Resources and Economic

1	Offshore Wind Power Potential	1
2	COST-RANKING	8
3	ECONOMICS	21
4	UNCERTAINTY IN ENERGY YIELD	24
5	RESEARCH NEEDS	25
6	SUMMARY	27
7	REFERENCES	28
8	ADDITIONAL INFORMATION SOURCES	33
Projects and References for on/off-shore wind energy		33
Publications dealing with onshore and offshore wind energy		34
Appendix		38

1 Offshore Wind Power Potential

In May 2000 the European Commission unveiled proposals to increase the proportion of energy supply from renewable sources to 12 percent (22 percent of electricity supply) by the year 2010 (Environment News Service, 2000). Offshore wind energy is expected to play a significant role in this expansion.

By the end of the year 2000, approximately 80 MW of offshore wind energy were installed and operating in Denmark, Holland and Sweden and the UK. Some Northern European countries have relatively detailed plans for offshore wind farm development and these are described. If all plans are realised, more than 11,000 MW of offshore wind capacity will be installed by the year 2030.

To provide a review of offshore resources and economics two data sources are used. The first is the country by country survey (given in the Appendix) which has been summarised in the Tables and Figures below. The second source are the myriad of reports on offshore wind energy which have appeared from local, national and international governmental and independent agencies.

Table 1 summarises the importance ascribed by each country to use of measurements or modelling to assess offshore wind resources. Clearly this is intended as an overview - the views expressed by the participants cannot be assumed to reflect governmental actions and policies. On the whole most important factors appear to be the physical constraints followed by onsite measurements and modelling with less importance given to comparison with national electricity consumption. This may reflect changes in the electricity market with individual countries wishing to exploit their available offshore wind resource whether it can provide a small or a large fraction of national consumption.

Table 2 gives an overview of resource assessment by country and the major criteria used in its development. Most studies are built on the first predictions of offshore wind energy resources from

(Matthies and Garrad, 1993) which uses voluntary observer ship data compared with WAsP. Their estimate of available wind resource was 500 TWh in water depths of less than 10 m and less than 10 km from the coast increasing to over 3000 TWh if water depths up to 30 m were considered with distance to the coast of less than 40 km. (DEA/CADDET, 2000) estimate the total European resource in water depths of less than 40 m and with the distance to the coast of less than 30 km (excluding Norway, Finland and Sweden) accounting for major but not local constraints to more than 3000 TWh/year. This is greater than European electricity consumption of about 2700 TWh/year. Different constraints substantially alter the resource estimate as shown in (DEA/CADDET, 2000). (BWEA, 2000) suggest a European resource of about 1623 TWh/y at water depths of less than 20 m and distance to the coast of less than 20 km. (Greenpeace, 2000) estimate potential from the North Sea areas of Belgium, The Netherlands, Denmark, the UK and Germany as a maximum of 1900 TWh per year, almost twice the annual consumption of these five countries.

Individual countries also have useful reports and papers e.g. studies of offshore data sets or modelling of wind resources; for the Netherlands (Cleijne *et al.*, 1991), (Van Wijk *et al.*, 1990), (Coelingh *et al.*, 1996) for Denmark (Barthelmie *et al.*, 1999a), (Frandsen S. (editor) *et al.*, 1996) and the UK (Moore, 1982), (White, 1983).

National exploitation plans are highly variable by country and are summarised in Table 3 below. Activities and plans range from none which are publicly known to full and detailed plans which are being implemented. Other countries are letting the market decide by allowing private developers to select sites and build offshore wind farms after negotiating individual planning and permit requirements.

The European Commission is supportive of both research and demonstration projects. Demonstration projects include a number of projects under the Thermie A program. These include the first and second phases of the Blyth Harbour and Blyth Offshore (UK) wind turbines and Bockstigen wind farm in Sweden. In addition, Thermie supported a semi-offshore (beach) development in Crete and the Scroby Sands wind farm in the UK. The status of the latter projects is not known. The European Commission has also supported research projects assessing resource and economics such as (Matthies and Garrad, 1993), Opti-OWECS (Kuhn *et al.*, 1999), POWER (Halliday *et al.*, 2001), Cost-optimisation (Svenson and Olsen, 1999), Vindeby (Frandsen S. (editor) *et al.*, 1996) and ENDOW (Barthelmie *et al.*, 2001).

Wind energy developers and manufacturers are optimistic about the offshore market. A company report on Vestas (Carnegie, 2000) predicts up to 7400 MW of offshore installations in the period 2000-06, 6% of the global market. These are based on Denmark 8.5%, Sweden 18%, Germany 31%, the Netherlands 15%, UK 11%, Ireland 7%, Belgium 4% and Norway 5%. Offshore wind energy is also supported by non-governmental organisations such as Greenpeace (Greenpeace, 2000), wind energy groups (BWEA, 2000) and the Danish energy Agency and IEA CADDET Renewable energy Technologies Programme (DEA/CADDET, 2000).

Development of offshore wind energy has to date been focussed on Europe due to pressure for land and resources, relatively low water depth and good wind resources. However, studies have also been conducted in the USA (Manwell *et al.*, 2001) and Japan (Nagai and Ushiyama, 2000). (Fioravanti, 1999) compared offshore wind energy with plutonium based power costs in Japan and concluded that offshore wind energy would be less expensive and faster to develop.

Table 1. Offshore wind resource: importance of various factors by country

Topic	1.a Onsite Measure-ments	1.b Available data	1.c Model estimates	1.d Physical limits	1.e Planned activity	1.f Electricity cons.	1.g. National potential
BE	2	1	2	1	1	3	1
DK	3	3	3	2	3	1	2
FI	2	3	3	3	3	1	3
FR	3	2	3	3	2	1	0
D	0	0	0	0	0	0	0
GR	2	2	3	2	1	0	0
EI	3	1	2	2	3	1	0
I	1	1	1	3	3	2	1
NL	3	3	2	3	3	2	0
P	1	2	2	2	1	1	0
ES	3	2	1	3	2	1	0
SE	3	3	3	2	3	1	0
UK	3	2	3	3	3	1	0
Mean	2.4	2.1	2.3	2.4	2.3	1.4	1.8

1=low,2=medium,3=high, 0=no data

No data for Portugal.

Table 2: Offshore resources by country

	Resource estimate		Target installation		Comments	Reference
	MW	TWh/y	MW	YEAR		
BE	1200	4	200	2004	Two projects of 100 MW have been announced .	http://www.electrabel.com
DK	8000	26	4000	2030	Additional 4000 MW water depth> 20 m Exploitable resource ~ 83-287 TWh/y	(Krohn, 1998), (DEA/CADDET, 2000), (BWEA,)
FI	6000	20	0			
FR	13000	44	0		EED studies indicate potential in four areas of 9125 MW or 30.1 TWh.	(DEA/CADDET, 2000)
D	13000	45	0			(DEA/CADDET, 2000)
GR	1500	5	0			(DEA/CADDET, 2000)
EI	3300	11			Water depth< 20 m, Min distance 5km, 32% of nat. electricity	
I	3000	10	1000	2030		(Gaudiosi, 1999), (DEA/CADDET, 2000)
NL	10000	33	1250	2020	~11% of national electricity consumption	(Greenpeace, 2000), (International Energy Agency, 2001)
PL	600	2-3	0		Technical potential is 11 PJ offshore wind energy. Two projects have consents and two more are pending.	Baltic Energy Conservation Agency, EC Brec, Elektownie Wiatrowe S.A.
PT	0	0	0			
ES	2000	7	0		Two projects in planning, monitoring at one	(International Energy Agency, 2001),
SE	7000	22.5	650	2005	Many projects at planning stage	(DEA/CADDET, 2000), (Border Wind, 1998a)
UK	70000	230-334	2600	2010	Planned 2% of UK supply by 2010	(Border Wind, 1998a)
Total	138600*	-76*[1]	5500			

*Resource supplied converted if necessary assuming 1000 MW ~ 3.3 TWh/y. (International Energy Agency, 2001) give 3530 'net full load hours' for North Sea sites and 3000 -3300 at interior water sites at Danish sites.

[1] Note that this figures varies substantially depending on the constraints (physical, social, environmental) used for the estimate and does not include all countries. It therefore differs from the (DEA/CADDET, 2000) estimate taken from BTM Consult which is 327 TWh/ year or from estimates without constraints.

Table 3. Offshore wind energy exploitation plans by country

	Plans	References
BE	3% electricity from renewables. Offshore wind energy is not yet eligible for green certificates (under discussion).	(Greenpeace, 2000)
DK	Government target set and plans for large scale developments in five areas mandated.	(Energistyrelsen, 1997), (Krohn, 1998)
FI	Plans to develop one wind farm	
FR	Several plans discussed.	
D	Target 5-6% electricity from renewables by 2010 and 50% by 2050, research project on on- and off-shore development. In spring 2001 a number of sites were announced.	(Greenpeace, 2000), (Schmidt, 2001)
GR	None publicly available	
EI	Measurements underway	
I	Discussion of 1000 MW target installation. Local feasibility studies.	(Ragusa, 1998)
NL	Targets set of about 1250 MW for offshore wind. Several feasibility/environmental studies underway. Two wind farms developed in Ijsselmeer. Demonstration wind farm 100MW planned at Egmond an Zee.	(Greenpeace, 2000), (International Energy Agency, 2001)
PL	Two wind farms of ~100 MW have consent near Bialogóra and near Karwia	Baltic Energy Conservation Agency, EC Brec, Elektownie Wiatrowe S.A.
PT	None publicly available	
ES	Some monitoring studies.	
SE	No target set but construction of wind farms undertaken by private developers.	
UK	Targets set. Measurements underway at 5 sites. One site developed. In April 2001 preliminary licences for 18 offshore sites were awarded.	http://www.offshorewindfarms.co.uk/

Table 4: Status of offshore resource assessment:	
On site data	Necessary because of project financing Resource has to be quantified with high degree of confidence
Available data	Typically useful for broad assessment (Ships, satellites etc)
Models	Useful tools, under development, still uncertainties
Physical limits	Maritime data (sea depth etc) - available for most countries Typically > 5 km from shore Water depth limit 20-30 m? North Sea: Large tidal range, water depth Baltic Sea: Ice and ice floes Mediterranean: Sea bed slope, water depth
Planned activity	Highly variable by country Targets set, plans in place: DK Targets set, feasibility studies: UK, NL, I No target set, monitoring underway ES, FI ,EI No target set, wind farms underway SE, FR Preliminary consents given: PL No plans publicly available: GR, PT
Comparison with national consumption	Not a major issue Varies from 2-40% Grid compatibility and penetration is more of a problem
National potential	(Table 2)

2 COST-RANKING

The first offshore projects were demonstrations giving extra costs, for example, for foundation design and to allow for pitch changes on the blades to improve performance. Due to the difficulties of access by cranes or other large maintenance equipment, turbines at the offshore wind farms are equipped with built-in hoists (Lely, Bockstigen) or cranes (Vindeby, Tunø Knob) for replacement of major components (van de Sande, 1997), (Midkraft, 1995), (Kelter-Wesenberg and Stiesdal, 1997), (Lange *et al.*, 1999). In 1998-2000 the first commercial projects were installed where electricity production is expected to be competitive with wind farms on land or other forms of energy. (DEA/CADDET, 2000) expect production costs of the order 0.05-0.055 €/kWh or equivalent to land sites. (Greenpeace, 2000) compared costs for projects at 30, 50 and 70 km from the coast and found breakeven costs with a wind speed at a height of 60 m of 8.5, 8.9 and 9.0 m/s, respectively. Costs of producing offshore energy with the current financing structure in the UK have been estimated at 5-6 p/kWh (approx. 8 €cent/kWh) (Border Wind, 1998b). The Opti-OWECs project illustrated that offshore wind energy should be economically viable in most Northern European coastal areas (Cockerill *et al.*, 1998). Energy costs in both studies and actual projects have steadily decreased over the last decade (Kuhn, 2001). Capital costs are around 30 to 70 % higher than onshore which is offset to some degree by higher energy yields of up to around 30% (Hartnell and Milborrow, 2000). However recent studies indicate that large offshore wind farms are competitive with other energy sources (e.g. (Svenson and Olsen, 1999)) and the trend towards large wind farms decreases unit costs.

Future developments include the Dutch Offshore Wind Energy Converter presently under development. The DOWEC has 5 or 6 MW rate power and a rotor diameter of approximately 100 meters with output for 4000 households (ECN, 1999).

Table 5 shows details of current offshore wind farms. There is a major difficulty in comparing costs of energy produced due to:

- the differences in project financing (lifetime, interest rates)
- costs of operation and maintenance
- commercial nature of projects means that this information is not in the public domain.

Hence costs are not compared on an equal basis since it is not possible to locate investment and operation and maintenance costs for each project. (Kuhn *et al.*, 1998) also show the average energy costs for offshore wind energy decreasing over the last ten years and give details of the sites.

Table 6 shows planned wind farms and Table 7 tentative site exploration. It is difficult to make this separation since some apparently promising projects stall or fall (Knight, 1995), (Renewable Energy World, 2000) at the last planning hurdle or due to some change in pricing regulations. In Germany for example a number of projects have been announced but none are yet under construction. In May 2001 a number of very large projects were detailed (Schmidt, 2001) for both the North and East Seas (southern Baltic). These sites are at much larger distances offshore than have previously been considered and so represent an interesting new challenge for offshore wind energy. Similarly the UK announced 13 sites for which different consortia have been granted preliminary licences. These are detailed at www.offshorewindfarms.co.uk.

Name	**#, size, make of turbines**	**MW**	**Year**	**€ cent kWh**	**Product -ion MWh/y**	**Investment[1] (€/kW)**	**Min fetch (km)**	**Water depth (m)**	**Comments**	**References**
Nogersund SE	220 kW Wind World	0.22	1990		0		0.25	6		(Larssen, 1994)
Vindeby DK	11 450 kW Bonus	5	1991	8.5	11200-11730	1939-2150	1.5	2-5	Availability > 95% in the first 5 years. Lightning strikes more frequent than on land. Mean wind speed 7.5 m/s.	(Olsen and Dyre, 1993) , (Kelter-Wesenberg and Stiesdal, 1997), (DEA/CADDET, 2000; Kelter-Wesenberg and Stiesdal, 1997), www.bwea.com, (Wind Developments, 1999), (Hartnell and Milborrow, 2000)
Lely, IJsselmeer NL	4 NedWind 500 kW	2	1994	8.6-13.7	3800	1700-2600	0.8	5-10	Stall-controlled on single pile foundations. Mean wind speed 7.7 m/s.	(van Zanten, 1996), (DEA/CADDET, 2000),(Henderson, 2000),(Wind Developments, 1999),(Hartnell and Milborrow, 2000)
Tunø Knob, DK	10 Vestas 500 kW	5	1995	6.6-8.17	12500-12700	2040-2200	6	3.1-4.7	Pitch controlled. Availability better than expected but slightly lower than for a neighbouring	(CADDET, 1996) , (Madsen, 1996) (Pedersen, 1998) (DEA/CADDET, 2000) (Kuhn, 2001),(Wind

									onshore farm. Mean wind speed 7.5 m/s.	Developments, 1999), (Hartnell and Milborrow, 2000)
Name	**#, size, make of turbines**	**MW**	**Year**	**€ cent kWh**	**Product -ion MWh/y**	**Investment[1] (€/kW)**	**Min fetch (km)**	**Water depth (m)**	**Comments**	**References**
Irene Vorrink, NL	28 Nordtank 600 kW	16.8	1996		37000		0.02	5		(DEA/CADDET, 2000), (Wind Developments, 1999)
Bockstigen, SE*	5 Wind World 550 kW	2.75	1998		8000-8500	1455	4	5.5-6.5	First to use drilled monopile foundations. Costs ~ 15-20% > land based	(Kuhn, 2001; Lange *et al.*, 1999), (Hartnell and Milborrow, 2000)
Blyth, UK	2 Vestas 2 MW	4	2000	7-8	12000		1	8.5	Coast approx. 5p/kWh	(BWEA, 2000)
Middelgrunden, DK	20 Bonus 2 MW	40	2000	6	89000		2-3	3-6	Owned equally by a wind energy co-operative with over 3000 members & local electricity utility. 56% cost reduction compared with Vindeby.	(Jessian and Larsen, 1999),(DEA/CADDET, 2000), (International Energy Agency, 2001), Sørensen et al. (2000), Larsen and Sørensen (2001).
Utgrunden, SE	7 Tacke 1.425 MW	10	2000		38000		8	7.2-10		(Kuhn, 2001)
Yttre Stengrund, SE	5 NEG MICON 2 MW	10	2001		30,000					(Whittaker T.J.T. et al.,)

Total		84			168,500					

*production figures estimated if not available. See also: (Goodall, 2001).

[1] Note that there is considerable variation in these costs from different sources.

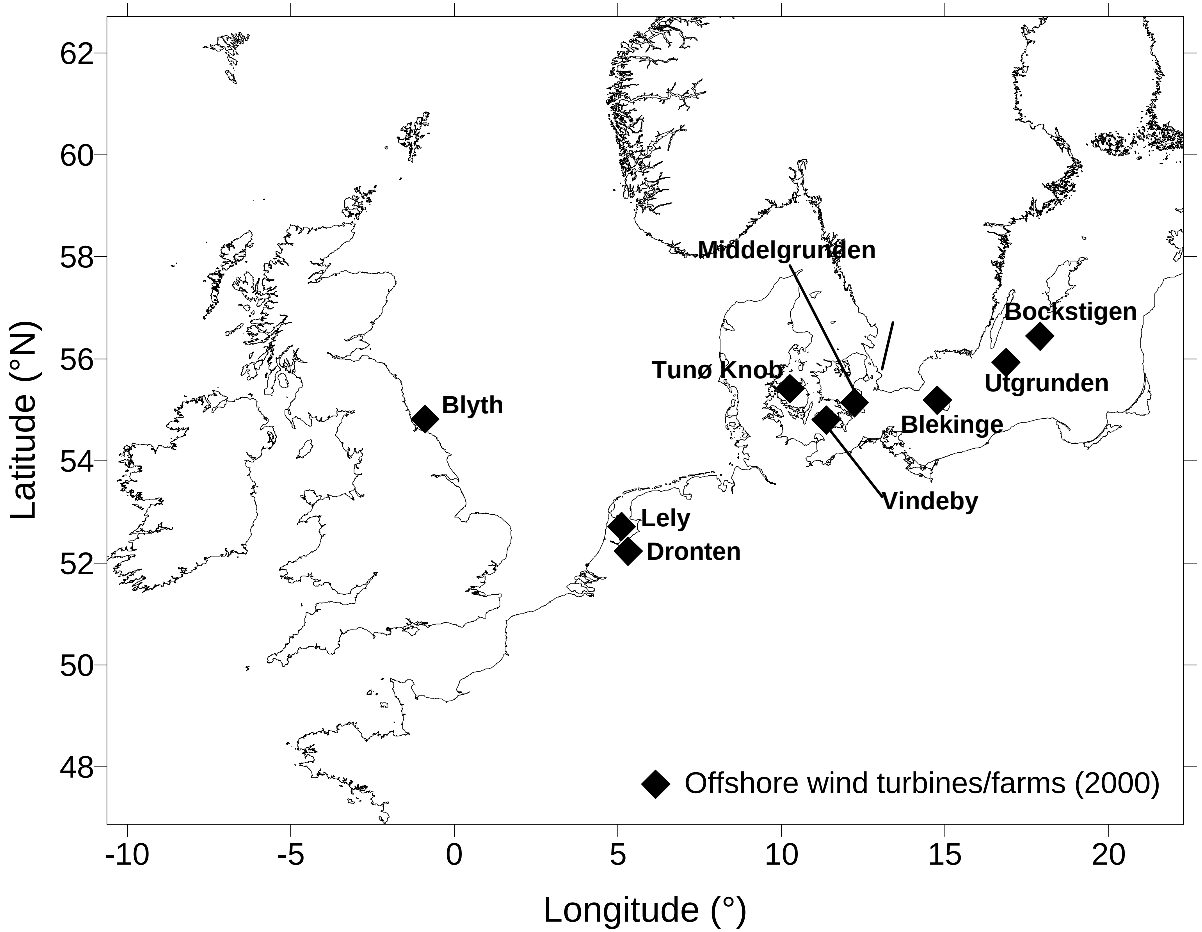

Figure 3-1: Current offshore wind farm developments in Europe (end of year 2000).

Table 6: Planned wind farms (Spring 2001):								
Name	**Turbines**	**Total MW**	**Year**	**Cost/ kWh**	**€cent/ kWh**	**Production MWh/y**	**Comments**	**Reference**
Klasården	21 NEG MICON 2 MW	42	2001?				Gotland	(Wizelius, 2000)
Horns Rev, DK	80 Vestas 2MW	160	2002	0.35 DKK	4.7			(Madsen, 1997), (DEA/CADDET, 2000),(Madsen, 1997)
Rødsand, DK	72 Bonus 2.1-2.2MW	151-158	2002	0.36 DKK	4.8			(Energistyrelsen, 1997),(Madsen, 1997),(DEA/CADDET, 2000),(Madsen, 1997)
Q7-WP, NL		100	2002				> 12 miles	
Breedt, FR		7.5	2002?		6.4			
Læsø Syd, DK		150	2003	0.35 DKK	4.8	396,000		(Madsen, 1997), (DEA/CADDET, 2000), (Hartnell and Milborrow, 2000; Madsen, 1997)
Nearshore, NL		100	2003	0.16 NLG	7-8	300,000	Requires subsidy of NLG 60 m	(Hartnell and Milborrow, 2000)
Omø Stålgrunde, DK		150	2004	0.37 DKK	5.0	434,000		(Madsen, 1997), (DEA/CADDET, 2000),(Hartnell and Milborrow, 2000; Madsen, 1997)

Name	**Turbines**	**Total MW**	**Year**	**Cost/ kWh**	**€cent/ kWh**	**Production MWh/y**	**Comments**	**Reference**
Gedser, DK		150	2006	0.38 DKK	5.1			(Anonymous, 1998) (Energistyrelsen, 1997) (Madsen, 1997), (DEA/CADDET, 2000),(Madsen, 1997)
Arklow Bank, EI		500					10 km to coast, licence granted for monitoring Sep. 2000. ~ 27% more investment than onshore	
Kish Bank, EI		250						
Lillegrund, SE	48 Enercon 1.5 MW	72					Öresund	(Wizelius, 2000),(Hartnell and Milborrow, 2000)
Samsø	10 2MW	20					Public hearing June 1999. Tenders issued November 2001.	www.veo.dk
Total		992						

* Note 13 sites in the UK, 17 in Germany and at least 4 in Poland are not shown. Information on UK sites www.offshorewindfarms.co.uk on German sites (Schmidt, 2001).

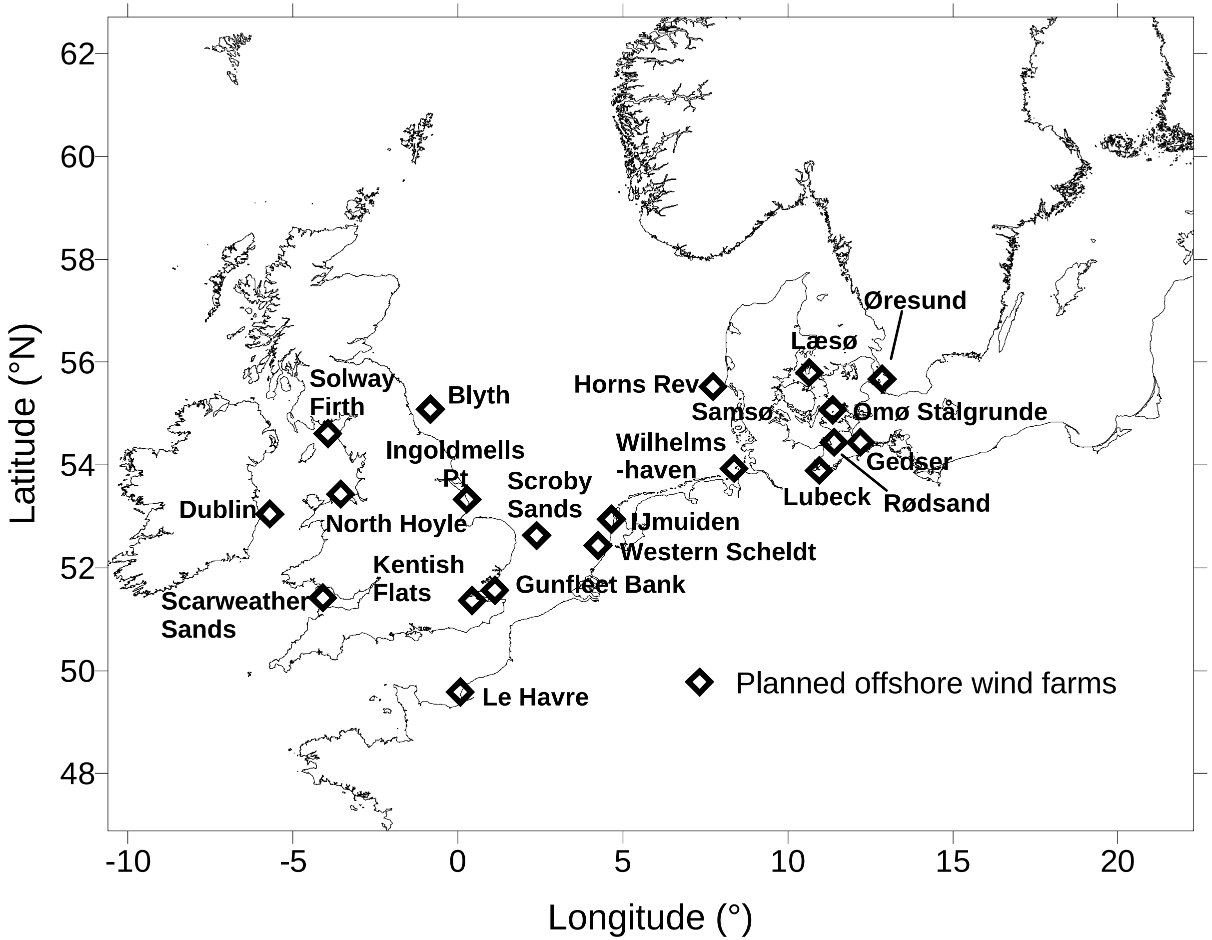

Figure 3-2. Planned offshore developments (2001 onwards). Note that detailed plans for Germany, the UK and Poland announced during spring/summer 2001 are not included.

Table 7. Tentative site exploration (Spring 2001).				
Name	**Total MW**	**Year**	**Comments**	**Reference**
Knokke, BE	100	2002 or later	12-15 km from coast	(Greenpeace, 2000)
Wenduine	100	2002 or later	5-11 km from coast	(Greenpeace, 2000)
Pori, FI				
Kish Bank, EI	220-250		10 km from coast. Licence granted for monitoring Sep. 2000	
Codling Bank, EI			Licence granted for monitoring Sep. 2000	
Blackwater Bank, EI			Licence granted for monitoring Sep. 2000	
Nord-Pas de Calais, FR			Study for local council or French Energy Agency (ADEME) 1998. 5 to 8 km from shore with water depth of 5 to 20 m. Estimated resource 775 MW giving 2.4 TWh/year.	
Brittany, FR			Study for local council or ADEME 1999-2000. 3 to 10 km from shore in water dpeths 5 to 20 m. Estimated resource 2050 MW or 6.3 TWh/year.	
Normandy, FR			Study for local council or ADEME 2000. Basse Normandie 5 to 10 km from shore in water depths 5 to 20 m. Resource estimated 3500 MW or 10.8 TWh /year.	
Languedoc-Rousillon, FR			3.5 to 10 km from shore in water depths 20 to 30 m. Estimated resource 2800 MW 10.6TWh/year.	
Cadiz, ES			Measurements underway.	
Bialogóra, PL			Consents issued for 49-61 2 MW turbines	
Karwia, PL			Consents issued for 50 2 MW turbines	
Solway Firth, UK			Off Maryport, Cumbria 9.5 km from shore, Off Rock Cliffe, Dumfries & Galloway	http://www.offshorewindf

			8.5 km from shore. Preliminary consents for 60 turbines[1]	arms.co.uk/
Barrow, UK			10 km from shore Off Walney Island, Cumbria. Preliminary consents for 30 turbines[1]	http://www.offshorewindfarms.co.uk/
Shell Flat, Uk			Off Cleveleys, Lancashire, 7 km from shore. Preliminary consents for 90 turbines[1]	http://www.offshorewindfarms.co.uk/
Southport, UK			Off Birkdale Merseyside, 10 km from shore. Preliminary consents for 30 turbines[1]	http://www.offshorewindfarms.co.uk/
Burbo, UK			Off Crsoby, Merseyside 5.2 km from shore. Preliminary consents for 30 turbines[1]	http://www.offshorewindfarms.co.uk/
North Hoyle/ Rhyl Flats, UK UK	60-90 for North Hoyle		Off Prestatyn, North Wales, 6km from shore and off Abergele, North Wales, 8 km from shore. Preliminary consents for 60 turbines[1]. The developers of North Hoyle, National Wind Power, report that the site has good wind resources and relatively low exposure in the predominant wind direction. Water depth is 12 m with a 9m tidal range. Plans are to install turbines of 2-3MW. The Delores of Rhyl Flats are Celtic Offshore Wind Ltd.	http://www.offshorewindfarms.co.uk/
Scarweather Sands, UK		2004-2005	Off Porthcawl, South Wales, 9.5 km from shore. Preliminary consents for 30 turbines[1]. Developers are United Utilities .	http://www.offshorewindfarms.co.uk/
Kentish Flats, UK		2004-2005	Off Whitstable Kent, 8 km from shore. Preliminary consents for 30 turbines[1]. The developers are Global Renewable Energy Partners UK, a subsidiary of NEG MICON. Turbines of 2-3MW will be installed on monopile foundations. Estimated production is 300 GWh/year.	http://www.offshorewindfarms.co.uk/
Gunfleet, UK	100?		Off SE Clacton-on-Sea, Essex, 7 km from shore. Preliminary consents for 30 turbines[1]. Developers are Enron Wind Gunfleet Ltd.	http://www.offshorewindfarms.co.uk/
Scroby Sands, UK	76	2003?	Off Caister, Norfolk, 2.3 km from shore. Preliminary consents for 30 turbines[1]. Developers are Powergen Renewables Offshore Wind Ltd. Plans exist to erect 38	http://www.offshorewindfarms.co.uk/

			2MW turbines.	
Cromer, UK			Off Foulness, Norfolk, 6.5 km from shore. Preliminary consents for 30 turbines[1]	http://www.offshorewindfarms.co.uk/
Lynn/ Inner Dowsing UK			Off Skegness /Off Ingoldmells, Lincolnshire, 5.2 km from shore. Preliminary consents for 60 turbines[1]. Developers of the Lynn Site are AMEC Offshore Wind Power Ltd. Earliest construction date is 2004. Developers of Inner Dowsing are Renewable Energy Systems and British Energy. Turbines are 2-3MW. Construction is anticipated in 2004.	http://www.offshorewindfarms.co.uk/
Teeside, UK			Off NE Teesmouth, Middelsborough, 1.5 km from shore. Preliminary consents for 30 turbines[1]	http://www.offshorewindfarms.co.uk/

[1] The UK Crown Estate announced the sites and names of the eighteen wind farm developers who have successfully pre-qualified to obtain a lease of seabed for development of offshore windfarms (April 2000).

3 ECONOMICS

Offshore projects require initially high investment due to turbine support structures and grid connection. Hence large multi-megawatt projects are likely to be the most cost effective. Additionally high reliability, optimum investment and operation costs spread over the lifetime of a project will improve offshore prospects (Wind Developments, 1999). The cost of grid connection to the shore is typically around 25% (Hartnell and Milborrow, 2000) a much higher fraction than for connection of onshore projects. Other sources of additional cost include foundations (up to 30%), operation and maintenance (with expected lower availability) and marinisation of turbines (Hartnell and Milborrow, 2000). Costs of installation onshore have been reduced from about 2200 € /kWh for the first Danish offshore wind farms to an estimated cost of 1650 € /kWH (Energistyrelsen, 1997) for Horns Rev giving an estimated cost of 4.9 € cents/kWh to 1990 € /kWH for Ijmuiden giving an estimated energy cost of 6.4 € cents/kWh. This compares with typical figures for onshore sites of investment 700-1000 € /kWh and estimated energy cost of 3-8 € cents/kWh for a mean wind speed of 5-10 m/s. This assumes the energy cost is distributed over 20% with a 5% discount rate (Wind Developments, 1999). Costs have been falling steadily and are estimated to be between 4.4 € cents/kWh for a mean wind speed of 9.0 m/s at hub-height to 5.1 € cents/kWh for a mean wind speed of 8.4 m/s (Cockerill *et al.*, 1998). Projected costs are downwards as the industry determines less expensive methods for installation and maintenance using experience gained in the offshore industry and at the first offshore wind farms and larger project and turbine size also reduces costs per installed MW.

The UK DTI gives target costs of £750 /kW installed by 2010 which is the upper limit of current onshore costs and operation and maintenance costs of 1p/kWh (just over current onshore costs). They also suggest 95% availability as the target compared with current onshore availability of over 98% (Fletcher, 2001). For specific projects (Hartnell and Milborrow, 2000) give a range of 1466-2050 €/kW installed giving a cost of production of 4.7-6.8 4.4 € cents/kWh. Operation and maintenance charges are variable according to site but a rough estimate is an annual charge of €30/kW with 0.5 € cents/kWh variable (Hartnell and Milborrow, 2000).

Figure 3-3 gives examples of planned offshore installation costs by component. Other models exist e.g. (Hartnell and Milborrow, 2000) suggest 51% for turbines, 18% for grid connections, 16% for foundations, 7% for electrical, 4% for planning and 2% for operation and maintenance facilities. (Kuhn *et al.*, 1998) give cost breakdown for initial costs:

- Turbine 45%
- Support structure 25%
- OWEC installation 7%
- Power collection 13%
- Transmission 8%
- Management 2%

Contributions to energy costs are given in Figure 3.3.

These vary slightly compared with those from (DEA/CADDET, 2000) which are given in Table 8. Investment costs onshore are approximately €1.5 million/MW compared with onshore costs of approximately €1 million/MW.

Table 8. Investment costs by component

	Onshore (%)	Large offshore (%)
Foundations	5.5	16
Turbines	71	51
Internal electrical grid	6.5	5
Electrical system	0	2
Grid connection	7.5	18
O&M facilities	0	2
Engineering and administration	2.5	4
Miscellaneous	7	2
Total	100	100

The most complete cost analysis to date is (Kuhn *et al.*, 1998) who suggest that the most important parameters are the distance to shore and the annual mean wind speed and provide maps of mean energy cost combining these parameters within a GIS database. Optimal costs are found by balancing these factors.

Forecasting wind energy also provides important advantages in term of increasing the penetration of wind energy and obtaining the best market price e.g. (Giebel, 2001), (Landberg, 1993).

Finally probably the most important development relates to market liberalisation which may jeopardise development at some sites. Guaranteed markets for large offshore wind energy developments may become extinct leaving private developers with capital intensive projects in a market within which the benefits of offshore wind energy are not cost-weighted. Despite the average cost of offshore wind energy being competitive with many traditional energy sources, projects may not be viable if the energy produced cannot be sold on the market at a reasonable rate at the time of production. This may leave Europe in the curious position of possessing an abundant environmentally friendly energy resource whose exploitation enjoys a high degree of public and governmental support but without the market framework which can support its development.

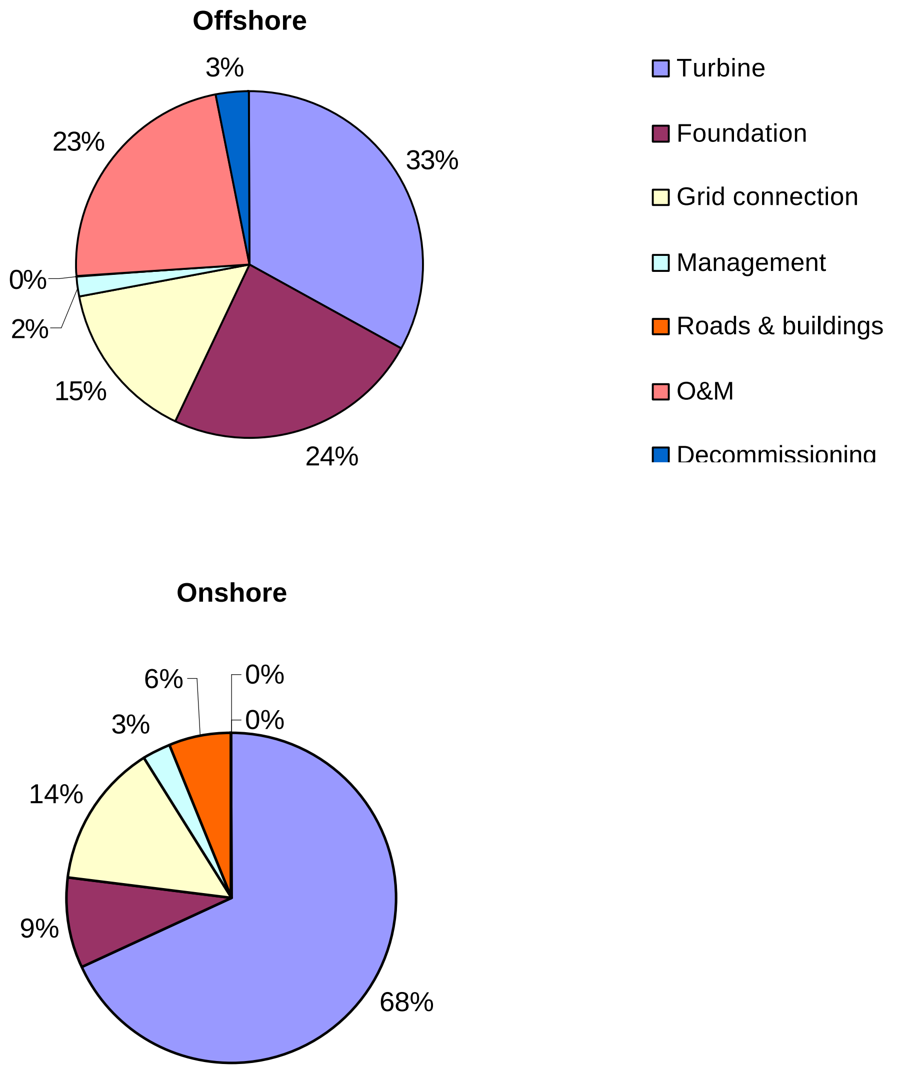

Figure 3-3. Examples of different component contributions to cost for on- and offshore wind farms

4 UNCERTAINTY IN ENERGY YIELD

Despite the lack of high mountains or obstacles predicting offshore wind resources is complicated by a number of factors. Low roughness gives low turbulence and wind shear but thermal effects are important. Not only can wind speed profiles deviate from logarithmic on average but strong temperature gradients can produce thermal flows such as sea breezes and low level jets which are not well accounted for by current models. Useful references include: (Coelingh *et al.*, 1998), (Barthelmie, 1999b), (Smedman *et al.*, 1996), (Smedman *et al.*, 1997). Additional uncertainty is introduced by the prospects of very large wind farms offshore. Wake effects within large wind farms are not well-known and offshore wakes are not well studied. Some useful references are: (Frandsen S. (editor) *et al.*, 1996), (Crespo *et al.*, 1999), (Magnusson *et al.*, 1996). Interactions between the wind and the sea surface is also complex, particularly for extreme wind/wave studies e.g. (Donelan *et al.*, 1993), (Johnson *et al.*, 1997). Successful planning for operation and maintenance is crucial (DEA/CADDET, 2000) to maximise availability when large offshore wind farms up to 40 km from the coast will have access problems.

Some sources of uncertainty relating to resource assessment are given below:

- Some sites without onsite data or nearby long-term records - very high uncertainty
- Mean wind speed (measurement error, year-to-year variability)
- Wind speed distribution (length of record, methodology)
- Contribution of thermal flow (sea breeze, low level jets)
- Vertical profile extrapolation beyond measurements (IBL, stability)
- Power curve (measured, offshore)
- Offshore wakes (lack of data)
- Large wind farms (lack of wake data/lack of offshore data, models need further development)
- Interaction between large offshore wind farms and coastal effects (lack of data, models need further development & evaluation)
- Availability of wind turbines (lack of experience with larger wind turbines, problems with planning for maintenance, access problems).

5 RESEARCH NEEDS

Successful demonstration wind farms have proved that wind energy technology is capable of operating economically in harsh offshore environments. However, the next generation of offshore wind farms will be installed on a larger scale ranging from 50-100 MW. Continued successful development and improved economic value of offshore wind energy requires careful design and planning. In 1999 a Research Requirements Workshop was held as part of the UK's Offshore Wind Energy Network series (Watson, 1999). Main recommendations (for resource and economics) were:

- Detailed prediction of the wind resource - relationships between onshore measurements and coastal winds out to 30 km, improved models (incorporating turbulence, gusts and diurnal and longer term variations) and linking wind and waves
- Prediction of extreme environmental conditions - use of existing data and relationships between extreme wind and waves
- Wind forecasting - improved models for coastal areas and evaluation of current techniques

Areas requiring further research include:

- Improved wind resource estimates particularly in coastal areas which are difficult to model. This should include accurate prediction of vertical wind speed and turbulence profiles. Resource and loading predictions are required on long-time scales for economic and fatigue assessments and variations on short-time scales are required for forecasting and for improved maintenance scheduling. Further development of methods to forecast wind power output up to several days ahead (see e.g. (Hutting and Cleijne, 1999), (Landberg, 1998)).
- Evaluation and prediction of wake impacts on power output and loads for large wind farms. Although monitoring at Vindeby has provided useful data on offshore wakes, significantly more research is required to develop models which can predict wake development in the lower turbulence environment offshore where atmospheric stability variations will be more important. Additionally there are very few data for large wind farms (onshore or offshore) so there is considerable uncertainty.
- Reduction in down-times. Access to offshore turbines for maintenance can be difficult leading to the potential for increased down times. This can be minimised both through careful design of mooring facilities, providing helicopter access, good predictions of offshore weather allowing better maintenance planning by innovative design solutions (Pedersen, 1998) and preventative maintenance and development of 'smart' wind farms which include component monitoring to predict component failures.
- Optimised design criteria to further understanding of complex wind/wave relationships and for assessment of combined wind-wave loads (Kuhn *et al.*, 1998). Calculation of extreme wind and wave events and their recurrence periods is also required.
- Optimisation of design of the major components such as foundations and towers to increase lifetimes. Use of lighter materials for some components (e.g. blades) such as carbon or glass fibre

may provide less expensive but more productive and durable wind turbines. See section *CA-OWEE 2.1*.

- Energy storage and transmission solutions to weak grid or loss in transmission problems (see e.g. (Gardner *et al.*, 1998), (Grainger and Jenkins, 1998). See section *CA-OWEE 2.2.*

6 SUMMARY

In the last decade of the 20th century 80 MW of offshore wind power was installed in Europe. These wind farms have operated successfully and have proved that offshore wind energy is technically, economically and environmentally viable. Continued monitoring and detailed investigation of these wind farms will provide invaluable data for use in better evaluating and harnessing the offshore wind resource and for meeting the challenges of installing large wind farms.

The next generation of wind farms in the 100 MW range consisting of multi-megawatt turbines provide new challenges. Hub-heights are beyond typical measuring heights, wakes within such large farms are not well-understood and the influence of upwind farms requires further research. The technology is less -proven than was the case for the first offshore demonstration projects. Larger distances to the coast and deeper water give harsher conditions for the turbines and supporting structures. Access for maintenance is more difficult, combined with the demand for better availability. However, the physical and environmental challenges are within the grasp of the offshore and wind energy industries. A greater challenge is posed by market uncertainty which has not been detailed in this report.

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8 ADDITIONAL INFORMATION SOURCES

Web sites

ATLAS (R&D Needs for renewable ; DG XVII) :
http://europa.eu.int/en/comm/dg17/atlas/htmlu/windint.html

Prospect for Offshore Wind Energy (Altener project, PDF file download) :
http://www.britishwindenergy.co.uk/offshore/index.html

Wind Force 10 (data on employment, avoided pollution for offshore/onshore wind, PDF file download) :
http://www.inforse.dk/projects_pro.php3?id=9

Greenpeace Germany (see in the Wind section of the page : report on North Sea Offshore Wind, PDF download) : http://www.greenpeace.de/GP_DOK_3P/THEMEN/C04UB01.HTM

OWEN site (UK, number of reports, articles, downloads)
http://www.owen.eru.rl.ac.uk/

ETSU study on offshore impacts (see et the end the page documents to download) :
http://www.dti.gov.uk/renewable/pdf.html

List of approved projects in FP5 (EC, with offshore projects involving GHP, GL...)
http://dbs.cordis.lu/fep-cgi/srchidadb?CALLER=PROJ_FP5&QM_EP_PGA_D=EESD&QZM_ACZ=&USR_SORT=EP_PGA_A+CHAR+ASC

Projects and References for on/off-shore wind energy

Projects

MORE CARE - MORE ADVANCED CONTROL ADVICE FOR SECURE OPERATION OF ISOLATED POWER SYSTEMS WITH INCREASED RENEWABLE ENERGY PENETRATION AND STORAGE (Contract number 1999/C 77/13).

Zephyr-project: Implementing short term prediction at utilities. (joint project of Risoe and IMM (Institute for Mathematical Modelling at the Danish Technical University, RAL 9UK), ELSAM/ELKRAFT, WECTEC (USA), E. David Consult (USA), OEM (USA), EU JOULER funded project JOR3-CT95-0008)

HIPOCAS: Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe

(Contract number EVK2-1999-00248). The objective of the project is to obtain a wind, wave, sea-level and current climatology for European Waters and coastal seas for application in coastal and environmental decision processes.

Coming Projects

ANEMONE: A NEW GENERATION MODEL COMPLEX FOR WIND ENERGY FORECASTING. A Joint project of SERG (UCC Ireland), IMM (DTU, Denmark), DMI (Denmark), CIEMAT (Spain), University of Oldenburg (Germany), Risoe (Denmark).

Other international projects can be found in the IEA Report (see below).

Publications dealing with onshore and offshore wind energy

<u>Reports:</u>

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Appendix

Country: ***Belgium***
Form filled out by: TEE

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	2	More important for characterisation of wind loads than for resource assessment.		
1.b Available data e.g. Ships, buoys, platforms, satellites	1	Sufficiently accurate resource estimates can be based on data from buoys and platforms combined with land-based meteo stations.		
1.c Model estimates	2	Models need to be refined for off-shore application.		
1.d Physical limits e.g. water depth, wave height, distance to shore	1	Required distance to shore is highly subjective parameter. No strong guidance. Water depth and wave height : a distinction needs to be made between short-term potential (eg. Water depth 5-20 m) and medium or long-term potential (water depth > 20m)		
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	1	Marine traffic and military areas. Two off-shore windparks of 100 MW each are planned for 2004		
1.f Comparison with national electricity consumption	3	Not important due to limited off-shore potential estimated at 1000 MWe (or 3 TWhr) in 2020. To be compared to an estimated 100 TWhr total electricity production in Belgium in 2020.	Ampere Commission Report 12 Dec 2000	Y (D, F) later available in English

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	No experience available.		
2.a Size of wind farm				
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast				
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other				

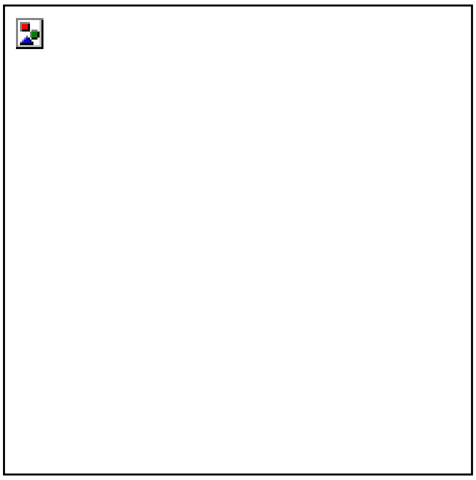
3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	1=low 2=medium 3=high			
3.b Availability	3	True availability (determined by technical availability and accessibility) is considered to be most important source of uncertainty. Also, relation between availability and maintenance cost should be analysed.		
3.c				

3.d				
3.e				

Country: Denmark

Form filled out by: Rebecca Barthelmie, Risø

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	3=high	Vindeby 1993 onwards Rødsand 1996 onwards Omø Stålgrunde 1996 onwards Gedser 1996-2000 Horns Rev 1999 onwards Læsø Syd 1999 onwards	(Barthelmie *et al.*, 1995), (Barthelmie, 1999c), (Barthelmie *et al.*,1999b), (Barthelmie, 1999a)	Reports available inside Denmark
1.b Available data e.g. Ships, buoys, platforms, satellites	1=low	Typically use purpose built masts. Satellite data under investigation in WEMSAR project		
1.c Model estimates	3=high	Yes for designated sites. Includes WAsP, Measure-Correlate-Predict and estimation based on Weibull distribution. Comparison with long-term land/coastal sites.	(Mortensen *et al.*, 1994) (Barthelmie *et al.*, 1998; Barthelmie *et al.*, 1999a; Højstrup *et al.*, 1997)	Reports available inside Denmark

1.d Physical limits e.g. water depth, wave height, distance to shore	3=high	Government approach designates four main areas for offshore wind farms with a capacity of 8,000 MW. The areas were selected based on water depths between 5 and 11 m and avoiding national park areas, shipping routes, microwave links, military areas, etc. The distance from coastal areas varies from 7 to 40 km. This also minimises the visual impact onshore.  If water depth limit is increased to 15 m the offshore potential in the main designated areas is of the order 16,000 MW	http://www.windpower.dk http://www.ens.dk/e21/e21uk/index.htm	Yes, energy Plan 21 available on line or for purchase in hardcopy.
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	3=high	Energy 21 Plan (see above). Two existing wind farms Vindeby and Tunø Knob. In addition to designated areas: Middelgrunden wind farm operating from December 2000. Another under investigation at Samsø. Full site description of planned and active wind farms in eastern Denmark (SEAS utility area) and in western Denmark (ELSAM utility area)		www.middelgrunden.dk : http://www.seas.dk/ https://www.elsam.com/default_ie.htm

1.f Comparison with national electricity consumption	1=low	If Energy Plan 21 is realised a total of 4000 MW of offshore wind power will be installed before 2030. Together with another 1,500 MW installed onshore Denmark will cover more than 50 per cent of total electricity consumption by wind energy. In comparison, the wind power capacity in 1998 was 1,100 MW.		
1.g. National resource estimate	1=low	See above		

<u>2. Economics</u>: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Horns Rev (1st phase)	https://www.elsam.com/default_ie.htm (in Danish), (Neckelmann and Petersen, 2000)	Yes
2.a Size of wind farm		150 MW		
2.b Year of construction		2002		
2.c kWh per year				
2.d Distance to coast		18 km		
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify		Tidal range of the order 3-4 m Relatively high waves and deep water in comparison with other Danish sites. Detailed environmental considerations - see web site (mainly Danish with English summary).		
2.f. Other		Extensive onsite wind and wave monitoring since 1999		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Læsø Syd (1st phase)	https://www.elsam.com/default_ie.htm (in Danish)	Yes
2.a Size of wind farm		150 MW		
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast				
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify		Special site for black duck to the south of the site.		
2.f. Other		Extensive meteorological monitoring since 1999		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**

2a. Name of wind farm	1=low 2=medium 3=high	Vindeby	(Barthelmie *et al.*, 1996a; Barthelmie *et al.*, 1994; Barthelmie *et al.*, 1996b; Barthelmie *et al.*, 1995; Dyre, 1990), (Frandsen S. *et al.*, 1996; Højstrup *et al.*, 1994; Olsen and Dyre, 1993)	Yes
2.a Size of wind farm		4.7 MW (11 450 kW Bonus turbines)		
2.b Year of construction		1991		
2.c kWh per year		~12,000 MWh	(Olsen and Rasmussen, 1994),(Dyre, 1992)	yes
2.d Distance to coast		2-3 km	(Barthelmie *et al.*, 1993)	
2.e. Cost cf. Onshore wind energy		Almost double	(Dyre, 1992)	
2.e Special considerations physical parameters e.g. icing, high waves please specify		Low water depth 2-5 m First offshore prototype. Extensive ongoing on-site monitoring since 1993 (includes meteorology and turbines)		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**

2a. Name of wind farm	1=low 2=medium 3=high	Tunø Knob	(Madsen, 1996)	Yes
2.a Size of wind farm		5 MW (10 turbines 0.5 MW)	https://www.elsam.com/default_ie.htm	
2.b Year of construction		1995		
2.c kWh per year		~14.6 GWh/y	(Barthelmie *et al.*, 1999c)	
2.d Distance to coast		3 km to Tunø, 6 km to east coast of Jutland	Promotional leaflet from Midkraft	
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify				

<u>2. Economics</u>: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Omø Stålgrunde	www.seas.dk	
2.a Size of wind farm		72 2.1 MW turbines. Total 150 W		
2.b Year of construction		October 2005		
2.c kWh per year		ca. 430 million		
2.d Distance to coast		5.6 km to Omø 11.1 km to Lolland		
2.e. Cost cf. Onshore wind energy		Investment ca. 16,000 million kr. (2000 prices)		

2.e Special considerations physical parameters e.g. icing, high waves please specify		Environmental considerations given on project web page (in Danish)		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Rødsand	www.seas.dk	
2.a Size of wind farm		150 MW (72 2.1 Bonus MW turbines)		
2.b Year of construction		October 2002		
2.c kWh per year		500 mill.		
2.d Distance to coast		9-10 km south of Lolland		
2.e. Cost cf. Onshore wind energy		Investment about 16000 million kr (2000 prices)		
2.e Special considerations physical parameters e.g. icing, high waves please specify		Ongoing intensive monitoring including meteorology, wave and currents. Special site for migratory birds. Environmental considerations given on project web page (in Danish)		
2.f. Other				

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Gedser	www.seas.dk	

2.a Size of wind farm		150 MW		
2.b Year of construction		October 2008		
2.c kWh per year		500 mill.		
2.d Distance to coast		5 km to Falster		
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify		Environmental considerations given on project web page (in Danish)		
2.f. Other				

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	Importance	Main Conclusions	References	Available (Y/N)
2a. Name of wind farm	1=low 2=medium 3=high	Middelgrunden	www.middelgrunden.dk, www.middelgrunden.com, Larsen & Sørensen (2001), Sørensen et al. (2000), Sørensen et al. (2001), (Barthelmie, 1999c)	Yes (Report available in Denmark)
2.a Size of wind farm		40 MW (20 turbines 2 MW)		
2.b Year of construction		2000		
2.c kWh per year		89,000,000 kWh		

2.d Distance to coast		2 km		
2.e. Cost cf. Onshore wind energy		Comparable. 0.34 DKK/kWh production price.		
2.e Special considerations physical parameters e.g. icing, high waves please specify		Built on an old dumpsite prohibited to shipping. Water depth 2-6 m. In the lee of the city of Copenhagen.		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Samsø	http://www.veo.dk	Yes
2.a Size of wind farm		10 turbines 22-30 MW		
2.b Year of construction	2002	At tender November 2001.		
2.c kWh per year				
2.d Distance to coast		4 km		
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify		Water depth 14-18 m		

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**

3.a Mean wind speed	3=high	Site dependent. Most designated sites have one year or more measurement data plus modelling. Uncertainties are estimated as ±4% with 6 or more years of measurement data and ±8% with one years measurement data. This analysis carried out using bootstrapping. In comparison with other sites using different models and long-term data sets uncertainties	(Barthelmie *et al.*, 1998)	In Denmark
3.b Availability	3=high	Most analysis focuses on access for maintenance. Studies ongoing.		
3.c				
3.d				
3.e				

Country: ***Ireland***

Form filled out by: **Brian Ó Gallachóir**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	3	Testing commenced at 7 sites following the issuing of 7 licenses in Sept 2000 Arklow Bank (4), Greater Codling Bank, Blackwater Bank and Codling Bank	[1]	n
1.b Available data e.g. Ships, buoys, platforms, satellites	1	Offshore buoys owned and operated by the UK Met Office at Malin Head, Belmullet, Porcupine, Valentia and Rosslare.	[2]	
1.c Model estimates	2	Assessment for offshore resource for the island of Ireland - based on windspeeds at 22 onshore locations, model developed for assessment and Weibull distribution with $k=2$	[3],[4]	y

1.d Physical limits e.g. water depth, wave height, distance to shore	2	Resource assessed at maximum water depths of 20m and 50m, with min distance from coastline 2, 3, 4, 5, 7 and 10 km (with max distance the 12 nautical mile territorial limit). Offshore stations will not typically be allowed within 5 km of the shore.	[3] [6]	y
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	3	Government targets exist for renewable energy up to 2005 (additional 500 MW). It is the policy of the Department of the Marine and Natural Resources to maximise the use of Ireland's offshore resources. No targets yet exist specifically for offshore wind energy but a policy document on regulation has been published and an assessment of impacts on the offshore environment.	[5], [6],[7]	y
1.f Comparison with national electricity consumption	1	Practical resource with max water depth 20m and min distance from shore 5 km is 11 TWh or 32% of annual predicted electricity consumption in 2005	[3]	

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	Importance	Main Conclusions	References	Available (Y/N)
2a. Name of wind farm		Arklow Bank	[1], [8]	Y
2.a Size of wind farm		500 MW	[8]	Y
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast		10km	[8]	Y
2.e. Cost cf. Onshore wind energy		€ 571m - € 635m (IR£ 450m - IR£ 500m) estimated	[8]	Y
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm		Kish Bank Wind Farm	[1]	Y
2.a Size of wind farm		200 – 250 MW	[9]	Y
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast		10 km	[9]	Y
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	Y

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm		Codling Bank Wind Farm	[1]	Y
2.a Size of wind farm				
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast				
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	Y

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm		Blackwater Bank Wind farm	[1]	Y
2.a Size of wind farm				
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast				
2.e. Cost cf. Onshore wind energy				

2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	Y

<u>3. Uncertainties in energy yield</u>: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	3	Model developed to assess Irish offshore wind speeds provides an estimate of the standard error of estimation.	[3]	
3.b Availability				
3.c				
3.d				
3.e				

References:

1. Department of the Marine and Natural Resources. *Investigations to begin on Suitability of Sites for offshore Wind Farms* Press Release 4 September 2000. http://www.irlgov.ie/marine/pressRelease/September00/4Sep.htm
2. The web site for the UK Met Office is http://www.metoffice.gov.uk/index.html. A map showing the location of the buoys is available at http://www.ndbc.noaa.gov/Maps/England.shtml
3. Department of Public Enterprise and Department of Enterprise Trade and Investment (2000) *Assessment of Offshore Wind Energy Resources in the Republic of Ireland and Northern Ireland.*
4. McWilliams B and Sprevak D (1980) *Wind Engineering* Volume 4 pp 227-238.
5. Department of Public Enterprise (1999) *Green Paper on Sustainable Energy*. Available at http://www.irlgov.ie/tec/energy/renewinfo.htm
6. Department of the Marine and Natural Resources (2000) *Offshore Electricity Generating Stations – Note for Intending Developers Impacts of Offshore Wind Energy Structures on the Marine Environment.*
7. Marine Institute (2000) *Assessment of Impacts of Offshore Wind Energy Structures on the Marine Environment, ISBN 1-902895-09-6.*
8. Eirtricity (2000) *Article posted 6 November 2000.* http://www.eirtricity.ie/eirtricity_ie/newsframeset.html

9. Powergen Renewables (2000) *Powergen Renewables Offshore Developments* http://www.powergenrenewables.com/harnessingoffshorewindpower.htm

Country: Spain

Form filled out by: CIEMAT

1. <u>Offshore wind resource potential</u>: Please specify national experiences and/or considerations concerning resource assessment					
Topic	*Importance*	Main Conclusions	**References**	**Availa. A/N**	**Language**
1.a Onsite Measurements	1	Plans for measurement in Cadiz (waiting for permission). Measuring at Huelva harbour dock.		N	

1.b	Available data e.g. Ships, buoys, platforms, satellites	3	1 - Data from measuring networks of Puertos del Estado (harbour measurements). REMPOR : Coast Meteorology. RAYO: Meteorology, Wave, Currents, Temperatures, Salinity.	www.puertos.es/redes-eng.html contact to: andres@puertos.es ignacio@puertos.es	A	ES, EN
			2.- Ships: Campaigns of Spanish Institute of Oceanography.	www.ieo.es/ship.htm contact to: carlos.masso@md.ieo.es	¿?	ES
			3.- Satellites: Images of the sea surface temperature	www.ieo.es/satesant.htm contact to: alicia.lavin@st.ieo.es (Díez, 1996b), (Sethuraman and Raynor, 1980),(Gaudiosi, 1994),(Díez, 1996a),(IDAE, 1999)	A	ES

1.c	Model estimates	3	"Puertos del Estado" is a public entity with a lot of information, both measurements and models but not focus on wind energy. Models: GESIMA Atmosphere, wind velocity HAMSOM Ocean Circulation PROPS Wave Propagation WAM Generation Wave Model WAVEWATCH Shallow Water Model Coupled Models WAM-PROPS Wave prediction: Public services of sea meteorological information (Nacional Intitute of Meteorology).	www.puertos.es/Modelos/models-eng.html www.inm.es/wwc/indinfmar.html contact to: maritima@inm.es	A A	SP, UK

1.d	Physical limits e.g. water depth, wave height, distance to shore		High water depth and sea bed slope seem to be one of the main drawbacks for the off-shore development in Spain.	-(Díez, 1996b) -" El Relieve de la Península Ibérica y de su Entorno Terrestre y Marino".In Atlas: "El Medio Marino".1989	A A	ES ES
1.d	Physical limits e.g. water depth, wave height, distance to shore	1	Cartography-marine charts. Three types of information sources: Spanish charts from Instituto Hidrográfico de La Marina (Army), British charts from British Admiralty and French charts from SHOM, in paper and digital formats Measuring networks of "Puertos del Estado" REMRO: Scalar Wave. EMOD: Directional Wave. REDMAR: Sea Levels. Navigational waves RADAR:Directional Wave and Currents	www.navegar.com/organismos/ www.bme.es/blmon www.nauticarobinson.com/cgi-bin/w3-msql/portada.html www.puertos.es	A	

1.e	Planned activity e.g. government mandate	2	Huelva Harbour: Plans for install 40-50 Mw. Cadiz: Depending on the measurements.			
1.f	Comparison with national electricity consumption	3	Not significant			

References:
1.-Plan de Fomento de las Energías Renovables en España. 1999. Instituto para la Diversificación y Ahorro de la Energía, IDAE.
2.- Díez, JM., 1996. Guía Física de España. Tomo 6. Las Costas. D. L., Alianza Editorial.
3.-Sethuraman, S., Raynor,G.S, 1980. Comparison of Mean Wind Speeds and Turbulence at a Coastal Site and and Offshore Location. American Meteorological Society,15-21.
4.-Gaudiosi, G.,1994. Offhore Wind Enegy in the Mediterranean and other European Seas. Renowable Energy, 5, pp. 675-691.

Country: Finland

Form filled out by: Jonas Wolff (VTT)

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment

Topic	*Importance*	Main Conclusions	References	Available (Y/N)
1.a Onsite Measurements	**2=medium**	**but models outdated and for lower heights a.s.l.**	**None**	**N**
1.b Available data e.g. Ships, buoys, platforms, satellites	**3=highest**	**Met stations in reasonable vicinity**	**Finnish Wind Atlas**	**Y**
1.c Model estimates	**3**	**Only way so far, wind atlas not yet updated for offshore areas nor heights > 50 m a.s.l.**	**Finnish Wind Atlas + Wasp**	
1.d Physical limits e.g. water depth, wave height, distance to shore	**3**	**Not to forget ice coverage in winter**	**Sea charts and specific reports**	**Y**
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	**3**	**First demonstrations important, information from turbines on peninsulas and islands**	**National production statistics**	**Y**
1.f Comparison with national electricity consumption	**1=lowest**			
1.g Overall national potential	**3**	**In detail studied only for a part of the coastline. Rough overall estimate ~ 20 TWh/a**	**Study**	**Y**

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	Importance	Main Conclusions	References	Available (Y/N)
2a. Name of wind farm		**Pori offshore**		
2.a Size of wind farm		**To be decided**		
2.b Year of construction		**Planned**		
2.c kWh per year	**3**			

2.d Distance to coast	**2**			
2.e. Cost cf. Onshore wind energy	**2**	**Limited resource of "cheap" onshore driving development offshore**		
2.e Special considerations physical parameters e.g. icing, high waves please specify	**3**	**Ice coverage in wintertime, requirements on foundation, economic impact negligible**		
2.f. Other				

10. **3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:**				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	**3**	**No experience yet**		
3.b Availability	**3**	**No experience yet**		
3.c				
3.d				
3.e				

Country: FRANCE

Form filled out by: P.BRUYERRE (EED)

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	1=low 2=medium 3=high			

1.b Available data e.g. Ships, buoys, platforms, satellites		Good intercorrelation (at the site of Dunkerque) between Met UK buoy (Sandettie), our own buoy (5 km offshore) and 2 onshore (seashore) measurements.	Study of the offshore wind farm in Dunkerque (northern France)	
1.c Model estimates	2	Need to be precise to take in account large scale effects (ie "Channel" effect)		
1.d Physical limits e.g. water depth, wave height, distance to shore	3	The sum "water depth + tide" is the major issue. A 30 m depth site in Mediterranean is equivalent to a 20 m site in Normandy (10 m tide). On the basis on EED studies in different french regions of offshore potential, the potential is estimated as 9125 MW or 30.1 TWh. This is a technical potential integrating also major environmental constraints. The analysis has been limited to about 20 km (limit of French territory) max and 3 km min. 30.1 TWh/y It has to be compared with 517 TWh of electrical power produced in France in 2000.		
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	2	The main question is the compatibility of offshore wind farms with exiting marine activities. No existing rule at the moment (the seabed belongs to the nation).		
1.f Comparison with national electricity consumption	1	The issue is more related to the possibility to have a sufficient onshore connection to the grid (ie in Brittany). Four r		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	BREEDT (DUNKERQUE)	Breedt Oddsfore wind farm	Y (partial)

2.a Size of wind farm		7.5 MW		
2.b Year of construction		PLANNED IN 2002		
2.c kWh per year		0.064 Euro + subsidies (25% of investment costs)		
2.d Distance to coast		5 km		
2.e. Cost cf. Onshore wind energy		+ 50%		
2.e Special considerations physical parameters e.g. icing, high waves please specify		Potential scour on sandbank + tidal currents		
2.f. Other		Difficulties with local fishermen		

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	Importance	Main Conclusions	References	Available (Y/N)
3.a Mean wind speed	3	On sites where no offshore data (buoys, light vessels) are available, the uncertainty is quite high.		
3.b Availability	3	Depending on the technology. Need for specific design		
3.c Technical risk	2	Related to 3b.		
3.d				
3.e				

References :

Identification of potential offshore sites" : Nord-Pas de Calais (1998), Brittany (1999-2000), Normandy (2000), Languedoc-Roussillon (2000). Studies realized for regional councils and/or ADEME (french energy agency)

Development of a 7.5 MW offshore wind farm at Breedt (Dunkerque) (1998, on going) with SAEML "Eoliennes Nord-Pas de Calais", Shell Renewable, TotalFinaElf and Framatome (Jeumont Industrie)
Development of 3 offshore sites for large wind farms : Normandy, Brittany, Languedoc
Form (Draft)

Country: ***Greece***
Form filled out by: **Dr. G. Lemonis, CRES**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	1=low 2=medium 3=high	Onshore wind data available from CRES. Nearshore wind data available from NTUA, National Technical University of Athens and the National Center for Marine Research	1 2-6	
1.b Available data e.g. Ships, buoys, platforms, satellites		Data available from the National Service for Meteorology, National Observatory, Greek Ministry for Defense, a.o.	www.mod.gr www.noa.gr	
1.c Model estimates		Different onshore wind prediction models have been developed or are currently under development at CRES. Direct application for nearshore locations possible. Further development for offshore applications possible.	1	
1.d Physical limits e.g. water depth, wave height, distance to shore		Seabed relief data available from the National Hydrographic Institute		
1.e Planned activity e.g. government mandate		No activities for OWE planned yet		
1.f Comparison with national electricity consumption				

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**

2a. Name of wind farm	1=low 2=medium 3=high			
2.a Size of wind farm				
2.b Year of construction				
2.c kWh per year				
2.d Distance to coast				
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other				

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	1=low 2=medium 3=high			
3.b Availability				
3.c				
3.d				
3.e				

References

P. Chaviaropoulos, D. Douvikas, (1998) “Mean-flow-field Simulations over Complex Terrain using a 3-D Reynolds Averaged Navier-Stokes Solver”, ECCOMAS ’98, Athens, Greece

Soukissian, T.H., Chronis G.Th. and Nittis, K., 1999, “POSEIDON: Operational Marine Monitoring System for Greek Seas”, Sea Technology, Vol. 40, ? ?. 7.

Soukissian, T.H., Chronis G.Th., “POSEIDON: A marine environmental monitoring, forecasting and information system for the Greek Seas”, 2000, ? editerranean ? arine Science, Vol. 1, No.1, pp. 71-78.

G.A. Athanassoulis, E.K. Skarsoulis, "Wind and Wave Atlas of the Northeastern Mediterranean Sea", ENEY/KD-11/92, GEN/OK-20/92, 20+191 pp., July 1992

G.A. Athanassoulis, M.T. Pontes, L. Tsoulos, B. Nakos, Ch.N. Stefanakos, A. Skopeliti, R. Frutuoso, "European Wave Energy Atlas: An Interactive PC-based system", Second European Wave Power Conference, 8-10 November, 1995, Lisbon, Portugal

L. Cavaleri, G.A. Athanassoulis, S. Barstow, “Eurowaves: a user-friendly approach to the evaluation of near-shore wave conditions”, 9th (1999) International Offshore and Polar Engineering Conference and Exhibition, ISOPE 99, 30 May – 4 June 1999, Brest , France

Country: Italy

Form filled out by: Gaetano Gaudiosi ENEA

1. Offshore wind resource potential: Please specify national experiences and/or consider ıtions concerning resource assessment

Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	1=low 2=medium 3=high	La Maddalena Sardinia	OWEMES	Y
1.b Available data e.g. Ships, buoys, platforms, satellites	1	Oil Platforms		
1.c Model estimates	1	Local in Sardinia WASP	OWEMES	
1.d Physical limits e.g. water depth, wave height, distance to shore	3	Water depth		
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	3	Some	ENEA. Ragusa Province Environment Ministry	
1.f Comparison with national electricity consumption	2	Significant resources		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**

2a. Name of wind farm	1=low 2=medium 3=high	***Planned Study Offshore Wind Farm***		
2.a Size of wind farm		?		
2.b Year of construction		?		
2.c kWh per year		?		
2.d Distance to coast		?		
2.e. Cost cf. Onshore wind energy		?		
2.e Special considerations physical parameters e.g. icing, high waves please specify		High salinity		
2.f. Other				

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	1=low 2=medium 3=high	2European wind atlas	Risoe	y
3.b Availability	2			
3.c				
3.d				
3.e				

Country: Netherlands

Form filled out by: Toni Subroto / Andrew Henderson (TUDelft)

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance* *1=low, 2=medium**3=high***	Main Conclusions	**References**	**Available (Y/N)**
			Summary in 1 and 2	Yes (Eng)
1.a Onsite Measurements	High	"MeetNet Noordzee" provides oceanographic and Meteorological data such as windspeed,-direction,waterlevel , waveheight and temperature. Data Voluntary Observing Ships provides wind data with a high resolution, long track record but poor accuracy. The Ness database provides accurate wind data over a long period (about 30 years) for a 30 by 30 km grid.	Rijkswaterstaat Directie Noordzee (RWS).3 KNMI 4 5	from RWS from the KNMI. You have to pay for it.
1.b Available data e.g. Ships, buoys, platforms, satellites	High	Data bases of "Rijkswaterstaat Directie Noordzee" and "MARIS" provides sufficient data concerning the Continental Shelf and Southern NorthSea	RWS 3	from RWS

1.c Model estimates	Medium	Preliminary study resulting in a Geographic Info. Syst. (GIS) and estimates on suitable and available space for LSOWE. An estimate for all European countries, including the Netherlands was made in the joint Germanischer Lloyd / Garrad Hassan European-Commission funded project: *Study of offshore wind energy in the European Community*. A new survey is currently being undertaken in the current European-Commission funded project: *Predicting offshore wind energy resources* (POWER), currently being undertaken by a consortium led by Rutherford Appleton Laboratories (RAL)	Report 6 CORDIS record [7] CORDIS record [8]	Y
1.d Physical limits e.g. water depth, wave height, distance to shore	High	Data bases of "Rijkswaterstaat Directie Noordzee" and "MARIS" provides sufficient data concerning the Continental Shelf and Southern NorthSea	RWS 3	from RWS
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	High	1/3 to 1/2 of planned 2750 MW renewable energy for 2020 must probably be offshore. A demonstration near shore project consisting of a 100MW windfarm is in preparation.	Report [9]	Y
1.f Comparison with national electricity consumption	Medium	An installed LOW capacity of 10.000MW will be able to provide 11% of the electr. demand in 2020.	Report [10]	

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1=low 2=medium 3=high	Near Shore Windpark Feasibility study	Report [11]	Y (Dutch)
2.a Size of wind farm		100MW		
2.b Year of construction		2003		
2.c kWh per year		Annually 250-300 GWh.		
2.d Distance to coast		approx. 8 km but will probably need to be further because of public concerns about visual impact		
2.e. Cost cf. Onshore wind energy		16 - 17 c(NL)/kWh (= 7-8 €c/kWh), would need a subsidy of NLG 60m	[12]	
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other				
2a. Name of wind farm		Offshore Q7-WP (E-connection)		
2.a Size of wind farm		60 turbines (~100 MW)		
2.b Year of construction		2002 (Depends on obtaining the permissions)		
2.c kWh per year				
2.d Distance to coast		More than 12 miles		
2.e. Cost cf. Onshore wind energy		The cost price is confidential but they state that it is a commercial project		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2.e Special considerations physical parameters e.g. icing, high waves please specify				
2.f. Other				
2a. Name of wind farm		Lely (Medemblik)	Conference Papers [13,14] and Final Report [15]	Y (Eng)
2.a Size of wind farm		four 500 kW NedWind turbines = 2 MW		
2.b Year of construction		commissioned in summer 1994		
2.c kWh per year		30% more energy than a corresponding windfarm in the south of the country due to the higher average windspeeds and the reduced turbulence 3.5 million kWh		
2.d Distance to coast		800 m		
2.e. Cost cf. Onshore wind energy				
2.e Special considerations physical parameters e.g. icing, high waves please specify		Bright coloured sections on the tower, night warning lights and horizontal blade parking further reduce the hazard to shipping fog detection, (park blades and activate hazard lights)		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2.f. Other		30 m long, 3.5 m diameter steel monopiles twin-blade 40.8 m diameter rotor turbines in 5-10 m water depth in the IJsselmeer, an inland (hence sweet water) sea thunderstorm detection, (reduce lightning strikes by parking turbine horizontally), additional automation, such as for lubrication, (reduce maintenance costs), a built in hoist, and additional pollution prevention measures (IJsselmeer is a potable water reservoir).		

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	high	9 m/s, variation : 8-10 m/s. 7-9 m/s (at 10 m height)	Report [16] Report 2	Y (Lng. NL) Y (Eng)
3.b Availability	high	the availability of the turbines has a very important effect on the overall costs of the generated electricity	Reports [17and 18]	Y (Eng)
3.c Environmental data		For an accurate determination of the combined wind and wave fatigue of the support structure, correlated long-term data on wind and waves are necessary	5	

References:

1. J.P. Coelingh (ed), Wind and wave data compiled for the DOWEC concepts study (report for DOWEC Concepts, working group 5/6), *Delft Section Wind Energy IW-00162R*, February 2000.
2. J.P. Coelingh (ed), Wind and wave data from the Measuring Network North Sea - a preliminary analysis (report for DOWEC Concepts, working group 5/6), *Delft Section Wind Energy IW-00169R*, September 2000.
3. http://www.waterland.net/
4. Korevaar, C.G., *Climatological data of the Netherlands lightvessels over the period 1949—1980*, WR 87-9, KNMI, De Bilt, 1987

5. Peters, D.J. et all, *Modelling the North Sea through the North European Storm Study*, Proceedings Offshore Technology Conference (1993), pn 7130
6. Grontmij, Ruim baan voor wind op zee, *Doc.nr.ROMT98001879*. 1998
7. Study of offshore wind energy in the European Community, CORDIS record number: 2441, *www.cordis.lu*, 1993
8. Predicting offshore wind energy resources, CORDIS record number: 45062, *www.cordis.lu*, 1999
9. Plaatsingsplan Windenergie Buitengaats, *Novem*, 1999.
10. Functionele eisen van offshore windparken, *KEMA, 60134-KST/ENR 98-2038*, 1998,
11. Haalbaarheidsstudie Demonstr. Project Near Shore Windpark, Novem, 1997.
12. Milieu-effectrapport, Locatiekeuze Demonstratieproject 'Near Shore Windpark', *Ministerie van Economische Zaken* en *Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer*, 2000
13. Kouwenhoven, H.J. *et al*, Windfarm "Lely", the First Off-shore Windfarm in the Netherlands, *EWEC Conference*, 1994
14. van de Sande A.M.C., Windfarm Lely - first off-shore project in the Netherlands, *OWEMES Conference*, 1997
15. Kouwenhoven, H.J, Lely Windturbine Project, Final Report for Project WE23/89NL, *Energie Noord-West*, 1996
16. globale analyse van Invest.kosten,eindrapport. *Stork Eng. Consultancy*, 1999.
17. Kühn, M. (editor), Cockerill, T.T; Harland, Harrison, R.; L.A.; Schöntag, C.; van Bussel, G.J.W.; Vugts, J.H. Opti-OWECS Final Report Vol. 2: Methods Assisting the Design of Offshore Wind Energy Conversion Systems. *Institute for Wind Energy, Delft University of Technology*, 1998.
18. Ferguson, M.C. (editor); Kühn, M.; Bierbooms, W.A.A.M.; Cockerill, T.T; Göransson, B.; Harland, L.A.; van Bussel, G.J.W.; Vugts, J.H.; Hes, R. Opti-OWECS Final Report Vol. 4: A Typical Design Solution for an Offshore Wind Energy Conversion System. *Institute for Wind Energy, Delft University of Technology*, 1998.

Country: ***POLAND***

Form filled out by: Dariusz Mikielewicz (BAPE)

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Importance*	Main Conclusions	**References**	**Available (Y/N)**
1.a Onsite Measurements	1=low			
1.b Available data e.g. Ships, buoys, platforms, satellites	2	Only through private communication with relevant authorities		
1.c Model estimates	2	Wind Energy Potential 1. 36 PJ (of which 11 offshore) - Economical and legal aspects of utilisation of renewable sources of energy in Poland - EC BREC 2000. 2. 4-5 PJ - World Bank Report, Hauff (1996).		
1.d Physical limits e.g. water depth, wave height, distance to shore	2	According to Maritime Bureau, after exclusion of all restricted areas (birds, fishing, offshore exploitation), ca. 2 800 km^2 for development of offshore wind power is available in Poland, that is 8.5% of the Polish territorial waters: in the Gdansk Bay, the area where implementing wind turbines is possible is ca. 40 km long and on the open sea coast line (from Jastrzebia Gora to Swinoujscie) - it is ca. 200 km long, excluding coastal banks at Wistula – and Szczecin Bays.		

1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	1	Additionally there seems to be a significant investment in the planning stage concerning the first offshore wind farm in Bialogora near Puck. The wind farm consisting of 49 turbines of 2MW power will be located on artificial island in a Puck Bay (North of Gdañsk bay). A foreseen end of investment is 2003, but first turbines were planned to operate in August 2001. Consents have also been given for 50 2 MW turbines near Karwia and two applications are pending at Slupsk Municipality. Technical potential of offshore wind is estimated at 11PJ and the strategy aims to increase renewable energy from its current 2.4% share to at least 7.5% in the year 2010 but no formal targets have been set.		
1.f Comparison with national electricity consumption	1	None		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm	1	None		
2.a Size of wind farm	1	Non applicable		
2.b Year of construction	1	Non applicable		
2.c kWh per year	1	Non applicable		
2.d Distance to coast	1	Non applicable		
2.e. Cost cf. Onshore wind energy	1	Non applicable		

2.e Special considerations physical parameters e.g. icing, high waves please specify	1	Non applicable		
2.f. Other		Non applicable		

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	Importance	Main Conclusions	References	Available (Y/N)
3.a Mean wind speed	3=high	Experiences only in onshore measurements by meteorological stations (10 m heights)	2	Y(PL)
3.b Availability	1	Non applicable		
3.c				
3.d				
3.e				

References:

1. Strategy for the development of RES
2. Proceedings of international seminar on Wind Power onshore and Offshore, Sopot 15-17 December 2000
3. Baltic Energy Conservation Agency (http://www.bape.com.pl)
4. EC BREC, (http://www.ibmer.waw.pl/ecbrec/)
5. Elektrownie Wiatrowe S.A., (http://www.elektrownie-wiatrowe.org.pl)

Country: Sweden

Form filled out by: Vindkompaniet

<u>1. Offshore wind resource potential</u>: Please specify national experiences and/or considerations concerning resource assessment

Topic	*Importance*	**Main Conclusions**	**References**	**Available (Y/N)**
1.a Onsite Measurements	1=low 2=medium 3=high	Onsite measurements are very important. Investors don´t believe in estimations		
1.b Available data e.g. Ships, buoys, platforms, satellites		Vindkompaniet have made onsite measurements on three off-shore sites around the Swedish coasts but only for in-house use. There is a network of off-shore meteorological stations owned by the Swedish State meteorology Service (SMHI) around the Swedish coast collecting wind data. Data is available.	SMHI	Y
1.c Model estimates		The Meteorological Institute of Uppsala University MIUU have worked out a meso-scale model with huge masses of computerised data.	MIUU	Y
1.d Physical limits e.g. water depth, wave height, distance to shore		We have practical experience in the country from three off-shore plants . Very useful for calculations and estimations of the potential for offshore windpower. A total national survey where all these limitations mentioned to the left are considered and estimated in order to determine the offshore windpower-potential is under construction.		

1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms		There are about 550 gridconnected windturbines in Sweden with about 230 MW installed effect. The first offshore-based windturbine in the world a 220 kW WindWorld with 27 m rotor was erected outside Nogersund in Blekinge (southeast of Sweden) 1990. It has a steel tripod foundation (very expensive) In September – December 1997 Vindkompaniet constructed an offshoreplant 5 X500 WindWorld machines on steel monopile foundations at Bockstigen, Valar. The site is a reef 4 km outside the Näsudden peninsula at the southwest coast of the island Gotland in the middle of the Baltic.. Näsudden has one of the biggest european windparks with nearly 85 turbines. The commissioning of Bockstigen was in february 1998. Vindkompaniet then in summer 1997 applied for permission at the site Utgrunden in Kalmarsund that is the sound between the island Öland and the Swedish mainland. Utgrunden is a reef in the sound, 8 km from the coast of Öland and 12 km from the coast of the Swedish mainland. In late 1998 Enron Wind bought all the Utgrunden rights. Permission and authorisations was granted in the winter 1999/2000 and Enron erected 7 X1,425 MW in september/november 2000. Theré working with starting up and testing now in december. 5 The third off-shore wind-plant is under construction. It is a 5 X 2 MW project outside the very southeast coast not far from Karlskrona in the Blekinge county. The name of the project (and the site) is Yttre Stengrund. It´s a Vindkompaniet/NEG-Micon project. 5 X 2 MW NEG-Micon 2 MW machines will be erected on the site during February and March 2001. The project started 2,5 years ago with making environmental assessments, windmeasuring, preparing all needed applications etc applications		

1.f Comparison with national electricity consumption		The electricity consumption in Sweden is about 140 TWh/year. Roughly speaking half of that comes from hydro power and the other half from nuclear power. The present windpower-capacity – ca 220 MW – contributes with only 0,35%. There is no decided political goal for an increasing of windpower-produced electric power but governmental and prime-minister statements the last year points out a fast growth for windpower. According to these statements the focus for the wind power growth in Sweden will be big off-shore located plants.		

2. Economics: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	**Main Conclusions**	**Ref**	**Available (Y/N)**
2a. Name of wind farm Bockstigen,Valar Utgrunden Yttre Stengrund	1=low 2=medium 3=high	1.Bockstigen/Valar 2.Utgrunden 3. Yttre Stengrund		
2.a Size of wind farm 5 x 0,5 MW 7x 1,425 MW 5x2 MW		5 x 0,5 MW 7 x 1,425 MW 5 x 2 MW		

2.b Year of construction 1997 2000 2000-2001		 1997 2000 2000/2001-01-01		
2.c kWh per year 1.		7 500 000 38 000 000 30 000 000		
2.d Distance to coast		4 km 8 km 5 km		
2.e. Cost cf. Onshore wind energy		Installation cost 7 MSEK compared to 4 MSEK onshore. Unknown. (Efforts to investigate can be made if wanted.) 143 MSEK compared to about 80 MSEK onshore		

2.e Special considerations physical parameters e.g. icing, high waves please specify		The foundation which is a steel mono-pile is designed after strong efforts to predict the wave- and iceloads. Data and information concerning the icing in the water and the waveheights have been obtained from SMHI (Swedish Meteorological and Hydrological Institute). The model with the worst year of the last fifty has been used. A special ice-protection is mounted on the monopiles. No special ice-cone. See 2.e,3 See point 1 above.		
2.f. Other				

<u>3. Uncertainties in energy yield</u>: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance**	**Main Conclusions**	**Ref**	

3.a Mean wind speed	1=low 2=medium 3=high	Very small uncertainties. The Bockstigen plant is built 4 km offshore from the Näsudden peninsula where 75 onshore windturbines are located. 25 of these are the same model WindWorld W3700, as the offshore-turbines. To calculate and predict the energy-production of the Bockstigenturbines there were not so sophisticated methods used, mostly Wind-atlas calculations and comparisons and cross-calculations between the future and the present turbines. It´s important to know that above all the present windturbines there is big wind-measuring mast on the Näsudden peninsula with gathered windspeed data since 1979 on seven levels, 10 – 145 meters. Today data show very good accordance with the predicted. The Utgrunden Windplant is located in the sound between the island of Öland and the Swedish mainland with a distance to Swd. Cost of approx. 12 km and approx. 8 km to Öland. There are 33 windturbines located on southern Öland within max 12 km radius from the Utgrunden site. They were erected between 1990 and 1997 and therefore work good as references to make reliable predictions for the future windenergy production at the Utgrunden site. Furthermore metmast measurements have been made on top of the Utgrunden lighthouse and cross calculations based on long-term winddata from the nearest meteorological stations.		
		The uncertainties are much bigger as there is neither windturbines nor metmasts in the close vicinity. To predict the production many calculations and cross calculations have been made using the nearest meteorological stations with long term wind velocity data. Even a close to site met mast has been used.		

3.b Availability		The availability is about 90-95 % which is much lower compared to the 99 % availability at the Näsudden peninsula windpark. The problems have been: 1. Sea-cable breakdowns with failure of current. 2. Stopped turbines with need for manual reset in the turbine combined with access-problems(i.e problems to board and climb up to the turbine platforms when the wave heights exceed 1.5 – meters) 3. The turbines are equipped with a more sophisticated control system to make possible connection to a weak grid on the coast. Many stopped-turbine-periods are caused by troubles with that control system. A standard on-shore control system Unknown. See 2.e,3 Based on experiences about availability presented above there are many steps taken to increase the availability.		
3.c				
3.d				
3.e				

Country: ***UK***
Form filled out by: **Colin Morgan, Garrad Hassan**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic		Main Conclusions	**References**	**Available (Y/N)**
1.a On-site measurements	3	All future projects will be project-financed requiring therefore a high degree of confidence in energy analysis.	-	
1.b Available data e.g. Ships, buoys, platforms, satellites	2	Ships – spatial-sparse and time-sparse observations, subjective so inaccurate, only useful for broad site selection Buoys – spatial-sparse observations (mainly coastal), low elevation (typically 5m) so inaccurate, only useful for broad site selection Platforms – very spatial-sparse observations. Satellites – coarse spatial resolution (approx. 25km x 25km), only 14 years of data and (in European latitudes) 6-8 samples per day. Becoming useful for site selection as database builds. Lighthouses / small islands – UK Met Office operate small number of met stations on islands or lighthouses which are proving useful for a very limited number of projects. Accuracy possibly insufficient and height of measurement inadequate.	1 2	N Y

1.c Model estimates	3	(Mainly) WAsP initiated from coastal stations, cross-validated with other coastal stations and possibly island or lighthouse stations. Very important in initial stages but inadequate for financing.		
1.d Physical limits e.g. water depth, wave height, distance to shore	3	Water depth is a prime factor in site selection – most UK sites chosen are 5-15m depth. Distance to shore is less important than distance to grid connection point. Wave height is known to be a capital cost-determinant.	3	Y
1.e Planned activity e.g. government mandate, other nearby off- or on-shore wind farms	3	2600MW offshore by 2010 (one-fifth of renewables total)	4	Y
1.f Comparison with national electricity consumption		2% by 2010	4	Y

<u>2. Economics</u>: Please specify national experiences and/or considerations concerning economics from current and planned *Offshore Wind Farms* in relation to the topics listed below:				
Topic	**Importance** 1=low 2=medium 3=high	Main Conclusions	**References**	**Available (Y/N)**
2a. Name of wind farm		Blyth	www.blyth-offshore.co.uk	Y
2.a Size of wind farm		4MW		
2.b Year of construction		2000		
2.c kWh per year		Confidential – but approx. 12 GWh/year total		
2.d Distance to coast		1km		

2.e. Cost cf. Onshore wind energy		Blyth £1000 / kW Typical UK onshore £800/kW		
2.e Special considerations physical parameters e.g. icing, high waves please specify		Depth (spring low) 5m Depth (spring high) 11m Max wave height 8m No icing 1km offshore existing Blyth Harbour wind farm		
2.f. Other				

Locations and configuration of all offshore wind farms planned in the UK is still to be determined.

3. Uncertainties in energy yield: Please specify national experiences and/or considerations concerning uncertainties in energy yield from *Offshore Wind Farms* in relation to the topics listed below:

Topic	**Importance** 1=low 2=medium 3=high	Main Conclusions	**References**	**Available (Y/N)**
3.a Mean wind speed	3	Extrapolated from experience on-shore in UK.		
3.b Availability	3	Ditto (mainly turbine, but also electrical system and grid availability)		
3.c Power curve	2	Ditto (including blade degradation and failure to maintain power curve up to cut-out wind speed)		
3.d Wake losses	2	Ditto		
3.e Access disruption	3	Turbine down but lost production not the risk of the O&M contractor so residing with the lender and owner.		

References:

I Troen and E L Petersen. Wind and wave conditions at 55 European coastal sea areas determined from weather and wave observations of voluntary commercial ships. Technical report, Germanischer Lloyd, Hamburg, November 1991.

Private correspondence between GH and Centre for Remote Sensing, University of Bristol, 12 October 2000.

H G Matthias, A D Garrad et all. Study of offshore wind energy in the European Community. Garrad Hassan and Partners, latest reprint 1999.

UK DTI. The Renewables Energy Obligation – preliminary consultation. October 2000. Additional DTI, Ofgem and ministerial statements October – December 2000.