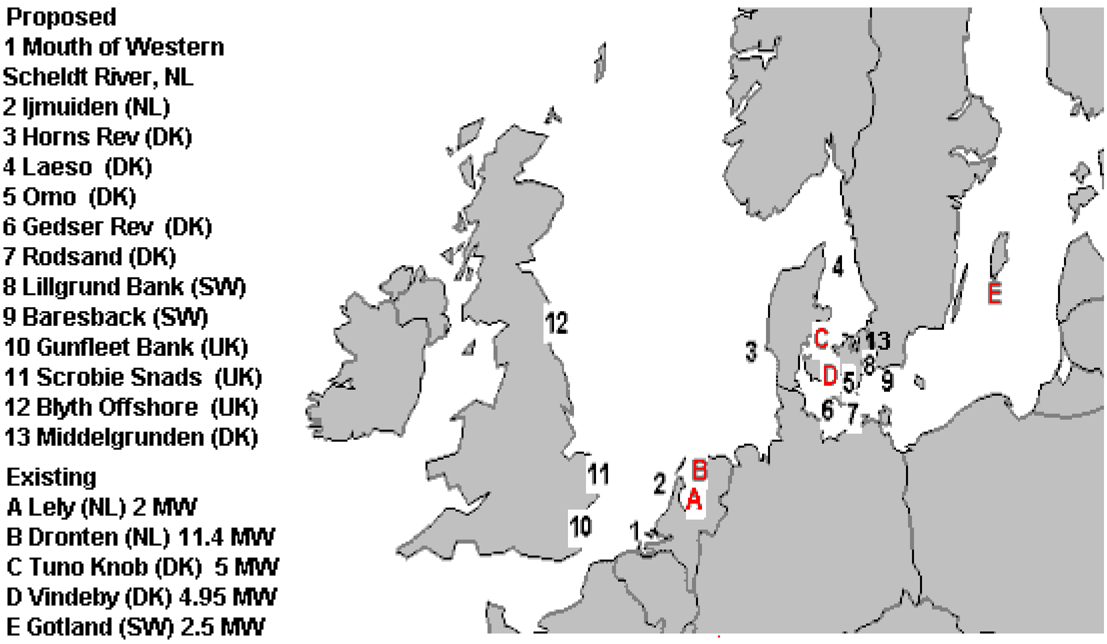
[1] Dixon, J C and Swift, R H, 1986. Offshore wind power systems: a review of developments and comparison of national studies. Wind Engineering, 10, 2, 64-77

Lely, NL	1994	4/500	2	5-10/800	Monopile
Tuno, DK	1995	10/500	5	3-5/6000[2]	Box caisson
Dronten, NL	1996	19/600	11.4	Shallow/50	Monopile
Bockstigen, SW	1998	5/550	2.75	6/4000	Monopile

The design, construction and operation of these early wind farms enabled many of the problems surrounding offshore wind projects to be identified, and solutions proposed for future farms. At Vindeby, for example, the utility allowed contractors to bid for more than one type of foundation as it was felt there was no obvious preferred option. Considerable attention was paid to the design of the jetty to facilitate access to the turbines. The specification for the turbines also demanded extra cranes in order to ease maintenance. (The normal method for lifting equipment onshore simply involves driving a crane adjacent to the machine to lift heavy items).

Operational experience at Vindeby identified a number of problems. The blade setting angles on the stall-regulated wind turbines were adjusted as excessive power was being generated and this was thought to be due to the lower-level of turbulence delaying the onset of stall. Despite the care taken over the design of the jetty on the turbines, mooring difficulties were experienced at lower wind speeds than anticipated. The need for as much flexibility as possible in maintenance schedules became apparent, so as to make the best use of the periods when access was possible. Overall, however, it was possible to gain access to the turbines for 83% of the total time in 1992[3].

Figure 1.1 shows the location of existing and proposed offshore projects



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[2] 3 km from the island of Tuno, 6 km from Jutland. Madsen, P S, 1996. Tuno Knob offshore windfarm. EU Wind Energy conference, Goteborg. HS Stephens and Associates, Bedford

[3] Olsen, F and Dyre, K, 1993. Vindeby off-shore wind farm – construction and operation. BWEA/DTI joint seminar, Harwell, UK. ETSU-N-126

2 OFFSHORE WINDS, WAVES AND RESOURCES

Winds

Offshore wind speeds are higher than coastal wind speeds at sea level. Ten kilometres from the shore, speeds may be 25% higher than at the coast and there are large areas of the North Sea and Baltic with wind speeds above 8 m/s (at 50m). In theory, estimating offshore winds should be straightforward, as the surface of the sea is more homogeneous than the land, but in practice the influence of land features can extend a considerable distance (c. 50 km or more) out to sea[4]. This makes estimation difficult in the zone where most early wind farms will be built. Another difficulty is a shortage of data against which to test predictions

Offshore winds are less turbulent than onshore winds, and wind shear is less. As the roughness of the sea increases with wind speed (as wave heights increase), so shear and turbulence slowly rise with wind speed above about 10 m/s. Typical mean values for mean wind speed[5] and turbulence[6], as a function of height, are shown in Figure 2.1

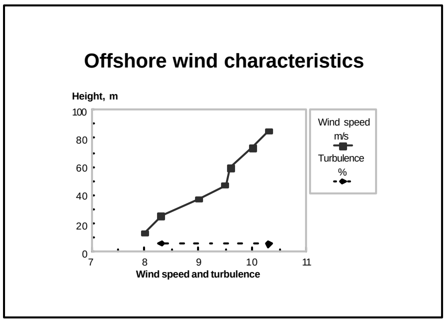

Figure 2.1 Offshore wi nd and turbulence profiles

Although there are disparities between estimates of European offshore winds, there is general agreement that the windiest zones are to be found in northern Europe, with Ireland, Scotland, northern Denmark and Sweden having the highest wind speeds. These may exceed 9 m/s at a height of 50 m, quite close to the shore. The rest of the Baltic region, Germany, the Benelux countries, England, Wales, France and parts of Spain have access to winds in excess of 8 m/s (again at 50m). Most of the Mediterranean region is less windy, although good winds are to be found in parts of the Aegean. Figure 2.2 indicates how the winds are distributed, based on three (sometimes conflicting) sources[7,8,9]. Typical mean winds at operating or proposed wind farms are shown in Table 4.1.

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[4] Barthelmie, R J, 1999. Monitoring offshore wind and turbulence characteristics in Denmark. British Wind Energy Association Conference, Cambridge. MEP Ltd, London

[5] Barthelmie, R J, Palutikof, J and Davies, T D, 1991. Predicting UK offshore wind speeds. Annales Geophysicae, 11, 708-715

[6] Pearce, D L and Ziesler, C D, 1999. The estimation of offshore wind resource. Proc 21st British Wind Energy Association Conference, Cambridge. MEP Ltd, London

[7] Moore, D, 1982, 10 to 100m winds calculated from 900 mb wind data. Proc 4th British Wind Energy Association Conference, Cranfield, BHRA

As the offshore wind resource is so large, uncertainties in the exact levels of wind speed are of little relevance, except in the context of assessing electricity prices from offshore wind farms, for which accurate estimates are vital. Most early installations are likely to be close to the shore, where the uncertainties are greatest. Any estimates from modelling techniques must therefore be backed up by site measurements and a growing body of data will enable a better understanding of offshore winds to be achieved.

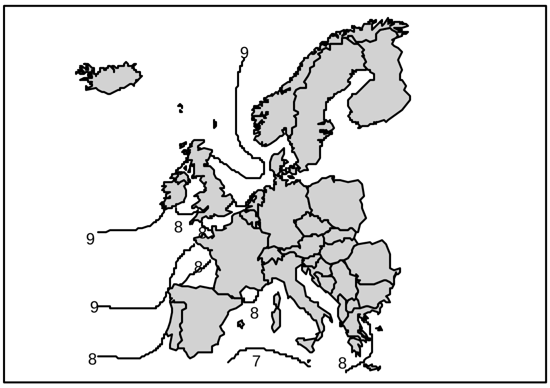

Figure 2.2 European offshore wind speeds (m/s)

Influence of wind characteristics on design

The lower turbulence levels and reduced shear reduce the fatigue loads on wind turbine blades, but are unlikely to bring about significant changes in design. They are, in any case, offset by the higher mean wind speeds. The design of wind turbines needs to take account of detailed information about the wind characteristics. In particular the existence of low level "jets" under certain atmospheric conditions[10] may influence both structural design and assessments of energy yield. These jets reflect instability in the airflow: the velocity increases sharply with height and reaches a maximum value at a height between 50 and around 1500m. It then decreases at higher levels before increasing again, as shown in Figure 2.3.

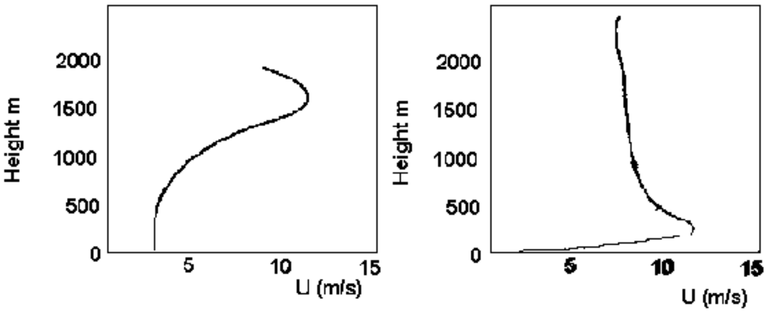

Figure 2.3 Low level jets

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[8] Riso Laboratories, 1997. Isovent map on Web site: http://130.226.52.108/oceanmap.htm

[9] Watson, G M et al. POWER – A methodology for predicting offshore wind energy resources. Proc 21st British Wind Energy Association Conference, Cambridge. MEP Ltd, London

[10] Smedman, A-S, Hogstrom, U and Bergstrom, H, 1996. Low level jets – A decisive factor for off-shore wind energy siting in the Baltic Sea. Wind Engineering, 20, 3, 137-147

The reduced shear may mean that there is less incentive to use very tall towers, but the increase in velocity between 50 and 70m is still around 5-6%, compared with around 7-8% on land. There is still an economic balance to be struck between tower height and energy yield and little sign as yet that the quest for tall towers is over. The rough rule of thumb "tower height equals rotor diameter" still holds, as the machine data of Table 3.1 shows.

Extreme winds at sea are generally similar in magnitude to those found in nearby coastal sites. The reduced level of turbulence means that gusts may be expected to be lower, but the mean winds (upon which gusts are superimposed) are higher. This may lead to the use of slightly higher extreme gust speeds but no dramatic impact on design is anticipated. The maximum 2-second gust speeds for the first batch of Danish offshore farms, for example, is 54 m/s[11].

Waves

The design of offshore wind turbines demands knowledge about wave conditions, particularly the extreme wave heights. Wave heights generally increase with wind speed although there is a time lag, so that extreme winds and waves do not necessarily coincide. Wave heights increase with water depth and so the extreme waves vary with geographical location. The first batch of Danish wind farms, for example, are mostly in fairly shallow water with wave heights between 4 and 8m. In an early British design study[12], where water depths were between 16 and 29m, the wave heights were between 16 and 20 m. As in the case of winds, modelling may enable reasonably accurate estimates to be obtained but site measurements are advisable.

Ice

The design of offshore wind farms may need to take into account the possibility of ice formation in the sea, particularly in more northern latitudes. This affects foundation design, the design of the structure (to protect it against possibility of collisions with ice floes) and operation and maintenance strategies. In regions where the sea freezes over completely, this is likely to influence estimates of the offshore resource, simply because access for maintenance purposes may be completely impossible for periods of up to five months[13]

Resources

One of the foremost attributes of offshore wind energy is the large resource. Numerous estimates have been made, on a country-by country basis and for Europe as a whole. Although the magnitude of the resource differs between estimates -- depending on the filtering criteria used -- the European resource is undoubtedly very large. Differences in the estimates also arise due to uncertainties in wind speed, but large areas of the Irish sea, the North Sea and the Baltic have wind speeds in excess of 8 m/s at 50 meters height, which is greater than onshore winds over most of Europe. As the offshore resources are generally plentiful, variations in the magnitude of

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[11] Action plan for offshore wind farms in Danish waters. SEAS, 1997

[12] Lindley, D, Simpson, P B, Hassan, U and Milborrow, D.J., 1980. Assessment of offshore siting of wind turbine generators. . Proc Third Int Symp Wind Energy Systems, Copenhagen. BHRA, Cranfield

[13] Offshore wind power in the ice-infested waters of the Gulf of Bothnia, Finland. Proceedings of the 1999 European Wind Energy Conference, Nice

the estimates are of little consequence. There are, however, variations in the resource between the various European states.

Table 2.1 shows show sample estimates for two states where several well-documented studies have been carried out, and for Europe as a whole. The spread of values shows the important effect of the filtering assumptions, but the fact that the resources are so large means high accuracy is not important.

Figure 2.3 shows the proportion of electricity which could be supplied by offshore wind energy for 12 European Union states. This covers all the members of the EU at the time the study was carried out. This latter study examined Europe's offshore resources up to 30 kilometres from the shore, and at water depths up to 40m. Figure 2.3 shows the resources at up to 20 kilometres and 20 meters depth respectively. This shows that almost every European State has access to offshore wind to supply at least 25 % of his electricity requirements and most have substantially more resources.

Table 2.1 Sample offshore resource data (TWh) for the EC

Criteria	**Denmark**	**UK**	**Europe**
Water depths>10 m[14],	79	60	359
Water depths 6-20m[15]	124		
> 5 km from shore, water depths 10-50m[16]		230	
Water depths<20m, <20 km from shore[17]	287	401	1623

Constraints

As the table shows, most offshore resource studies have used water depth and distance from shore as parameters to qualify the resources. These features have also acted as constraints, although opinions differ as to when they become actual constraints. Most studies have also examined the implications of other "blocking" constraints such as:-

- the slope of the sea bed,
- shipping lanes,
- military exercise areas,
- regions where dredging concessions existed,
- known dumping grounds for ammunition, explosives and other hazardous materials,
- obstructions such as pipelines, cables and oil platforms and
- Nature conservation areas.

These constraints are additive and can in some instances eliminate substantial areas.

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[14] Selzer, H, 1986. Potential of wind energy in the European Community

[15] Research Association of Danish Electricity Utilities, 1983. Offshore wind power in Denmark

[16] Milborrow, D.J., Moore, D J, Richardson and Roberts, S C, 1982. The UK offshore windpower resource. Proc 4th International Symposium on Wind Energy Systems, Stockholm. BHRA

[17] Matthies, H G et al. Offshore wind energy potential in the EC. European Commission, Brussels.

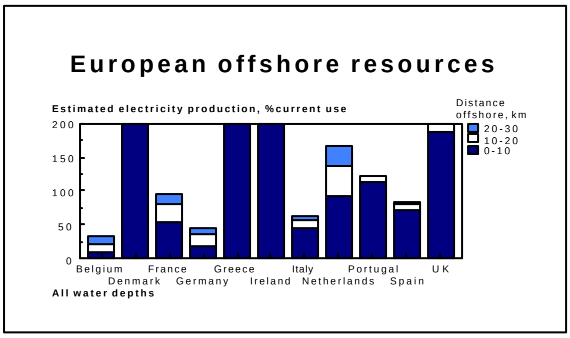

Figure 2.3 European offshore resources, related to present electricity use

What might initially be an additional constraint, at least in the early days of offshore wind energy development, is the need for a "strong" grid connection point at or near the shoreline. This might restrict the development of offshore wind in some coastal areas, but it may be noted that power stations are often sited in coastal zones so that cooling water is available. This does not nullify the conclusion that Europe's offshore resources are considerable, capable of supplying a substantial proportion of Europe's electricity.

3 THE TECHNOLOGY AND TECHNICAL ISSUES

Wind turbines

Early conceptual design of wind turbines for offshore use recognised the need for adaptations to onshore designs, principally to ensure that the structures were adequately protected against corrosion and the entry of salt laden air to sensitive equipment such as control systems. Most studies produced concepts specifically optimised for offshore use, which took into account the higher wind speeds. This meant that high power ratings could be used to deliver increased energy yield.

In contrast, the first offshore wind farms used modified versions of commercial machines. The specification for the machines at Vindeby, for example, required the following:

- Airtight towers and nacelle,
- A de-humidification system,
- Surface finishes to guard against corrosion,
- A permanent crane in the nacelle for small components up to 300 kg, and provision for a temporary crane to deal with the larger components
- Transformers and switchgear to be located inside the turbine towers.

These requirements led, in turn, to other modifications, including the provision of a heat exchanger for the cooling air and a platform for the transformer in the base of the tower. The specification for the second wind farm, at Tuno Knob, built on the experience gained at Vindeby and demanded improved corrosion protection and a higher access door to prevent icing in the winter. The turbine manufacturer supplied machines with a rotational speed 10% higher than normal. This increased the energy capture, as peak aerodynamic efficiency was reached at a higher wind speed than normal, but the higher wind speeds made this worthwhile.

More recently, anticipating the growth in offshore wind developments, a number of manufacturers are now promoting machines designed specifically for offshore use, or "particularly suited to offshore installations". Examples are shown in Table 3.1

Table 3.1 "Offshore" Wind turbines (Data from manufacturers' literature)

Manufacturer	**Bonus**	**NEG Micon**	Nordex	Tacke	**Vestas**
Type	Bonus 2 MW	NM1500/64	N80/2500	TW 2.0	V66 – 1.8 MW
Rated power, kW	2000	1500	2500	2000	1800
Rated wind speed, m/s	15	16	14	c.13	17
Rotor diameter, m	78	64	80	70.5	66
Rotor speed, rpm	2-speed, 12/18	17	Variable, 10.3-19.2	Variable, 13-23	2-speed, 15.4/22
Blades	3	3	3	3	3
Hub height, m	60-80	60-80	60-80	65	61-78
Power control	"CombiStall"	Stall regulation	Pitch	Pitch regulation	Pitch regulation

The key features of each of these machines are shared with onshore machines, with the chief difference being the increase in size, although there are numerous adaptations to make the machines suitable for offshore use.

One manufacturer, for example, lists the following items of equipment designed to facilitate offshore construction and maintenance:-

- An 8.5 t entry crane located at the rear of the nacelle, for lowering or dismantling of the generator or rotor blades,
- An air-cooled generator with separate heat exchanger,
- An additional platform near the base of the tower (but above wave height) with a crane for lifting components onto the turbine and a container for all the electrical equipment with its own air conditioning system,
- A transition piece that fits between the tower and a monopile (the preferred foundation support).

The machines in table 3.1 with around 200 tonnes, with the tower typically accounting for over 50% of the weight, rotors weighing around 25-30 tonnes and the remainder accounted for by the nacelle and electrical equipment.

Once offshore wind farms start to be commissioned, more substantial changes to design features may come about. Two-blade machines, for example, may make a comeback as they are lighter and transportation is easier as there is one less of the very large components. Two-blade machines generally have higher tip speeds and therefore higher noise levels, but this is unlikely to be an important consideration offshore. Concerns about the visual impression created by two-blade machines onshore are also reduced. The aerodynamic efficiency of two-blade machines may be 1-2 % lower and it remains to be seen whether reduced weight and ease of transportation is the more dominant factor in the energy cost calculation.

Offshore support structures

A wide variety of foundation types have been used and proposed for offshore wind turbines. No hard and fast rules can be laid down as to preferred choices, since the this depends on an optimisation which takes into account sea-bed conditions, the distance from shore and the estimated wind and wave loadings. The three principal types of foundation are:-

- **Gravity base**. This type is simply a large and heavy mass of material -- normally concrete -- which rests on the sea bed. Various shapes are used. The block on which the tower of the wind turbine is fixed may be an integral part of the foundation structure or perhaps fixed to it on site.
- **Piled structures**. These come in various forms, the simplest being a "monopile" which, as the name implies, is a single pile driven into the sea bed. Alternatively, tripod-type structures may be used, spreading the loads over wider area.
- **Floating structures**. These have been proposed, either for single turbines or for several machines, but they have yet to be used in practice.
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Gravity bases are not necessarily hollow and possibly the most popular solution for wind farms which have already been constructed has been to use the so-called "deep gravity base" solution. This is a large hollow bell-shaped structure which can be floated out to the site and then filled with sand or hard-core. The cost of these structures tends, however, to be high, partly because of the volume of material, partly due to the expense involved in towing them to site. For this reason the monopile may emerge as a preferred solution, but the more complex dynamics mean that a high degree of confidence in the design techniques is required. Any trend away from gravity structures is therefore likely to be gradual.

The weight of the foundations depends upon the method of construction; a monopile for the machines described above weighs about a hundred tonnes, but a gravity base would weigh considerably more.

Wind farms: Electrical Connections

The electrical connections within offshore wind farms, and from the wind farms to the electrical network, are essentially similar to those of onshore installations. Connection between machines are typically made at around 11 kV, whilst the connection to the shore will depend on the total output of wind farm. It is very likely that the cables connecting the wind farm to the shore would be buried, but those within the wind farm would not. Fishing and anchoring pose serious threats to cables, and the risk of damage from these activities would in most cases justify the substantial additional cost of burying the cable.

Existing offshore wind farms have power outputs around 5 MW and so 11 kV is also appropriate level at which to connect into the distribution system. The larger wind farms proposed have much larger power outputs and the Danish wind farms, for example, with power outputs up to 150 MW of likely to be connected at 132, 150 or 400 kV.

The exact connection voltage depends not only on the power output of the wind farm, but also on the location of offshore connection points and the strength of the local grid. If the wind turbines in a farm have induction generators, then the availability of reactive power in the local network may also be a technical constraint. The need to keep voltage flicker within limits may also impose the requirement to introduce time delays on machine start-ups. Further into the future, the use of high voltage D.C. links to the shore may be appropriate for wind farms located several tens of kilometres out to sea.

The cost of the cable connection to shore forms a significant proportion of offshore wind farm costs, typically in the range 17-34%. At Vindeby (5 MW), the first Danish offshore farm, and at Laeso (117 MW), one of the proposed sites, this translates to around €250/kW, which can be taken as a guide figure. Exact levels will be site-specific, dependent on the cable length and burying method used.

Integrating the output

It is a commonly held, but erroneous, views that the introduction of intermittent sources of electricity such as wind energy into a utility network causes operational problems and necessitates the provision of energy storage. In practice, most utility networks are able to assimilate significant amounts of intermittent renewable sources without any change to their operating procedures. The point that is overlooked is the fact that there are numerous uncertainties in the electricity supply and demand balance and the variability associated with wind energy only causes problems once wind energy raises the statistical error margin. The point at which this occurs depends on the particular plant mix in a given utility, but a figure which is often quoted is that the capacity of wind energy exceeds about 20% of maximum demand, then measures may need to be taken to accommodate it. This does not imply that there is any step change in operating procedures, but simply that additional reserve may need to be scheduled (at modest cost) to allow for variations in the wind-generated output.

Nevertheless, the likely introduction of offshore wind energy in several European states may mean that significant proportions of wind energy may be operating on some networks and it is therefore useful to recap on the some of the key issues[18].

- Modest amounts of wind energy (up to, say, 10% of peak demand) can be assimilated without incurring additional costs or changes in operating procedures
- As the wind capacity approaches around 20% of peak demand additional reserve may need to be scheduled to cope with wind variability; alternatively some wind energy may need to be rejected at certain times.
- As wind penetration increases above 20% of peak demand, further thermal plant may need to be scheduled as reserve, (i.e. operating at part load) but costs are modest. An analysis for England and Wales[19], for example, suggested that with 10 % penetration (on an energy basis) the cost of holding extra plant in reserve would be around 0.0015 €/kWh.
- The provision of "dedicated storage" for wind energy is neither necessary nor desirable and simply increases costs. Any assessment of the economic benefits of storage should take into account the operation of the electricity system as a whole.
- Utility networks already have access to storage, at the very least in the form of the mechanical and thermal inertia of the fossil fuel-fired plant.

The precise levels at which changes in operating procedures become necessary vary between utilities. Those with a high proportion of inflexible plant (such as nuclear or CHP) are less able to cope with intermittent generation; those with plenty of pumped storage or hydro can easily cope with wind generation. It may be noted that the high level of offshore wind proposed for Denmark can be assimilated as the Danish system is linked to Sweden, where there is plenty of hydroelectric capacity.

Cross-border trading of electricity seems likely to increase, irrespective of developments in offshore wind. This means assimilation of offshore wind will probably become easier, as fluctuations in output will be “lost” within the European system – provided there are strong links between the various networks.

With increasing privatisation of the European electricity utilities, some countries, e.g. the UK are introducing trading arrangements that attempt to match all generation with demand on a contract-by-contract basis. This tends to overlook the uncertainties associated with the operation of utility networks and may penalise renewable energy sources such as wind. This does not negate the validity of the technical arguments set out above, and can penalise intermittent generation over and above the actual costs that the intermittency imposes on the system.

It is more difficult to lay down general guidelines governing the assimilation of wind into local networks (as distinct from the main transmission network), as the issues tend to be site-specific. The existence of weak networks in some areas may, however, inhibit the introduction of offshore

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[18] Milborrow, D J, 1993, Understanding Integration. Windpower Monthly, September, pp27-33.

[19] Milborrow, D J, 1994, Wind Energy Economics. British Wind Energy Association, Sixteenth Annual Conference, Stirling, MEP Ltd, London.

wind energy and other factors such as the availability of reactive power may also cause problems. Generally however, the large wind farms will be connected into the main transmission networks, where such difficulties are likely to be less severe.

4 ELECTRICITY PRICES

Offshore wind has the potential to deliver substantial quantities of energy more cheaply than most other renewable energies, but it is more expensive than onshore wind. Cost reductions may be expected during the next decade, however, as the technology is further developed.

Economics: wind farm costs

A number of factors combine to increase the cost of offshore wind farms above onshore costs:-

- the cost of the cable connection from the wind farm to the shore; this increases with the distance from the shore, and accounts for between 17 and 34 % of the total cost
- the need for more expensive foundations. The cost increases with water depth and can account for up to 30 % of the total cost
- increased operation and maintenance costs, with a risk of lower availability due to reduced access to the wind turbines during bad weather, and
- the need to "marinise" the wind turbines, to protect them from the corrosive influence of salt spray. These measures may add up to 20% to turbine costs.

Foundation and grid connection costs are substantially more expensive when compared with onshore wind energy. In the budgets for the first batch of large Danish offshore wind farms, from which figure 4.1 is drawn, these items together account for around a third of the total cost. (Onshore foundations are typically less than half this amount, whilst grid connection costs are frequently even lower). This observation underscores the reasons for the interest in larger wind turbines and also for the enthusiasm for larger numbers of machines. Both these trends should result in progressive reductions in wind farm costs per unit of installed power.

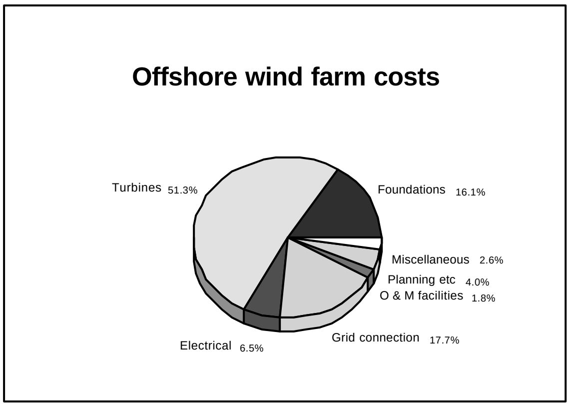

Figure 4.1 Analysis of offshore wind farm costs

Cost and performance comparisons

It is possible to compare the costs of existing offshore projects with onshore wind farms and future proposals. Table 4.1 summarises the principal operational data for the early Danish wind farms at Vindeby and Tuno Knob[20], together with the pilot Dutch farm in the Ijsselmeer [21], and a more recent Swedish wind farm. (The quoted costs of Tuno exclude the extra cost of special environmental studies). Future wind farms include a proposed installation by the English Company PowerGen, off the east coast of England[22], and recent proposals for large projects off the coast of the Netherlands and Denmark [23].

Although the cost of the Vindeby wind farm was 85% higher than the cost of an onshore installation, the anticipated energy yield was 20% higher, partly because availability was higher than expected. Concerns about low availability offshore - due to problems of access - have not been realised. The costs of the early wind farms were significantly higher than those of the most recent installation, at Bockstigen in Sweden. As Table 4.1 shows, most estimates for near-shore farms are now around €1,600/kW. This is the approximate level being quoted for the larger Danish installations now being planned and also in a recent British analysis[24]. It must be emphasised, however, that the number of wind farms actually completed is still very small and so it is too soon to make definitive statements. Just as with onshore wind farms, prices will vary depending on the exact location, with distance from shore and sea bed conditions being key factors. Installed costs increase with water depth and distance offshore[25] but this analysis focuses on near-shore costs, as wind farms in these zones are likely to be developed first.

Another key determinant in offshore wind farm costs is likely to be the number of machines. There is likely to be a trend toward larger wind farms than onshore, to spread the cost of offshore transport, cable connection, and operation and maintenance costs.

Table 4.1 Offshore wind farm performance and costs

Location	Date	Turbines	Capacity	Wind	Output	Cost		
		No./kW	MW	m/s	GWh	MECU	ECU/kW	ECU/MWh
Vindeby, DK	1991	11/450	4.95	7.9*	11.2	9.6	1939	857
(Comparable onshore farm at that time)				7.2*	10	5.3	1071	530
Ijsselmeer, NL	1994	4/500	2	7.7	3.8	5.2	2600	1370
Tuno, DK	1995	10/500	5	7.4*	12.5	10.2	2040	817
Bockstigen, SW	1998	5/550	2.75		8	4	1455	500
Scroby, UK	Planned	25/1500**	37.5	8.2*	102*	55	1466	539
Ijmuiden, NL	Planned	100/1000	100	8.8	300	205	2050	683
Omo, DK	Planned	96/1500	144		434	212	1476	488
Laeso, DK	Planned	78/1500	117	9.1	396	184	1570	465

*Authors' estimate

** Particulars as announced in 1996, liable to change

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[20] Madsen, P S, 1996. Tuno Knob offshore wind farm. EU Wind Energy Conference, Goteborg, Sweden, 20-24 May. H S Stephens and Associates.

[21] Van Zanten, W, 1996. Lely wind farm. Caddet Newsletter, September 1996

[22] Norfolk offshore wind farm takes off. Modern Power Systems, September 1996

[23] Action plan for offshore wind farms in Danish waters. Elkraft, 1997

[24] DTI, (UK), March 1999. New and Renewable Energy: prospects in the UK for the 21st century. Supporting Analysis. ETSU, R-122.

[25] Schwenk, B and Rehfeldt, K, 1998. Untersuchungen zur Wirtschaftlichkeit von Windenergieanlagen im Qffshorebereich der norddeutschen Kustenlinie. Proceedings DEWEK98 Conference

Offshore and onshore electricity prices

The indicative level of €1600/kW for near-shore installations is roughly 60% higher than installed costs for typical onshore farms, which average around €1000/kW. To provide an indication of how onshore and offshore energy prices compare, Figure 4.2 shows data for:-

- onshore: mid-range installed costs of €1000/kW,
- offshore, a mid-range cost estimate of 1600€/kW.

The test discount rate is 5% real, and the depreciation period 20 years, in line with Danish practice. The higher offshore cost estimates are for sites further away from land.

Direct comparisons at identical wind speeds may be misleading. In Denmark, Germany and the Netherlands, for example, offshore installations benefit from higher winds than onshore. This reduces the energy price premium, to around 16-30%, depending on location. Elsewhere in the EU, notably in the UK, offshore winds are not necessarily higher than those onshore and so offshore prices may be up to 80% higher.

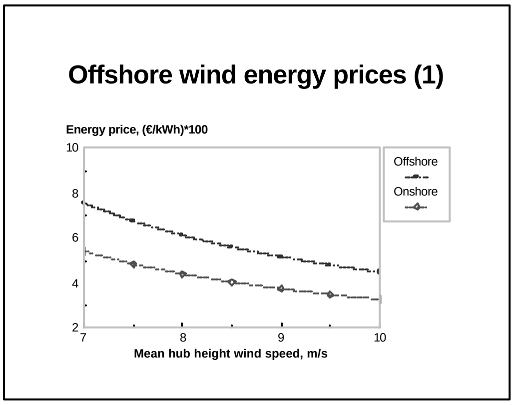

Figure 4.2 Indicative comparison: offshore and onshore wind energy prices (Public sector basis)

Private sector test discount rates and depreciation periods vary across the EU and also depend on the particular support framework for wind energy. In the UK, for example, interest rates are set by the market but the depreciation period is set by the length of contracts under the market support mechanism -- the Non-Fossil Fuel Obligation. These run for 15 years and this sets the depreciation period. Market rates of interest vary with time but recently the "cost of capital" to electricity utilities (likely to be major players in the early offshore market) has been around 7.5% real, i.e. net of inflation. These parameters have therefore been used to derive typical "private sector" offshore wind prices shown in figure 4.3, along with an installed cost of €1600/kW, fixed annual operation and maintenance charges of €30/kW and variable O&M charges of €0.005/kWh.

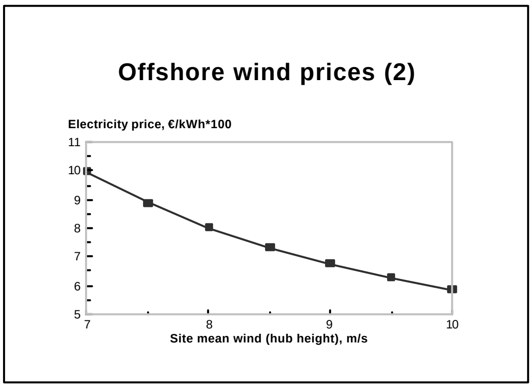

Figure 4.3 Offshore wind energy prices (Private sector basis)

The proposed wind farm at Laeso is part of a much bigger programme, which will eventually see around 4,000 MW in Danish waters. Analyses of offshore energy prices for the Danish utilities have shown that the use of large wind turbines - up to 1500 kW rated output - will realise substantial savings. Assuming a wind farm is sited around 6 km from the coast, in a water depth of 5-6 m, the electricity price may be expected to fall by around 33% from the price achieved at Tuno[11,26]. Since that study was completed, however, larger machines have come on to the market, which may possibly yield even greater savings.

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[26] Morthorst, PE, and Schleisner, L, 1997, Offshore wind turbines - wishful thinking or economic reality? Proc EWEC97, Dublin, 6-9 October. European Wind Energy Association.

5. ENVIRONMENTAL AND SOCIAL ISSUES

Introduction

The most significant drawbacks associated with onshore wind energy, such land use and amenity, are largely avoided when wind turbines are located offshore. However, this does not mean that offshore wind energy is devoid of any environmental impact.

Many of the minor environmental impacts associated with onshore wind energy may also be relevant offshore. Apart from the environmental impacts of carrying out construction work offshore, many of which are generic to offshore industries such as oil and gas and telecommunications, there are few issues, which are unique to offshore wind energy. One of these is underwater noise and vibration from operating turbines. As with the onshore wind energy, many of the impacts are of a socio-economic rather than truly environmental nature. They include issues such as potential interference with human activities such as fishing and radar.

This chapter deals first with emissions savings, the main positive driver for offshore wind energy and renewables in general. It then deals with potential negative impacts, discussing their significance and potential mitigation or avoidance measures. This section draws heavily on a report undertaken for ETSU, titled "An Assessment of the Environmental Effects of Offshore Wind Farms[27]". This study considered all conceivable environmental aspects of offshore wind energy at all stages of project development and assessed their importance. It looked at both normal and emergency situations and covered physical and biological receptors as well as socio-economic impacts. Finally the employment effect of offshore wind energy is discussed.

Emission savings

Numerous utility studies have shown that a unit of wind energy saves a unit of energy generated from coal, gas or oil - depending on the utility's plant. It follows that each unit of electricity generated by wind energy saves emissions of greenhouse gases, pollutants and waste products.

The exact amount of emissions saved depends on which fossil plants are displaced by wind energy. In most of Europe this is coal, a situation likely to continue for a few years yet. The reason for this is that nuclear plant and combined cycle gas turbines almost all operate at high load factors, to cover “base load”. This is the minimum load on the system, usually between 20 and 40% of the peak load. At higher loads other plant, mostly coal, are brought on line to cover demand. These plant are sometimes referred to as “load following”. As wind energy has priority access to the grid its output contributes to that of the base load plant. The addition of wind therefore has the effect of displacing coal plant and hence the emission savings are those associated with coal plant, currently around 900g/kWh of carbon dioxide, plus oxides of sulphur and nitrogen and other chemicals. Table 5.1 shows these emissions, from various types of thermal plant[28]. 10 GW of offshore wind, with a capacity factor of (say) 30% will therefore save around

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[27] Metoc Plc, 1999. An Assessment of the Environmental Effects of Offshore Wind Farms. ETSU report W/35/0054300/REP.

[28] Milborrow, D, 1997. Emissions saved by wind energy. Windstats, 10, 1, p5

23 million tonnes of carbon dioxide each year if coal plant is displaced, plus substantial quantities of other harmful pollutants.

Table 5.1 Emissions from thermal plant, in g/kWh of electricity

Technology	Coal	Coal+FGD/ low NOx burners	Oil	Gas
Stack emissions				
Carbon dioxide	830-980	870-980	670-750	380-420
Carbon monoxide	0.03-0.14	0.03-0.15	0.14	0.03
Sulphur dioxide	11-16	0.2-1.6	1.3-13 (2)	0
Nitrogen oxides	0.5-4.5	0.2-1	0.8-3.7	0.35-0.7
Methane	0.01	0.01	0.01-0.03	0.11-0.14
Particulates	0.2-0.5	0.2-0.5	0.4	Low
Waste products				
Ash	58-178	35-230	0.1	0
Gypsum	-	23-30	25	-

The economic savings due to the reduction of these emissions do not presently figure in economic assessments of wind energy. The "external costs" of fossil fuel sources, associated with the damage the emissions cause, may be difficult to quantify, but they are real. A review of several studies[29] indicated that several assigned the external costs for coal fired generation at around €10/MWh.

Although the capacity of gas plant is set to rise, nuclear closures are expected after the turn of the century, so coal is likely to continue to provide the bulk of the load following plant. Emission savings by renewables are therefore unlikely to change markedly, although country-specific analyses will be needed to establish exact numbers.

The environmental impacts of turbine installation

The effects of moving installation equipment to the site, the temporary disturbance of the seabed during construction and cable laying and the disturbance caused by maintenance vessels will all be site specific. These effects are generic to all offshore industries and are well understood and mitigation measures are available in many cases. For example, underwater bubble curtains can be used to prevent sound propagation during pile driving, if necessary. It is important during the site selection and initial scoping stage of the project to identify potential areas of conflict and minimise interference with other activities e.g. shipping, fishing and defence activity.

Turbine installation

A variety of different kinds of foundation can be used as described in section 3. Gravity foundations require the seabed to be smoothed and covered with a layer of shingle. Monopiles require no sea bed preparation, however they are unsuitable where large boulders are present or

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[29] Milborrow, D, 1999. External costs, in: Wind energy: The facts. EWEA for European Commission

the seabed is uneven. It is anticipated that cables from wind farm to the shore will mostly be buried, in order to protect against damage from anchoring and fishing[30].

The environmental effects of both laying cables and installing foundations include the loss of habitat (the foundation footprint) and possible direct loss of marine life during the installation process. There can also be disturbance from sediment movement and noise. It is important that any chemicals or oils used offshore are safe for the marine environment. It is recommended that any chemicals or oils used be registered for use offshore. For example operators in the UK oil and gas industries have agreed a voluntary code of practice for chemical usage. The UK Offshore Chemical Notification Scheme provides offshore operators and subcontractors with information on the chemicals and components, which should not be used offshore or are banned by international agreement.

Commissioning and operation

As an overview of the environmental impacts, table 5.2 summarises the similarities and differences onshore and offshore wind energy.

Table 5.2 Environmental impact comparison with onshore wind energy

Environmental impact	Offshore in comparison with onshore
Visual impact	Reduced - greater distance from viewers
Noise (airborne)	Reduced - greater distance from receptors
Bird strike	Still site specific
Electromagnetic interference	Reduced
Microwave interference	Still site specific
Shadow flicker	Not an issue
Under water noise and vibration	Unique to offshore wind energy

Visual impact

The onshore wind energy industry has developed a very sophisticated battery of tools for qualitative and quantitative assessment of visual impact. These include:-

- mapping the zone of the visual influence (ZVI), to show how many turbines are visible from what location and how dominant they appear,

- photo-montage techniques which place computer-generated images of turbines on a photographic image of the landscape,

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[30] K. Mair (1999). The installation of submarine cables for offshore wind farms. Wind Energy 1999, Professional Engineering Publishing Limited, Bury St Edmunds.

- animations, which show moving turbines superimposed on the landscape. A variation of this is the "fly through" technique which allows the viewer to "move" through a proposed development looking at the turbines from various angles.

These tools can be adapted for offshore projects. The accuracy of photomontage and video techniques was tested in a Thermie study on the Tuno Knob wind farm. The photographic techniques were shown to be successful in predicting a technically correct image, provided the scope of the image was not too wide. A wide panorama makes the turbines appear less tall as the viewer tends inadvertently to compare the height of the turbines with the width of the picture. Video methods were found to be unsatisfactory at long distances, due to the low-resolution achieved.[31].

The visual impact of an offshore wind farm will form a very important part of the Environmental Assessment, as it does with onshore projects. Factors likely to be taken into account include:

- Turbine and wind farm design, and its distance from the shore
- The importance or significance of the seascape and the landscape from which it will be viewed, and the landscape designations
- Public access to the seashore
- An assessment of the effects on tourism and recreation and the impact of the view from sea users looking from the sea to the shore.

Birds

As with onshore projects, sensitive location is extremely important in order to avoid migratory routes or sites of special significance to bird populations. If a project is to be developed close to a sensitive area then a full and detailed assessment of the likely impact will be required. There has been a large amount of research on birds and wind turbines[32], which generally shows that sensitive siting can avoid problems.

A three year study of the impact of Tuno Knob on Eider Duck populations by the Danish National Environmental Research Institute concluded that observed changes in the abundance of the ducks could not be attributed to the construction of the wind farm, but to natural variations in the food supply [33]. Experiments involving stopping and starting the turbines and using decoys to attract birds to the turbines concluded that there was no detectable difference in behaviour when the turbines were rotating, but that the ducks were reluctant to approach nearer than 100 metres[34].

Marine life

Experience from the Vindeby and Ijsselmeer wind farms suggests they had a positive effect on fish populations. Both these wind farms have concrete gravity based foundations, which act as artificial reefs for seabed-dwelling organisms, thus increasing the amount of food available to

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[31] P Madsen, Tuno Knob Offshore Wind Farm, European Wind Energy Conference, Goteborg, may 1996..

[32] Birds and wind turbines: can the co-exist? Proceedings of a seminar organised by ETSU , 26th March, 1996. ETSU, Harwell, UK.

[33] Renewable Energy Best Practice Yearbook, 1994 - 1996, DG XVII, project 3.5 IDAE, Madrid Spain.

[34] www.windpower.dk

fish. Monopile foundations will be less effective as artificial reefs and therefore few conclusions can be drawn from the experience of these early projects.

Less is known about the effect of underwater noise and vibration on marine life. Available information suggests that the underwater noise generated by offshore wind farms will be in the same range of frequencies as existing sources such as shipping vessels, wind and waves. Therefore the noise may merely contribute to the background level of low frequency noise present in the sea [35]. Also it should be noted that the design of an offshore turbine and support structure is driven by the overriding objective of avoiding resonance, therefore vibration should be "designed-out" as far as possible, in order to prolong machine life.

The ETSU report suggests that further work to fully characterise underwater noise and vibration from offshore wind farms and its effect upon biological (and human) receivers should be undertaken.

Interference with electro-magnetic radiation

Wind turbines can cause interference with electro-magnetic communications, such as radio, TV and radar transmission. Just as with onshore wind energy, careful siting in offshore locations can avoid potential problems or alternatively remedial action can be taken. The large spacing between wind turbines, along with the reduced amount of electromagnetic communication in most areas, will mean that it is less of an issue than with onshore. Television transmission is not an issue for offshore wind energy, unless transmission within a country has to cross an area of sea. Interference with mobile phone transmission has not been a problem with onshore wind energy, indeed mobile phone transmission operators sometimes use wind turbines to mount transmission or signal reinforcement apparatus, thus bringing a small additional income to the turbine owner.

One early study concluded that with the exception of low level air-defence radar no problems were anticipated with AM radio, navigation systems or (other radar) transmission[36]. There is evidence from independent studies[37] suggesting wind farms do not have a significant adverse effect on military radar operation. However, in the experience of UK wind energy developers, military radar safeguarding remains a significant, unresolved issue.

Employment creation potential

There are different ways of estimating the number of people employed in wind energy. The results obtained vary between different approaches, and there is sometimes confusion about how to interpret the figures.

A simple multiplier is useful for forecasting the employment creation potential of future wind energy deployment. There is often a tendency to come up with a single multiplier, which can be

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[35] Metoc Plc, 1999. An Assessment of the Environmental Effects of Offshore Wind Farms. ETSU report W/35/0054300/REP.

[36] Taywood Engineering Ltd and CEGB, 1982. Offshore wind energy assessment (Phase IIA, Part 2), The UK resource. ETSU for UK Department of Energy

[37] Annex to ELEKTRO 21840:17668/97. 1997. Disturbance of radar stations by wind turbines, Swedish Defence Material Administration.

GEC Marconi, 1998. MTR/98/25D. Proposed Wind Farm at Craigenlee.

used, on cumulative installed capacity to give the total employment effect. In reality any single number would be misleading as O&M jobs lend themselves to an *output* multiplier, e.g. man years/TWh, whereas turbine manufacture, windfarm construction and project management should be quantified in man years per MW of capacity installed *during that year*. Not all the studies make this distinction, and this leads to discrepancies.

There is also the added complication of where the employment is created. For example Denmark, which exports around 70% of its turbine manufacture (by MW), will have a higher level of employment than the amount of domestic capacity installed that year would suggest. This is complicated further as some components are imported, prior to re-export in assembled units.

The multipliers have to be determined from estimated employment levels as determined by input - output analyses or industry surveys.

The Danish Wind Turbine Manufacturers Association gathers comprehensive statistics on all aspects of the Danish wind market, and has produced some robust employment estimates using the input-output analysis method[38]. However, the results are specific to Denmark and the multipliers are expressed as person years per million DKK expenditure. Both the employment effect in Denmark itself and a global figure for Danish turbines installed elsewhere are calculated. The figures for Denmark are shown in table 5.3. The Association has estimated that 12,000 people were employed in 1998[39].

Table 5.3 Direct and indirect employment from wind power in Denmark.

	1991	1992	1993	1994	1995
Wind turbine manufacturing	2900	2,700	3,650	5,632	7,800
Installation of turbines	300	150	150	231	316
Research, consultancy, engineering, financial, administration etc	200	200	250	300	300
Total (rounded figures)	3,400	3,100	4,100	6,000	8,500

Other input-output analyses have been carried out in the UK [40], Canada (1994) [41] and the USA (1994)[42]. The other approach commonly taken to estimating employment levels is the survey. A survey of employment in the UK wind industry [43] reviewed these studies along with others, and concluded that a reasonable figure for direct jobs for wind energy at the time (1995) was 7 - 8

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[38] Employment in the Wind Power Industry. Wind Power Note 2, March 1996. Available as pdf file from www.windpower.dk.

[39] www.windpower.dk

[40] Ecotec Research and Consulting, 1995. The Potential Contribution of Renewable Energy Schemes to Employment Opportunities. ETSU K/PL/00109/REP.

[41] R Peters, SECDA, 1994. Evaluation and Recommendations for Saskatchewan's Electric Options 2003 to 2020. Publication No G800-94-P-005.

[42] F Murray, L Marsh, P. Bradford, October 19894. New York State Energy Plan Volume III - Impact Assessment. New York State Energy Office, USA

[43] G. Jenkins, Survey of Employment in the UK Wind Energy Industry 1993 - 5. November 1995, ETSU, W/13/00354/47/00.

man years per MW for all manufacturing related to grid connected wind energy systems and around 0.2 - 0.5 direct O&M jobs per MW for current technology. The survey suggested 6.7 UK jobs per MW of capacity installed (with 12.4 jobs/MW for total employment in the UK and overseas) and 0.49 O&M jobs per MW installed.

The EWEA Action Plan suggests that "1 MW of wind power creates jobs for 15 - 19 people under present European market conditions" [44].

However the employment levels in offshore wind energy will be different from that of onshore and few authoritative estimates specific to offshore have been undertaken. The conclusions below must therefore be treated as tentative.

A total of 4.5 full time jobs per MW was estimated in a report for Greenpeace [45]. This figure appears to have been carefully calculated and includes all aspects of the industry, manufacture, project design, installation and operation and maintenance. It was derived following consultation of existing developers and offshore operators, based on experience gained from working on onshore and semi-offshore wind farm sites. The employment effect specifically for O&M is estimated at 0.06 jobs/MW, a factor of ten lower than estimates for onshore. These figures have been used in compiling Table 5.4, which shows the employment effect from an offshore programme of 4,500 MW rising to over 9,000 jobs by 2010. A multiplier of 2.2 has been used to convert direct jobs into total jobs.

Table: 5.4 Forecast offshore growth, and employment implications (figures rounded)

Year	Cumulative MW	Yearly installation rate	O&M jobs @ 0.06/cumulative MW	All other jobs @ 4.5/MW	Total direct jobs	Plus indirect jobs
2005	1125	405	70	1,820	1,890	4,160
2010	4500	855	270	3,850	4,120	9,060

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[44] European Wind Energy Association. Wind Energy the Facts. European Commission, Brussels, 1999. P 124.

[45] Border Wind, June 1998, Offshore wind energy - building a new industry for Britain. Greenpeace.

6 CONSTRUCTION AND OPERATION & MAINTENANCE

The equipment used for constructing large offshore wind farms will have to meet some very demanding specifications. In the short to medium term, vessels designed for other sectors of the offshore industry will be used for offshore wind energy, perhaps with some modifications, but as the industry expands it is very likely that specialist vessels will be developed. This is because the vessels used for the oil and gas industry are prohibitively expensive and because those used for other marine construction or salvage activities are too few in number or are not ideal for the purpose.

Ports

Finding suitable ports from which to dispatch components or pre-assembled units is unlikely to be a constraining factor. A good quay, with plenty of space and 24 hour access is necessary. If necessary mobile cranes can be moved to ports not already equipped for heavy lifting. The European Sea Ports Organisation publishes a directory with contact details for all major European ports [46].

Installation of turbines

The typical conditions that installation vessels will have to contend with are:-

- water depths in the region 5 - 10 metres,
- tidal currents of up to 1.4 - 2 knots (depending on water depth),
- tidal ranges up to 4 - 8 metres, and
- wave heights of up to 6 metres (depending on water depth).

They will also be required to drive or drill piles weighting up to 150 tons, to a depth of up to 20 metres; to lift turbine components or assemblies weighing up to 175 tonnes to heights of around 55 metres above sea level and to be capable of remaining on location during periods of down time during adverse weather conditions. These requirements are considerable and are certainly not routine in any offshore industry.

The vessels currently available fall into two categories, large floating craft and jack-up construction vessels. Jack-up vessels have legs, which extend to rest on the seabed and push the body of the vessel clear of the water. Table 6.1 summarises the characteristics of these vessels and their suitability for installing offshore wind energy equipment

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[46] The Ports of Europe. European Sea Ports Organisation Handbook, 1998 / 99. Compass Publications Ltd, Norfolk, UK.

Table 6.1 Comparison of available offshore vessels

Aspect	Jack-up vessels	Floating vessels
Relocation time between installation of each turbine	Longer, as calm water is required to move jack-up vessel	Faster, as the same anchor arrangement can be used for three or four turbines
Susceptibility to wave - current activity	Stable platform unaffected by waves and current	More susceptible, resulting in increased overall down time
Other comments	Can be raised high above water level, reducing the need for size of crane.	Deeper draft required. Better in deeper water. Generally larger with more storage space.
	Generally not self propelling	Self propelled

Jack-up vessels are probably better for shallower water (less than 10 metres). They are also essential where piles need to be drilled, rather than driven, as the drill must be kept precisely above the hole, and the platform must not twist round. Floating vessels have some advantages and vessel choice must be made on a site by site basis. Floating vessels are generally larger and have more storage space.

A shipbroker identified only two suitable construction jack-ups currently located in Europe[47]. Although a limited number are available further afield, which could be deployed if necessary, it is likely that a new generation of vessels will be developed very quickly once the market develops. The availability of installation craft is a constraint on the rate of offshore wind energy deployment while this situation lasts.

The new purpose-built vessels are likely to have increased jack-up speeds - the currently available vessels were designed for use in near-shore waters, whereas offshore wind farms will be located further offshore in more hostile waters. Faster jack-up speeds would allow vessels to relocate in less calm sea states. Accommodation facilities may be considered, if the vessel is likely to be used for projects further offshore. Self-propulsion is also a consideration, but may be prohibitively expensive.

One offshore operator estimated that a new vessel could be built within eight months.

Installing the foundations

Although a variety of possible foundation types are available, it is likely that the lighter monopile or multi-pile structures will predominate in the future[48]. Gravity foundations are floated out whereas monopiles would be carried on a barge.

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[47] Personal communication, DBS Offshore Ltd.

[48] www.windpower.dk (from the offshore tour)

Installing the turbines

There is considerable disagreement on the best technique for installing turbines. AMEC Marine provided a detailed analysis of the various vessels available for installation, and suggested the turbines should be assembled on site, with each component attached separately. Even lifting a nacelle with two blades attached would be problematic, due to the difficulty of transporting the semi-assembled unit to the site: "The idea of lifting a whole turbine hub and blades, which is currently done on shore seems to be very difficult since there is nowhere onshore that is big enough to lay out the nacelle and indeed many dock entrances around the UK are narrower than 30 metres, therefore not allowing the turbine hub to go through"[49].

Other studies suggest installing the turbine in two stages: the foundation, followed by the tower, nacelle and rotor unit installed as a single assembly.

The Opti-OWECS[50] study carries this integrated installation approach a stage further. Again tower, nacelle and rotor are assembled prior to installation, but the whole assembly is floated out in a vertical orientation and then lowered onto the support structure. For turbines with gravity foundations the whole assembly *including* foundation is floated out as one unit.

An early Swedish study suggested that support structures would be built in a dry dock, have the turbines attached and then floated out to the site using a crane barge. One demonstration turbine was erected using this method, 250 metres from the shore near Norgersund in the Blekinge region of southern Sweden.

The Vindeby turbines were taken, two at a time, fully assembled on their gravity support structures on a 20 by 40 metre barge. This barge, along with a second crane barge were manoeuvred simultaneously by tugs to the site and two turbines were installed per day[51].

With the Bockstigen [52] project the turbine components were taken by ship to the harbour. The monopiles were sealed and floated out to site and the assembled turbines were taken by barge. They were lifted onto the monopile by a jack up barge using its crane and extra height from fully extending its legs.

One of the key lessons learned from this project was that anchoring the cables in areas where the cable could not be buried was problematic. Currents and waves were stronger than anticipated, and the initial attempts to secure the cables (using concrete sacks to weigh down the cable, followed by pinning down with 12 mm steel hooks) did not work. In the end 25 mm U-shaped hooks had to be used.

Relatively few conclusions can be drawn from earlier projects, which consist of small numbers of relatively small turbines. Future offshore wind projects will comprise much larger numbers of bigger machines and economics will dictate rapid and efficient installation techniques.

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49 Kent, D, 1999. Does size matter? 21st British Wind Energy Association Conference, Professional Engineering Publishing Limited, Bury St Edmunds.

[50] Kuhn, M, et al, 1998. “Opti – OWECS” Study. Structural and economic optimisation of bottom-mounted offshore wind energy converters. EU Joule III project JOR3-CT95-0087

[51] Matthies, H G and Garrad, AD 1993. Study of Offshore wind energy in the EC. EC Joule 1 project, Jour 0072

[52] B Lange, E Aagaard, P Andersen, A Moller, S Niklasson and A Wickman, 1999. Offshore Wind farm Bockstigen - Installation and operation Experience. Proceedigns of European Wind Energy Conference, Nice, France.

Offshore operators suggest that floating out pre-assembled turbines is not the best approach. Any lifting operations would have to be carried out in very calm sea states, as any swell in the sea will be translated into much larger movements at the top of the crane. The combination of heavy load and high centre of gravity makes for a very unstable situation.

Whilst specialist installation craft have not been developed and large-scale projects have not yet been constructed, it is perhaps not surprising that there is a wide range of approaches to the turbine installation problem. The range of opinions span theoretical academic studies through to that of experienced offshore operators with existing vessels which could be adapted for the wind energy market.

Electrical layout and connections

There is a variety of cable-burying techniques and specialist cabling equipment available[53]. Cable can be laid and buried simultaneously or in sequence. The burial process can involve ploughing a trench, air-lifting or water-jetting sediments aside, and excavation or sawing through rock. Different burying tools may have to be interchanged on route. If seabed conditions allow, water jetting is likely to be cheapest[54].

Within the wind farm turbines could be connected by hauling the cables using winches temporarily mounted on the turbine support structures[55]. Alternatively they could be laid by barge, and therefore may not require specialist vessels[56].

Operation and maintenance

O&M may form a large part of overall energy costs offshore wind energy. The increased cost of transport to the turbines and reduced access are the major cost drivers. Therefore O&M strategy is extremely important. There is little data currently available on which to base judgements on future strategy. Existing offshore projects are few in number and consist of relatively small marinised land-based machines. There are data for larger machines, but these are, of course, for land based turbines (mainly in Schleswig Holstein) and few conclusions can be drawn from them. The Opti-OWECS study examined a range of maintenance philosophies and practical solutions to O&M tasks. These are summarised in table 6.2.

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[53] K. Mair (1999). The installation of submarine cables for offshore wind farms. Wind Energy 1999, Professional Engineering Publishing Limited, Bury St Edmunds.

[54] www.windpower.dk (from the offshore tour)

[55] W. Grainger, A. Gammidge, and D. Smith (1998). Offshore wind data for windfarms. Wind Energy 1998, Professional Engineering Publishing Limited, Bury St Edmunds.

[56] P. Gardner, L. M. Craig, and G. J. Smith (1998). Electrical systems for offshore windfarms. Wind Energy 1998, Professional Engineering Publishing Limited, Bury St Edmunds.

Table 6.2 Maintenance issues

Maintenance philosophy	Examples of other issues
• Preventative & corrective maintenance: carrying out a preventative schedule along with corrective maintenance when required (the usual strategy for onshore wind farms) • Opportunity maintenance: repair the turbines when they fail, but take the opportunity to carry out preventative maintenance tasks at the same time. • Corrective maintenance only: repair the turbines when they fail.	• Hire repair crews when necessary / have a permanent O&M team • Purchase a dedicated O&M vessel / charter vessels as required • Carry out access by crane barge / Jack-up vessel / helicopter • On site storage of spare parts on separate support structure / at purpose built shore-side location / at the nearest harbour • Repair component on site / replace component and repair at base

The overall conclusions reached by the Opti-OWECS study include:-

- O&M strategy should be optimised with respect to localised production costs rather than pure O&M costs,
- the lifting equipment required for exchanging major components, such as blades, gearboxes, etc, together with the devices for crew transportation are identified as the main cost drivers of installation costs,
- a self propelled, modified jack up platform is very promising in cases where at least 20 lift operations per year are required,
- remote control and monitoring are mandatory to reduce the number of visits, and
- an opportunity maintenance strategy is likely to provide the best maintenance philosophy.

Future consideration of O&M

As described in section 3, manufacturers are beginning to produce machines specifically designed for offshore use. Given the increased difficulty of access of offshore wind farms, machine reliability becomes more important. There are various approaches to increasing reliability:-

- reducing failure rates of components,
- marinising existing land based machines and including redundancy and increased monitoring, or
- design for reliability, availability, maintainability and serviceability i.e. consideration of maintenance issues from the outset.

Therefore there are trade-offs between design for increased energy output and design for increased reliability. The former may be a more efficient, lighter weight machine which aims to increase the energy generated between O&M visits, the latter a more robust machine which aims to increase the time between O&M visits. The Opti-OWECS report suggests that the latter is a better approach.

7 FUTURE ACTIVITY IN THE EU

Denmark

Denmark has the most ambitious and well developed plans for offshore wind energy in the EU, with plans for 750 MW of utility developed capacity to be installed between 2001 and 2005, and a goal of 4000 MW by 2030. These targets were presented in an Offshore Action Plan published in July 1997[57].

The Danish Environment Agency has already approved, in principle, 790 MW of capacity at 6 sites. These include five large projects to be developed by the utilities, along with a 40 MW project being developed by a wind power co-operative and a local utility. The projects are summarised in table 7.1, and their locations shown on figure 1.1. The initial assessments were based on the use of 1.5 MW turbines, but larger machines may be used. Water depths at the sites range up to 15m. Detailed environmental statements are required for all six projects [58].

The Middelgrunden project will be developed and owned by a wind energy co-operative and the local utility, the Copenhagen Electricity Company. The project was awarded 4.3 million DKK from the Danish Ministry of Environment and Energy to investigate technical and environmental matters concerning development in shallow waters, as well as to prove the feasibility of co-operative ownership of offshore projects. The project is to be built in an area formerly used as a dump site for material dredged from the harbour. The favoured design for the wind farm is a single line or turbines in an arc around the harbour[59]. Studies have been undertaken on contamination of the marine environment, risk of collisions with vessels, the impact on marine flora and fauna, potential conflict with other interests and visual impact. The project has a website www.middelgrunden.dk where more information can be found.

The Action Plan anticipates that until 2014 development will be concentrated in the original four study areas: Horns Rev, Gedser, Omo and Laeso.

Table 7.1 selected areas sites for future wind farms

Location	Developer	turbines	Total capacity	Distance offshore
Horns Rev	Elsam	80	120	20km
Laeso	Elsam	78	117	40 km
Omo Stalgrunde	SEAS	96	144	10 km
Gedser Rev	SEAS	96	144	6-20 km
Rodsand	SEAS	96	144	6-20 km
Middelgrund	Middelgrundens Vindmolleaug (MV) Co-op and local utility	20x 2MW	40	2 km

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[57] Birger T. Madsen. 4000 MW of Offshore wind power by 2030. Winstats Newsletter Vol. 10 No 3 Summer 1997.

[58] Windpower Monthly, July 1999, page 20.

[59] S. Jessien & J. Larsen. Offshore wind farm at the Bank Middelgrunden near Copenhagen Harbour. EWEA Conference, Nice, March 1999.

Sweden

Two offshore projects - a small wind farm and a single turbine are in operation, and a range of further projects has been proposed, as shown in table 7.2. These are at various stages in the consent process. However all offshore developments have been delayed due to a test case over the Utgrunden project. All consents were in place for this project except for that from the coastal authority and construction was to have begun in spring 1999.

The coastal authority Kammarkollegiet is contesting the economics of the project, which it states, poses an unreasonable economic burden on Swedish citizens. The project is being tested against Sweden's water law, which is intended to protect societal interests from hydropower expansion. The case will go to the supreme environmental court [60].

Offshore wind energy was given a political boost with a statement by the Prime Minister[61] that the Government intents to implement the law to close the Barseback 1 reactor by December 1999. A second reactor will cbse three years later if enough wind power is available to replace their 8 - 10 TWh contribution. 3000 to 4000 MW of wind power capacity would be necessary to meet this gap, most of which is expected to be offshore. The fist reactor was indeed shut down on 30th November 1999[62].

Sweden is undergoing a transition to a more liberalised electricity market. A transition mechanism starting in 1996 obliges all regional utilities to purchase electricity from renewable plant at a price near that of the household tariff (plus embedded generation benefits and an environmental bonus of around 0.017 ECU/kWh). The average price paid for onshore wind energy is 0.402 SEK/kWh[63]. This transitional arrangement lasts until 2000.

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[60] Wind Directions, September 1999. Page 18.

[61] Wind Power Monthly, November 1999, page 12.

[62] www.sydkraft.se

[63] IEA Wind Energy Annual Report 1998, NREL, Colorado, USA.

Table 7.2 Swedish projects

Location	Status	Developer	# Ts	Total cap.
Norgersund	Operational research turbine		1 x 220 kW	0.22
Bockstigen	Operating since March 1998	Windkompaniet	5 x Wind World	2.75
Lillgrund bank	Environment Ministry, Water board.	Eurowind	48 x Enercon 1.5 MW	72
Utgrunden, Oland	Challenged as a test case by Kammarkollegiet	Vindkompaniet	7 x 1.4MW	9.8
Blekinge, Oland	Regional Authority	Vattenfall	100 x 3MW	300
Rone, Gotland	Prelim. planning	Vindkompaniet	35 x Nordic 1MW	35
Ystad, Skane	Prelim. planning	Vindkompaniet		10
Blekinge, Oland	Prelim. planning	Vindkompaniet		10
Southern Skane	Prelim. planning	Eurowind	30 x 1MW	30

Netherlands

Due to land use pressures, around half of the government's target of 2750 MW of wind power by 2020 is likely to be located offshore. As a first step towards this aim, Novem conducted a feasibility study for a 100 MW wind park situated at a distance of 8 to 10 kilometres offshore in water depths of less than 10 metres. Two sites were identified, one around 8 km from Ijmuiden in Northern Holland and the other in the Scheldt river mouth in Zeeland. The latter is cheaper and the water is shallower but energy output is estimated at 15% less[64].

The government pledged a subsidy of NLG 60 million. This project has been termed 'near-shore' and its objective is to gather knowledge and experience on installation, construction and operation required to develop truly 'offshore' wind farms in the future. Table 7.3 shows the various proposals put forward for other near shore projects. Work on the legal and administrative procedures required began in 1998; and memorandum and environmental assessment were published in July 1998 and public hearings took place in September that year [65].

Table 7.3 Dutch projects

Location	Developer	# turbines	Cap	Distance from shore (km)	Output, GWh estimated	Capital cost
Mouth of western Scheldt River			100	19?	218 - 260	446 NLG

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[64] Windpower Monthly, January 1998, page 38.

[65] IEA Wind Energy Annual Report 1998, NREL, Colorado, USA

or Ijmuiden			100	8+	250 - 300	456 mil NLG
Noordwijk and Sandvoort	Nordzeewind (consortium Stork, ING-Bank WEOM NUON/ENW	50	2000			430 mil NLG (WPM Sept 1999)

An area of 680 km^2 of the Dutch Continental plate has been identified as suitable for offshore wind, capable of housing an estimated 4000 to 6000 MW, according to a study carried out by KEMA. A study commissioned by Greenpeace identified a potential of up to 10,000 MW. The first phase of development is likely to comprise 200, 3MW turbines in 20 metre deep water. If capital costs were 2.5 - 3 billion NLG, a wind speed of 9 - 10 m/s would be required to make the project economically viable. This would require a location outside the 12-mile zone. There is no international agreement on jurisdiction beyond this limit, and so the legal framework may present a major obstacle [66].

UK

Six offshore wind projects were bid into the fourth NFFO order, and two were successful in winning contracts. These together with other projects, on which there is (limited) information in the public domain, are shown in table 7.4. Further details of Scroby Sands are given in Table 4.1. Unit Energy, a joint venture between Unit Energy Europe and UK renewable investment company ESD ventures Ltd, has indicated its interest in developing two projects in the UK, one for 80 MW and the other 100MW[67].

Table 7.4 UK projects

Location	Gunfleet Bank	Scroby Sands	Blyth Offshore
Status	NFFO4 contract, but no information on progress made	No power purchase agreement, as yet	Construction due April 2000
Developer	Windmaster Developments	PowerGen Renewables Ltd	Border Wind
Number of turbines		25 or more *	2
Turbine rating, kW		1800 - 2000 *	1800
Total capacity, MW	29.8	37.5	3.6
Generation cost p/kWh #	< 3.8	>3.8 <6.97	<4.95

Price information deduced from NFFO4 bid range and contract prices (1997 prices).
* Yet to be finalised.

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[66] Windpower Monthly, July 1999, page 19.

[67] Windpower Monthly, March, 1999, p. 27.

The range of NFFO4 bid prices for wind energy was 3.11 to 6.97p/kWh and so all offshore projects must be within that price range. Further conclusions can be drawn on the possible prices, according to the size of project.

Offshore wind energy was precluded from entering the NFFO5 competition, with the expectation that a special order would be announced once more detailed plans on how to develop the resource had been produced. This process has taken place - a consultation paper on incorporating offshore wind energy into future NFFO arrangements was distributed at the British Wind Energy Conference in September 1998.

The offshore consultation document suggested that between four and eight contracts could be let at prices of around 4 -6 p/kWh, with the key determinant of the size of the order being the cost and quality of bids received.

Prospective developers have continued to work on lease proposals with the Crown Estate, the body that owns the seabed. Specific sites of interest remain confidential but the likely areas of interest are south of the river Humber, as far as the Thames Estuary and from Blackpool down to North Wales. Metering equipment has been permitted at five sites; Robin Rigg, Solway Firth, North Hoyle off North Wales, Scarweather Sands, off South Wales Kentish Flats, in the Thames Estuary and Ingoldmells Point off the Lincolnshire coast [68].

The prospects of an offshore order, following on shortly after NFFO5 has been complicated by forthcoming changes to the structure of the electricity supply industry and new electricity trading arrangements. These will change the framework within which NFFO operates. Legislation to implement these changes will be introduced during 2000.

If there is to be some form of NFFO for offshore wind under the new legislation, contracts could not be awarded until autumn 2001 at the very earliest. The prospects for interim arrangements, such as a NFFO6 under the existing legislation, which would allow the industry to get going, are uncertain. An announcement is expected early in 2000.

Finland

The wind resource in Finland is limited by its dense forest cover, which reduces the mean wind speed. The land-based wind resource is estimated to be 300MW to 400 MW along the coastline and around 250 MW on Lapland hilltops. The potential in the Baltic Sea however is very large. The Baltic Sea offshore from Finland is covered with ice for up to 100 days per year, and so poses special problems for turbine foundations. R&D has focused on placing turbines on small rocks an islands which could act as natural foundations, although no projects have been undertaken due to difficulties in getting planning permission [69]. A 660 kW turbine was installed in a semi-offshore location on a tiny island south of Oulu in March 1998. Land based construction methods were possible due to the sea ice [70].

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[68] Windpower Monthly, January 1999.

[69] IEA Wind Energy Annual Report 1998, NREL, Colorado, USA

[70] New Energy, No 2, May 1999 p35.

Ireland

A feasibility study for a ECU 245 million, 250 MW project off the coast of Dublin on the Kish sand bank is being undertaken by a consortium comprising ESB, Saorgus Energy, PowerGen Renewables and the Abbott group. Seabed studies, wind, wave, tide and current monitoring has started. The project would require a licence from the Department of Marine and Natural Resources. A green paper published in September 1999 sets a 500 MW target of additional renewable capacity by 2005. Most of this is expected to come from wind [71].

Germany

Over 10,000 MW of offshore wind projects has been proposed and pre-examined at the relevant authorities, some of which are shown in table 7.5. Most are still in a pre-feasibility stage.

Table 7.5 German projects

Location	Status	Developer	Date	Turbines	Total capacity	water depth (m)/distance offshore
Wilhelmshaven	Cancelled	Winkra Energie		11, 1.5 Enercon E66		
Lubecker Bucht "SKY 2000"		1.SHOW et al.	End 2002?	64, including Husumer Schiffswerft, Jacobs Energie, Vestas and Aerodyn	100MW	15km,
Helgoland	supported by federal ministry for transport	Winkra Energie	Phase 1, 4 - 5 years' time?	100, various makes including 4-5 MW for first phase	500 MW phase 1, eventually 1200 MW	10 - 28 m, 30 - 50 km
Rostock		Neptun Techno-Product, Nordex Balcke-Durr and Nordwind	end 2000?	15 – 20		20m
Mecklenburg-/Vorpommern	Rejected by land-based planning authority[72].	Neptun/Nordex/Nordwind		15 or 20, 2.5 MW Nordex		20 m

The furthest advanced project, at Wilhelmshaven, was abandoned due to concerns that it may have affected a new harbour planned for 15 - 20 years' time. The developer hoped to have this project up and running before May 2000.

The proposed projects include some very large installations, using 5 MW turbines a great distance offshore. For example phase one of the Winkra project, 17 km east of Helgoland and 25 km from the mainland, comprises 100 turbines of 4-5 MW capacity. Three manufacturers, De wind Technik, Husumer Schiffswerft and Jacobs Energie have set up a working group to produce the prototype machine and guarantee to deliver a technically reliable and economically competitive turbine to Winkra Energie by 2002 [73]. The final development is expected to be 1,200 MW in size,

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[71] Windpower Monthly, November 1999, p 21.
[72] New Energy, No 4, November 1999 p59.
[73] Windpower Monthly, November 1999, p 23.

covering an area of 200 square Kilometres [74] . A similar project has also been proposed 35 km east of Rugen Island, near the Polish border [75].

Planning procedures have begun for the SKY 2000 project, put forward by 1.Schleswig-Holsteinische Offshore-Windpower Verwaltung (1.SHOW) working with Husumer Schiffswerft, Vestas Deutschland, Jacobs Energie, Aerodyn Energiesysteme, Windtest Kaiser-Wilhlelm-Koog and Germanischer Lloyd, a regional investment bank and planning office. Unit Energy Europe, formerly the Utility WRE, owns a 50% stake in the venture. The planning procedure is expected to last 2 years, and the turbines should be commissioned before 2003[76]. The official approval agency is the German Agency for Shipping and Hydrography in Hamburg. The Transport Ministry is one of the authorities responsible for approval.

France

An offshore project has been awarded a contract in the latest tender under EOLE - 2005 a programme with the objective of installing 500 MW of wind capacity by that year. Society Anonyme d'Economie Miste Locale won a contract for a 7.5 MW project, using Jeumont 750 kW machines 5 km of the cost of Dunkirk [77]. Oil companies Shell and Total are partners in the project.

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[74] New Energy, Issue 3, August 1999, p 55. BWE, Germany.

[75] New Energy, No 4, November 1999 p59.

[76] Windpower Monthly, October 1999, p 19.

[77] Windpower Monthly, November 1999, p 19.

8 INSTITUTIONAL ISSUES

As offshore wind energy can be developed on a large scale, relatively rapidly, it is attractive in countries where there is pressure to achieve renewable energy targets. The increasing pressure towards a single electricity market, harmonisation of renewable energy support measures and increased cross-border renewable energy trading could therefore have an influence on the rate of deployment of offshore wind energy, particularly where national support measures are ineffective

Offshore targets

European policy is to double the amount of renewable energy from 6% to 12% of primary energy supply by 2010. This is set out in the White Paper, along with an Action Plan for achieving this goal. The contribution from wind energy is expected to be 40 GW, of which 10GW is anticipated to lead to increased costs, such as offshore. These 10 GW are part of the Campaign for Take Off, a strategy in the White Paper, which suggests more specific help for certain technologies. This campaign was activated in 1999. Table 7.6 gives more detail on the wind element of the Campaign. Offshore wind energy is expected to receive a substantial amount of support in capacity terms. The main bulk of the 3000MW of utility developed projects, as well as a substantial part of the 4,500 MW for large commercial projects, are for offshore installations. New multi-megawatt machines are also envisaged in the new turbine category.

It is estimated that the total investment cost of the Campaign for Take Off will be €30 billion, of which wind energy will comprise €10.1 billion. Around three-quarters of the overall investment is expected to come from the private sector. Other funding will come from national governments in the form of grants and subsidies and from specific European Community programmes. The total amount of public support is expected to be 7 billion Euro, of which wind energy accounts for 2.02 billion.

Table 8.1 support for wind energy in the Campaign for Take Off [78]

Market segments to be supported by the campaign	Estimated capacity
Large commercial wind farms (5 - 100 MW). Large projects built and operated by specialised developers / IPPs, in **offshore** locations, hostile sites, remote and low wind sites.	4,500 MW
Utility owned wind farms (5-100 MW). The main support should be given to **offshore** installations, but also to those installed in hostile areas and low wind sites.	3,000 MW
Small commercial wind farms	1,000 MW
Niche markets	1,000 MW
Privately owned wind turbines	450 MW
Developing and testing new turbines, e.g. including a new generation of multi-megawatt machines, especially for offshore applications.	50 MW
Total	**10,000 MW**

Renewable Energy Policy

At present a wide variety of renewable energy support mechanisms exist among EU Member States. These are outlined in the boxes below. This situation is contrary to the thrust of EU energy policy and the Commission is pushing for a greater degree of harmonisation in this area.

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[78] DG XVII, 1999, Energy for the Future: Renewable Sources of Energy (Community Strategy and Action Plan) Campaign for Take-Off. Commission services paper doc. SEC (99) 504, 9.4.99.

The central thrust of European Energy policy is increasing liberalisation and progress towards a common electricity market. This applies to renewable energy too and eventually a Europe-wide market for renewable electricity is envisaged. An essential element of this will be for EU Member States to harmonise their renewable energy support mechanisms, at least to the extent that they do not result in trade distortions.

The Electricity Directive (96/92/EC) concerning common rules of the internal market in electricity was adopted by the Council of Ministers in December 1996, and entered into force in February the following year. The Directive establishes common rules for the generation, transmission and distribution of electricity. There are rules about tendering for new generation capacity, access to the network, unbundling of accounts etc. A minimum level of liberalisation is set, but Member States are free to go further if they wish.

The Directive contains five categories of public service obligations, of which environmental protection is one. An example of such an obligation would be a requirement for customers to purchase a certain percentage of their electricity from renewables [79]. The Directive also provides an explicit mechanism for the favourable treatment of electricity from renewable energy sources; that of giving priority in dispatching energy from renewable sources or waste or combined heat and power stations.

The Directive specified that a report on harmonisation requirements should be produced a year after implementation of the Directive. The first harmonisation report [80] concentrated entirely on the subject of renewable energy policy. It noted that the current situation might lead to trade distortions and that some types of support mechanism are not explicitly allowed under the single market Directive and may run counter to State Aid rules.

There has been much debate on the merits of the contrasting measures of renewable energy support. Although many EC documents recognise the benefits of feed-in tariffs, they also state that the continued co-existence of feed in tariffs and quota-based systems is problematic.

For example the White Paper [81] suggested that the price to be paid to a generator form renewable sources should at least be equal to the avoided cost of electricity on a low voltage grid plus an premium reflecting the renewables' social and environmental benefits and the manner in which it is financed [82]. It also clearly identified the success of the (old) Danish, the German and the Spanish fixed-price mechanisms as key in establishing a strong market for wind power.

Table 8.2 Comparison of feed-in-tariff and quota based policy deployment characteristics

	Country	Installed capacity winter 98 (MW)	Expansion only 98 (MW)	Installed capacity per capita (w/cap)	Installed capacity per area (kW/km^2)
Countries with price regulations (feed-in-law)	Germany	2,875	794	35.1	8.1
	Denmark	1,448	300	275.3	33.6
	Spain	707	195	18.0	1.4
	Sum	**5,030**	**1,289**	**39.8**	**5.6**
Counties with amount regulations (call for tenders)	GB	333	14	5.7	1.4
	Ireland	73	20	20.3	1.1
	France	19	9	0.3	0.03
	Sum	**425**	**43**	**3.5**	**0.5**

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[79] Guide to the Electricity Directive. DG 17. http://europa.eu.int/en/comm/dg17/memor.htm

[80] Report to Council and the European Parliament, Harmonisation Requirements. COM (1998) 167, European Commission 16th March 1998.

[81] Communication from the Commission. Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan COM (97) 599 final. European Commission, 1997.

[82] Section 2.2.1 White Paper, Ibid.

However it also called for the positive effects of competition to be taken into account to allow market forces to bring down the costs of producing renewable energy as rapidly and as far as possible[83].

A Working Paper [84] attempted to clarify the various arguments. It discussed the different policy approaches and appeared to come down in favour of quota based systems. *It concluded that "fixed feed-in-tariff schemes do not permit trade between Member States nor competition between renewable generators, and it is difficult to determine how they could do so in the future, at least while they fail to insure equivalent price reductions to other quota-based systems"[85] It also stated "...it is generally accepted that the move from this approach to one based on trade and competition is at some stage inevitable."* [86]

The Commission puts forward *green certificates* as a means of facilitating trade in RE between Member States, see the box. The idea behind green certificates is to separate the physical units of electricity and their environmental benefits, and allow the two to be traded separately.

It is clear that both physical and contractual costs exist when electricity is transmitted over long distances or between Member States and this will have to be taken into account in progressing an EU-wide green certificate trading system. The amount of electricity currently traded across borders is shown in figure 8.1[87]. The second EU harmonisation report [88] produced in 1999 drew attention to the barriers to the single electricity market. These barriers will have to be dealt with before a singe *renewable* electricity market can become a reality.

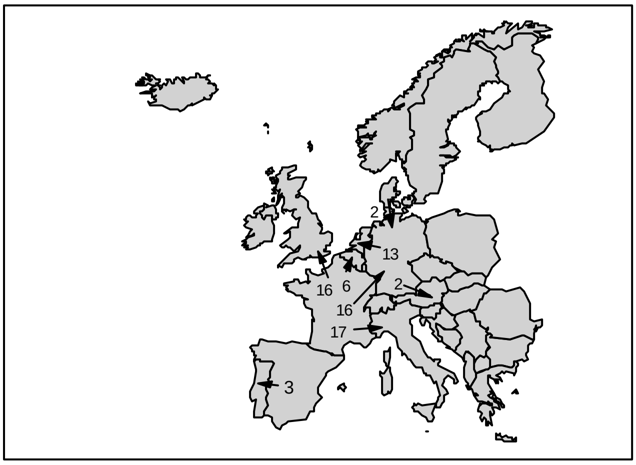

Figure 8.1 Principal net electricity transfers in the EU (TWh)[89]

A great deal more work is required on green certificates. Among other issues, which will have to be addressed, is how emissions savings are quantified [90]?

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[83] Paragraph 2.3. Free competition and state aid. White Paper, ibid.

[84] Towards a Single Market for Electricity from Renewable Energy Sources, Working Paper of the European Commission. 25 February 1999.

[85] Para. 4.2.1.

[86] Para. 4.2.5.

[87] Union pour la Co-ordination de la Production et du Transporte de l'electricite (UCPTE), 1998. Annual report, 1997. UCPTE, Luxembourg.

[88] Second report to the Council and the European Parliament on Harmonisation Requirements. Concerning Common Rules for the Internal Market in Electricity. Directive 96/92/EC. European Commission, 1999.

[89] UCPTE Annual report, 1997, Luxembourg.

[90] Hartnell, G. 1999. Problems with harmonising renewable energy policy in the European Union - progress to date and issues to overcome. Wind Energy 1999, Professional Engineering Publishing Limited, Bury St Edmunds.

A group of electricity suppliers, renewable generators and consultants are undertaking a feasibility study and planning to run an operational trial with the aim of proving the viability of a EU-wide green certificate market[91].

Feed in tariffs

Feed in tariffs set the price to be paid to renewable energy generators and let the market decides on the amount of capacity developed. This is in contrast to quota based systems, where the capacity level is set and the price is determined by the market.

Feed in tariffs, where renewable generators are assured of a certain price for their output have been used in Germany, Spain and until shortly, Denmark, with great success. Table 8.2 is taken from an article on the benefits of feed in tariffs[92]. It contrasts the amount of wind capacity installed in countries with feed in tariffs and those with competitive tendering policies.

Germany is in the process of revising the feed in tariff, and may replace it with a fixed tariff payable for a limited period of time or for a limited amount of electricity. The BWE is proposing that either a tariff of DEM 0.19/kWh or 75% of domestic consumer price is payable for a period of 5 years, followed by DEM 0.14/kWh (or 55% of domestic price) until the turbine(s) are decommissioned. They suggest that offshore wind plant should receive the higher rate of payment for 10 years[93].

Quota based systems

These systems set the level of renewable energy to be achieved, either in terms of a percentage of supply, or desired capacities of different technologies, and let the price be dictated by the market.

Competitive tendering policies

The UK Non-Fossil Fuel Obligation (NFFO) and the Irish Alternative Energy Requirement (AER) are competitive tendering policies. The Member State decides on the desired level of renewable energy supply according to public policy requirements and implements a series of tenders for its supply. Prospective bidders enter their projects and contracts are awarded on the basis of least cost. The additional costs of the renewable electricity are recovered through a non-discriminatory levy on electricity consumption.

Supply obligations backed by Green Certificates

Another approach is to set the amount of renewable energy desired as a percentage of supply, and leave the technology mix and level of security offered to generators, to the market. The Netherlands has adopted this approach on a voluntary basis at present.

Denmark also intends to adopt a green certificate system. This was to be in place by January 2000 although it has been postponed due to technical problems. Under transition arrangements lasting until 2003, generators will continue to be paid a feed-in type subsidy, with green certificate trading providing "top-up" revenue. Minimum and maximum prices for certificates will be in place over this period.

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[91] C. Crookhall-Fallon. The impact of liberalisation on the European renewables market and new developments in an EU green certificate market. Paper presented at the Renewable Energy Finance Forum, September 27th & 28th 1999, Le Meridien, Piccadilly, European Energy Events. A web site has been set up to disseminate the results of this work www.recs.org

[92] Minimum price proponents demand sensible EU guideline. New energy, May 1999, BWE, Germany.

[93] Germany prepares to change wind law. Windpower Monthly, October 1999, page 16.

The Industry and Environmental NGO position

The European Wind Energy Association (EWEA) policy is to allow Member States to choose or retain their own renewable energy support mechanism. Several policy recommendations were made in a document [94] produced by the EWEA, Greenpeace International and the Forum for Energy and Development.

On renewable energy policy it states

> The most important elements in attracting investment to "green power" are that the renewable energy market is clearly defined, stable and provides sufficient returns to investors. Various policy mechanisms have been shown to successfully deliver wind power and other renewables capacity. The available options include
>
> a) Defining the market for private investors by clearly setting the purchase price or the demand volume for renewable energy. This could include setting minimum prices, quotas or a system of portfolio standards.
> b) Establishing mechanisms for support and investment in new technology, industrial development and resource mapping.
> c) Establishing priority procurement for renewable energy capacity and priority dispatch for produced energy.
> d) Setting fiscal and taxation incentives to accelerate market development.

Consents procedures

The arrangements for obtaining consent for the construction of an offshore wind energy project will vary between different member states. The factors, which have to be taken into consideration, are the same, but the authorising body will vary.

Broadly speaking, developers will need a consent (or consents) to authorise them to;
- erect an installation if it may cause an obstruction to navigation or shipping
- carry out an activity which has an environmental impact, and
- connect to the electricity network.

In many countries, the novelty of offshore wind energy development means that the details of the authorisation procedure(s) have not yet been determined or parallel routes to consent exist. This has resulted in developers experiencing delays in obtaining consent.

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[94] EWEA/FED/Greenpeace, 1999. Wind force 10 – A blueprint to achieve 10% of the world's electricity from wind power by 2020.

9 FUTURE PROSPECTS

The wind energy market

The future of offshore wind is inextricably linked with that of onshore wind. The pace of technology development continues to be rapid, partly due to the research and development programmes currently under way in most of the industrialised nations, largely due to market stimulation programmes. The primary aim of the market stimulation programmes is to encourage the development of technologies with low (or in the case of wind energy, zero) carbon dioxide and other emissions.

Rapid growth in Denmark, Spain and Germany shows no sign of slowing and there are plans for further capacity in the United States, Canada, the Middle East and the Far East. One forecast 95 (Madsen, 1998) suggests there might be over 50,000 MW of wind energy world-wide by 2005, and over 1.2 million MW by 2020. Of this, it is suggested 200,000 MW might be in Europe.

The rate of development will depend on the level of political support from the national governments and international community. This, in turn, depends on the level of commitment to achieving the carbon dioxide reduction targets now internationally agreed.

Offshore market development can also be estimated using figures from the Campaign for Take Off, as shown in table 8.1. If half of the estimated amount from large commercial wind farms and 75% of the Utility owned wind farms are offshore, this would give a figure of 4,500 MW by 2010. Figure 9.1 shows the employment creation associated with this level of development. The working behind the figures is explained at the end of section 5.

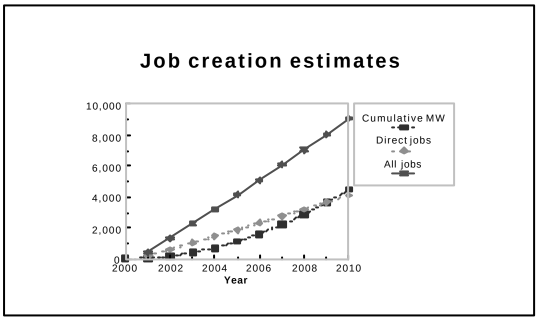

Figure 9.1 Job creation estimates

Technology

The competition fostered by the market support programmes has pushed up reliability to the point where most wind turbine manufacturers now guarantee availabilities of 95%. The competition has also pushed costs down. Most European manufacturers have increased machine sizes in an effort to reduce wind farm costs, since the larger sizes enable significant savings to be made in the costs of turbines, foundations and electrical interconnections. Although the technology has developed rapidly during the past ten years there is a general consensus that significant further improvements can be expected both in performance and cost. Wind energy capacity is likely to continue doubling every three years or so, accompanied each time - assuming recent trends continue - by a 15% reduction in production costs.

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[95] EWEA/FED/Greenpeace, 1999. Wind force 10 – A blueprint to achieve 10% of the world's electricity from wind power by 2020

Future price trends

There are a number of factors that are causing a steady fall in the cost of wind energy systems: -

- the trend towards larger wind turbines,
- falling infrastructure costs, and
- possible reductions in the cost of raw materials.

Manufactured items that are produced in quantity benefit from increased production, as the manufacturer improves his manufacturing and assembly techniques. The way in which costs fall as a function of increased production varies depending on the product, and is a function of the relative inputs of material and labour.

There is no indication that the trend in price reductions is slackening. The European Renewable Energy Study[96] reached a similar conclusion. It also expects that further R&D will enable further technological advances to be made. By 2020 capital costs are expected to be 50-75% of 1995 levels, allowing financially viable, unsubsidised wind on high and medium wind regime sites.

Among the additional design features likely to contribute to further performance and cost improvements are: -

- tall towers (which increase energy capture), made of lightweight materials,
- advanced aerofoils, light blades, with the weight savings being reflected throughout the drive train and tower assembly,
- further advances in power electronics, particularly for variable speed operation, and
- direct drive generators - already demonstrated on a number of machines

All the factors discussed above will contribute to lower offshore wind prices. Denmark, Sweden and the Netherlands already have prototype offshore installations as part of their ongoing research and development activities and a number of schemes for offshore wind in the Mediterranean and elsewhere are under discussion. Several manufacturers are now marketing machines specifically for the offshore market, with ratings up to 2 MW. In addition, it is possible that the removal of some of the onshore constraints may lead to significant changes in design. The use of faster rotational speeds and of two bladed machines are two options which would result in significant weight reductions and the use of carbon fibre-reinforced plastic (CFRP) for the blades would also result in significant weight reduction. Although CFRP is presently too expensive it is possible that a higher demand for the product would lead to cost reductions[97].

In addition, the European Union and national funding bodies are funding a number of studies of alternative concepts. Floating wind turbines have been the focus of several studies. A British consortium has examined the feasibility of individual floating structures[98] and another concept is a multi-unit floating wind farm[99]. This employs a barge-like structure to support a number of wind turbines. A semi-submersible hull provides support for the wind turbines and it is claimed that concentrating the cables and services together in this structure will make savings. The bulk of the structure means that it will be less susceptible to dynamic loads than single floating turbines with additional stability being provided by the configuration of the semi-submersible hull. The initial concept is for an assembly of eight 1 MW machines, with a suitable machine type to be identified at a later stage.

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[96] Energy for Sustainable Development (ESD) Ltd, 1996. “TERES II” – The European Renewable Energy Study. ESD for the European Commission, DG XVII.

[97] Jamieson, P and Quarton, D, 1999. Technology development for offshore. Proceedings of EWEC99, Nice. European Wind Energy Association

[98] Dudgeon, C, 1993. Windmills put to sea. Offshore Engineer, September

[99] Henerson, A R, Patel, M H, Halliday, J and Watson, G, 1999. Multiple turbine floating offshore windfarms. Proceedings of EWEC99, Nice. European Wind Energy Association.

Other concepts are under investigation, for both onshore and offshore installations. Even if only a few of these projections are realised the prospects for cost effective wind energy - in direct competition with conventional sources - will improve markedly. If fossil fuel prices rise in real terms then the future becomes very bright indeed.

USEFUL CONTACTS

An extensive list of wind turbine manufacturers, component suppliers and consultants is included in "The World Directory of Renewable Energy Suppliers and Services", published by James and James (Science Publishers) Ltd, London.
Phone: +44 207 387 8558
www.jxj.com

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