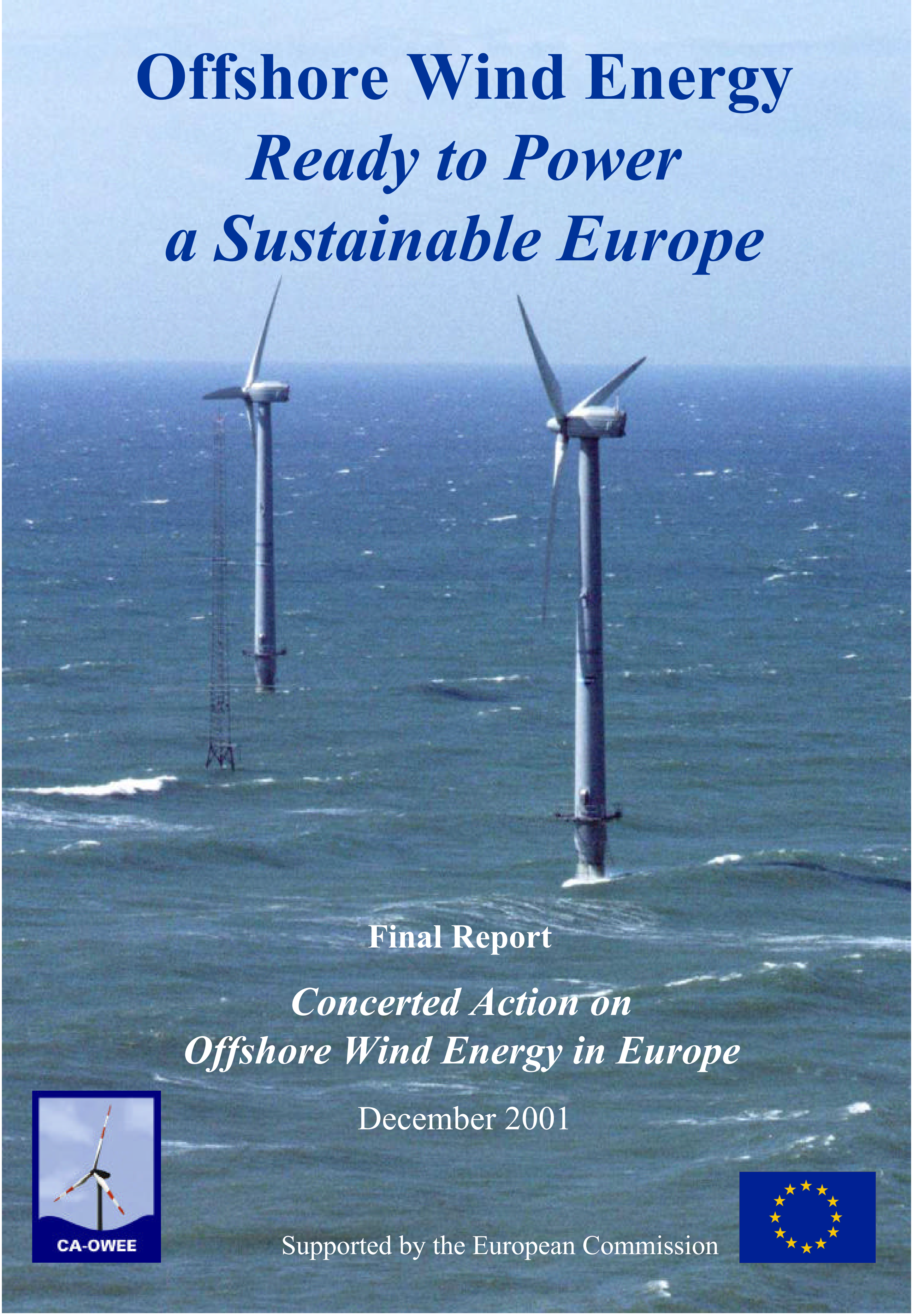
Offshore Wind Energy

Ready to Power a Sustainable Europe



Final Report

Concerted Action on Offshore Wind Energy in Europe

December 2001

CA-OWEE

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The contributions by all the members of the project are gratefully acknowledged; a list is given on page 1-3.

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SUMMARY

Chapter 1: Introduction

The objective of the project Concerted Action on Offshore Wind Energy in Europe [CA-OWEE] is to define the current state of the art of offshore wind energy in Europe through gathering and evaluation of information from across Europe and to disseminate the resulting knowledge to all interested, in order to help stimulate the development of the industry. The project is being funded by the European Commission and will be completed at the end of 2001. The knowledge gathered will be freely available through an internet site, a workshop and a printed report.

This project divides offshore wind energy into five clusters of subjects and reviews the recent history and summarise the current state of affairs, relating to:

Cluster 1 offshore technology, of the wind turbines and the support structures,
Cluster 2 grid integration, energy supply & financing,
Cluster 3 resources & economics,
Cluster 4 activities & prospects,
Cluster 5 social acceptance, environmental impact & politics.

The conclusions from these surveys are then used to define recommendations for the future RTD strategy for Europe.

The project's 17 partners come from 13 countries, thus covering the majority of the European Community's coastline. The partners cover a wide range of expertise and include developers, utilities, consultants, research institutes and universities.

Chapter 2: Offshore technology

The objective of this chapter is to analyse the current state of the art with regard to offshore wind turbine technology and to identify expected technology trends.

Wind turbine size: rotor diameter and power rating for offshore applications is continuously increasing. Commercial turbines are available in the diameter range 65 - 80 m and 1.5 - 2.5 MW. Prototypes are under development with respective values up to 120 m and up to 5 MW. It appears that the largest current machines (offered especially for offshore markets) exploit significantly higher tip speeds than onshore machines. An increase of between 10 % and 35 % is typical, resulting in tip speeds of up to 80 m/s. Increased tip speeds result in lower torque, less mass and thus reduced costs of tower top systems.

Costs: under conditions of true similarity in design style, state of technological progress and design specification, costs of large turbines might be expected to scale cubically with rotor diameter. Considering however historical data over the range of machine sizes, ongoing technology development results in a scaling closer to a square law than a cubic law. Price data of onshore machines show a gently rising cost/kW for rotor diameters of 40 m and greater. Although marinisation of onshore design generally adds 10% in costs, the currently available specific offshore machines are now essentially on lower cost curves than onshore predecessors.

Blade technology: the demand for high strength blades of low solidity in conjunction with diminishing carbon fibre costs may drive the industry in the direction of carbon epoxy. Carbon prices are falling and if it were used in significant quantities in blades for offshore machines, that could become by far the largest outlet for high quality carbon fibres, thus resulting in further cost reduction.

Gearbox: it is not clear whether the current gearbox concept (three stage units, input stage planetary, the two higher speed stages parallel with helical gears) will be applicable for larger, offshore turbines, since it is likely that for larger machines > 3MW an additional gearbox stage will be required, resulting in increased complexity and probability of failure. This may be an important driver towards direct drive systems.

Variable speed: there is a tendency towards variable-speed designs. Wide range variable speed has a further advantage in the ability to avoid damaging resonances, important for offshore turbine structures, where the resonant frequencies have proved difficult to predict accurately, and may also change over the lifetime of the structure. It remains somewhat unclear whether power electronic converters can be made reliable enough at suitable cost.

Support structure: the current design philosophy for wind farms in water depths up to 20 ~ 30 m is based on the monopile. The installation methodology (driving, drilling or combination) will depend on soil properties and water depth.

Operation and maintenance of offshore wind farms is much more difficult and expensive than for equivalent onshore wind farms. The current reliability and failure modes of commercial offshore wind turbines are such that a "no maintenance" strategy is not a viable option. Improved preventive and corrective maintenance schemes will become crucial for economic exploitation of offshore wind power. The paper explores the issues of preventive and corrective maintenance, dealing with all major aspects such as operational expenditure, serviceability and accessibility. In particular improving the accessibility is a key factor in increasing availability. A number of current projects are discussed which address the issue of improved access to offshore wind turbine installations: most focus on maintaining existing boat access methods with emphasis on addressing the issue of motion compensation or complete removal of the vessel from the water at the turbine location. Improvements made to the base of OWECS to facilitate safe personnel access include: fixed platforms, flexible gangways, friction posts against which the vessel maintains a forward thrust during transfer, vessel lifting facilities and winch / netting for personnel and equipment (eliminating the need for specialist lifting vessels for major component replacement).
The issue of availability should also be addressed through improvements in offshore wind turbine reliability. Unplanned maintenance levels can be reduced by increasing the reliability of the turbine. Particular emphasis is being placed on reliability issues from overall design improvements through to component level.
Designing for reduced maintenance could drive wind turbine designs away from current onshore standards, such as towards two bladed configurations, direct drive technology or application of electrical actuators.
Electrical systems: There are many areas where technical developments in electrical systems are expected which will improve the economics and reliability of offshore wind farms. Some of these will arrive because of developments in other industries and in onshore wind, but others are specific to offshore wind and are therefore more risky. Developments will take place within the wind turbine (such as ABB's Windformer's concept) and with the wind farm electrical systems, regarding set-up of substations, use of HVDC technology and cable technology

Chapter 3: Grid integration
The objective of chapter 3 is to analyse the current state of the art in grid integration of offshore wind farm. Grid integration issues are discussed against the EU target of 10.000 MWe of large wind farms.
In principle, large-scale offshore wind power results potentially in increased unbalance between production and consumption. Cross-border power transmission limitations prevent a geographical smoothing of the production/consumption imbalance. Solutions to deal with this unbalance discussed in the paper are: Demand Side Management, increased flexibility and dispatching capability of conventional plants, the use of energy storage, application of wind power forecasting techniques and increasing the controllability of wind farm output. It is concluded that, although all options could eventually contribute to the solution (requiring much more RTD), the most promising immediate step is to increase the accuracy and reliability of wind power forecasting techniques.
The impact of large-scale offshore wind power on power systems performance (power quality) requires special attention since coastal connection points will often be relatively weak. Flicker, harmonics and interharmonics and static stability are not considered as limiting factors but dynamic grid stability may be a limiting factor, in particular in relation to wind farm correlated sudden shut-down of wind turbines. These problems may eventually lead to modifications in wind turbine control philosophies at high wind speeds.

Large scale offshore wind power will further impose an increase of primary control (response time of the order of seconds)) and secondary control (response time of the order of minutes) requirements of the conventional production components of the system; such requirements could also be imposed on large wind farms, although it remains unclear how such requirements could be efficiently implemented.

The connection technology between offshore wind farms and the grid is characterised by large power (> 100 MW) and potential large distances. The paper addresses the potential advantages of using HVDC links, which could also contribute to power quality management problems mentioned above.
Access of large offshore wind farms to the grid must be in accordance with national grid codes. Current requirements imposed by national grid codes are in general not considered to be a limiting factor for the development of large-scale offshore wind power, although these requirements are not particularly suitable for non-predictable, highly variable energy sources. Project developers may have to take additional measures to comply with the grid codes, such as: use of variable speed wind turbines, special purpose remote control systems (with individual power set points for the wind turbines, etc). In the long term, HVDC transmission and/or on-site large storage facilities with controllable reactive power output, might present interesting opportunities allowing large scale offshore wind power plants to meet grid access requirements more easily.

Chapter 4: Offshore wind power potential

The objective of chapter 4 is to review of offshore resource modelling techniques and to discuss estimates regarding the offshore wind potential in Europe.

Wind resource studies for EU offshore regions are based on monitoring data and modelling techniques. The issue of offshore wind resources is complicated by a number of factors. Low roughness gives low turbulence and wind shear but thermal effects are important, particularly in coastal regions: wind speed profiles deviate from logarithmic and thermal flows are generated, such as sea breezes and low level jets. The paper discusses both offshore wind monitoring and state of the art modelling techniques. A major conclusion is that while current-modelling techniques can provide good representation of general resources, specific site resource estimation still requires on-site measurements.

The offshore wind potential is derived from the wind resource in combination with a number of local constraints, such as technology limits (such as water depth), economy, ecology and conflicts of interest with other users. The resulting wind potential is thus a function of constraints considered, the assumptions applied and the level of detail. In the paper, available studies of the offshore wind power potential in the EU are collected, analysed and discussed in the context of the above. Unfortunately, most studies have been performed on a national basis and a specific set of assumptions and can not easily be combined for the EU total. Notwithstanding this difficulty, the paper develops an overall estimate, which comes at 140 GW, which is well in excess of the EU White paper target of 10 GW in 2010.

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.

Chapter 5: Market developments
The objective of this chapter is to describe market developments in the energy industry, which are relevant for the development of offshore wind power. In a number of EU countries (such as Belgium, Denmark) minimum shares of renewable energy are required, either for utilities to sell, or consumers to buy. In other countries (Ireland, The Netherlands) green certificate markets have been established. Both systems are expected to support the demand for renewable energy in general and experience has to show which system has the strongest impact on RES development.

Chapter 6: Economics and financing
The objective of this chapter is to give a review of state of the art and trends regarding offshore wind farm economics and financing.

Economics: Offshore projects require initially higher investments than onshore due to turbine support structures and grid connection. The cost of grid connection to the shore is typically around 25% 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. Investment costs have been reduced from about 2200 € /kW for the first Danish offshore wind farms to an estimated cost of 1650 € /kW for Horns Rev (giving an estimated cost of 4.9 € cents /kWh). This compares with typical figures for onshore sites of investment 700-1000 € /kW and estimated energy cost of 3-8 € cents/kWh for a mean wind speed of 5-10 m/s.
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. Operation and maintenance charges are variable according to site but a rough estimate is 30 € /kW with 0.5 € cents/kWh variable.
A tentative conclusion is drawn that for good sites (not too deep water, benign wave climate, not too distant from shore, high enough resource) large offshore wind farms could in the near future generate electricity at costs, which allow for commercial exploitation. The paper gives an estimated range of production costs in €cents/kWh.
Whether offshore wind power could be commercially viable depends on whether sufficient project income can be generated. This depends on whether the energy produced can be sold on the (than) fully liberalised market at a reasonable rate and how the environmental benefit is valued. The paper discusses a number of factors (such as use of forecasting techniques), which are of influence on energy sales in a liberalised market. It is concluded that severe risks exist associated with market liberalisation where the environmental benefits are not adequately valued, which may jeopardise development at some sites. Despite the average cost of offshore wind energy being competitive with many traditional energy sources, projects may not be viable. 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.

Financing: From the current developments of demonstration offshore projects of various sizes, it would appear that sufficient equity capital is available for financing offshore wind farm projects. Some major oil & gas companies and utilities have announced projects, which could be financed by company equity. However it still remains to be determined under which conditions (due diligence, certification, insurance etc) bank loans will be granted for offshore wind farm projects. Only test and demonstration projects will provide information to allow an answer to this question. At least they will reduce the present uncertainties related to the cost of energy generated.
Important support comes from a variety of national incentive mechanisms, such as investment subsidies, tax exemptions, fixed tariffs and green certificate schemes.

Chapter 7: Environment, conflicts of interest and planning
The objective of this chapter is to analyse the current state of the art concerning offshore wind farms in relation to the following subjects:
- environmental impacts
- social acceptance

- conflicts of interest
- national planning rules throughout the EU

The chapter reviews the knowledge regarding environmental impacts of offshore wind farms, especially in relation to birds and the visual impact. The main conclusion is that although there are no strong indications of severe environmental effects, there is yet very little real experience. This uncertainty and lack of actual experience threatens to develop into a limiting factor delaying licensing procedures for offshore wind farms.

Public attitudes are in general positive but may turn negative with actual projects. This is based on two different issues:

- the perceived potential of ecological damage, in particular in relation to birds
- the perceived visual and noise impact, in particular in relation to the recreational use and value of the adjacent coast.

Suitable strategies to manage this problem are discussed.

The main other conflicts of interest in developing offshore wind farms are with radar systems and marine traffic. Careful planning should resolve this conflict, as especially the potential effects on radar systems may become a barrier for future development of offshore wind energy projects. Regarding marine traffic, improved and suitable ship collision risk and damage consequence models should become available.

Since in most countries the political attitude towards offshore wind power is positive, national planning and regulation rules are being adapted for licensing offshore wind farms, both in and outside the 12 mi zones. Examples are given presenting legislation adaptation to promote offshore wind energy in different EU countries.

Chapter 8: Social aspects

Chapter 8 deals with employment prospects and industry benefits of the development of large scale offshore wind power.

The direct employment effects of offshore wind power are estimated as 4,5 ft jobs/MW. European industry could greatly benefit from taking the lead in offshore wind farm development and construction.

Chapter 9: Activities, projects and plans

The objective of this chapter is to give a comprehensive review of ongoing and planned activities in the European Union regarding RTD, projects and national plans on offshore wind energy.

It brings together current work from each of the EU member countries to help identify future strategies for adoption by the European Offshore Wind Industry.

The chapter addresses recent and current research activities in offshore wind energy. A very large number of national and international R&D projects on offshore wind energy have been undertaken over the last decades, the more recent and more relevant for today are each briefly described. These are divided into groups, approximately relating to:

- Resource assessment,
- Wind turbines (including support structures)
- Wind farm
- Installation
- O&M
- Integrated methodologies
- Environment and planning aspects

Conclusions are drawn regarding the main topics currently being studied.

Chapter 9 further summarises the various national plans that have been put forward by countries across Europe.

Chapter 10: RTD recommendations

The objective of this chapter is to identify RTD requirements and to develop recommendations for an RTD strategy for development of offshore wind energy.

Based on the information collated as part of the Concerted Action, the project team has attempted to identify the key problem areas, which affect the future development of offshore wind energy

Particular issues, which have been addressed when drawing up the recommendations for an appropriate RTD strategy, include the following:

- Offshore technology with consideration of RTD requirements relating to wind turbine design, support structure and foundation design, installation and de-commissioning, O&M and reliability, electrical transmission and grid reliability;
- Grid integration and energy supply;
- Resource and economics;
- Recent and current activities and prospects;
- Social, political and environmental aspects.

Recommendations have been formulated for a programme of RTD, which is aimed at providing solutions to these problems.

The overall aim of the work has been to provide directives on the research requirements for offshore wind energy applications within the next five years. This chapter will present those directives and invite feedback from wind turbine manufacturers, project developers, financiers, government authorities, politicians and other interested parties.

CONTENTS [1]

[1] Detailed list of contents is provided at the beginning of each Chapter; page numbering combines chapter number and page number within chapter.

CHAPTER 1

INTRODUCTION

SUMMARY

After several decades of theoretical developments, desk studies, experimental wind turbines and prototype wind farms, the first large-scale commercial developments of offshore wind farms are now being built. To support and accelerate this development, the European Commission is funding a project, 'Concerted Action on Offshore Wind Energy in Europe' (CA-OWEE), which aims to gather and distribute knowledge on all aspects of offshore wind energy, including: offshore technology, electrical integration, economics, environmental impacts and political aspects. The partners are from a wide range of fields and include developers, utilities, consultants, research institutes and universities.

Based on the information collated as part of the Concerted Action, the project team has attempted to identify the key problem areas which affect the future development of offshore wind energy. These problem areas include technology development, integration in the energy supply system, economics, public acceptance, environmental impact and the relation between onshore and offshore wind energy. Building on this work, recommendations have been formulated for a Research and Technological Development (RTD) strategy which is aimed at providing solutions to these problems.

Information will be freely disseminated through a web site, www.offshorewindenergy.org, printed reports, and via the EWEA Special Topic Conference on Offshore Wind Energy in Brussels on December 10^{th} - 12^{th} this year (2001).

CONTENTS OF CHAPTER 1 : INTRODUCTION

1 INTRODUCTION

1.1 OFFSHORE WIND ENERGY

Offshore wind farms promise to become an important source of energy in the near future: it is expected that within 10 years, wind parks with a total capacity of thousands of megawatts will be installed in European seas. This will be equivalent to several large traditional coal-fired power stations. Plans are currently advancing for such wind parks in Swedish, Danish, German, Dutch, Belgian, British and Irish waters.

Onshore wind energy has grown enormously over the last decade to the point where it generates more than 10% of all electricity in certain regions (such as Denmark, Schleswig-Holstein in Germany and Gotland in Sweden). However, this expansion has not been without problems and the resistance to windfarm developments experienced in Britain since the mid 1990s, is now present in other countries to a lesser extent. One solution, of avoiding land-use disputes and to reduce the noise and visual pollution, is to move the developments offshore, which also has a number of other advantages:

- availability of large continuous areas, suitable for major projects,
- higher wind speeds, which generally increase with distance from the shore (Britain is an exception to this as the speed-up factor over hills means that the best wind resources are where the turbines are also most visible),
- less turbulence, which allows the turbines to harvest the energy more effectively and reduces the fatigue loads on the turbine,
- lower wind-shear (i.e. the boundary layer of slower moving wind close to the surface is thinner), thus allowing the use of shorter towers.

But against this is the single very important disadvantage of capital cost:

- there will be additional cost due to the more expensive marine foundations,
- more expensive integration in to the electrical network and in some cases an increase in the capacity of weak coastal grids,
- more expensive installation procedures and restricted access during construction due to weather conditions,
- limited access for O & M during operation which results in an additional penalty of reduced turbine availability and hence reduced output.

However the cost of wind turbines is falling and is expected to continue doing so over the coming decade and once more experience has been gained in building offshore projects, the offshore construction industry is likely to find similar cost-savings. Onshore wind energy is an increasingly cost-competitive resource at a stable price compared to conventional power generation, especially when environmental benefits are accounted for. Hence it would seem likely that offshore wind energy will also become competitive in time.

1.2 EUROPEAN DIMENSION AND EU POLICIES

The total wind power resources available offshore are vast and will certainly be able to supply a significant proportion of our electricity needs in an economic manner. Earlier studies concluded that a large proportion of Europe's power could be supplied from offshore wind turbines

The EU White Paper on Renewables aims at doubling the share of renewable energy by the year 2010 with a target of 40.000 MW wind power, of which 10.000 MW with "large wind farms" and thus a significant share of offshore wind power.

The EU have pursued this target through a number of actions and in particular support of RTD activities. Examples of relevant EU funded projects are the "Study of Offshore Wind Energy in the EC"(1990-1993), "Measurements and Modelling of Offshore Wind Farms" (1994-1996), the Opti OWECS project (1996–1998), "Design methods for Offshore Wind Turbines at Exposed Sites" (1999-2002) and the "Efficient development of offshore wind farms" (2000 – 2003) project.
EU funding was in addition also given to actual offshore wind farm development, starting with protected inland sites (Lely 1992), proceeding step by step to more exposed sites such as: Vindeby (1992), Fjellerup Flak, Blyth Harbour Offshore (2000) and Scroby Sands.

Over the last decade, a clear development is take place from relatively small projects at protected sites to preparation of real large scale offshore wind farms at very exposed sites.

To support this development, the European Commission is funding a project, 'Concerted Action on Offshore Wind Energy in Europe' (CA-OWEE), which aims to gather and distribute knowledge on all aspects of offshore wind energy.

1.3 CONCERTED ACTION ON OFFSHORE WIND ENERGY IN EUROPE

The objectives of the project *Concerted Action on Offshore Wind Energy in Europe* [CA-OWEE] are to define the current state of the art of offshore wind energy in Europe through gathering and evaluation of information from across Europe and to disseminate the resulting knowledge to all interested, in order to help stimulate the development of the industry. The two year project started in early 1999 and will be completed at the end of this year (2001). The knowledge gathered will be freely available through an internet site, www.offshorewindenergy.org, a printed report, and via the EWEA Special Topic Conference on Offshore Wind Energy in Brussels on December 10^{th} - 12^{th} 2000.

This project divides offshore wind energy into five clusters of subjects and reviews the recent history and summarise the current state of affairs, relating to:

- offshore technology, of the wind turbines and the support structures,
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- resources and economics,
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The conclusions from these surveys are then used to develop recommendations for the future RTD strategy for Europe.

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- Risø National Laboratory, Denmark
- Tractebel Energy Engineering, Belgium
- CIEMAT, Spain
- CRES, Greece
- Deutsches Windenergie-Institut (DEWI), Germany
- Germanischer Lloyd, Germany
- ECN, The Netherlands
- Espace Eolien Developpement (EED), France
- ENEA, Italy
- University College Cork, Ireland
- Vindkompaniet i Hemse AB, Sweden
- VTT, Finland
- Baltic Energy Conservation Agency (BAPE), Poland

1.4 STRUCTURE OF THE REPORT

The various subjects of interest, which were for operational reasons clustered in the five clusters mentioned in Chapter 1.3 above have been rearranged into the following 8 main chapters of this report

chapter 2:	Offshore technology
chapter 3:	Grid integration
chapter 4:	Offshore wind power potential
chapter 5:	Market development
chapter 6:	Economics and financing
chapter 7:	Environment, conflicts of interest and planning
chapter 8:	Social aspects
chapter 9:	Activities, projects and plans

The RTD recommendations are given in chapter 10. Each chapter is preceded with a summary and a detailed list of contents. References are collected per chapter and numbered as they appear in the text.

As a result of the rearranging of subjects over the chapters, the authorships and responsibilities of Clusters are not similar to those of the chapters used in this Report. Appendix 1 gives details on the CA-OWEE project and relevant authorships and responsibilities. In addition, Appendix 1 lists other references resulting from the project

The information gathering and evaluation process within the CA-OWEE project was partly based on national questionnaires. The responses from the participating countries are reproduced in Appendix 2.

Appendix 3 collects general bibliography on offshore wind energy.

1.5 ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions made by all partners in the CA-OWEE project to this report.

The project *Concerted Action on Offshore Wind Energy in Europe* [CA-OWEE] was funded by the European Commission under contract number NNE5-1999-00562.

CHAPTER 2

OFFSHORE TECHNOLOGY

SUMMARY

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aspects such as operational expenditure, serviceability and accessibility. In particular improving the accessibility is a key factor in increasing availability. A number of current projects are discussed which address the issue of improved access to offshore wind turbine installations: most focus on maintaining existing boat access methods with emphasis on addressing the issue of motion compensation or complete removal of the vessel from the water at the turbine location. Improvements made to the base of OWECS to facilitate safe personnel access include: fixed platforms, flexible gangways, friction posts against which the vessel maintains a forward thrust during transfer, vessel lifting facilities and winch / netting for personnel and equipment (eliminating the need for specialist lifting vessels for major component replacement).

The issue of availability should also be addressed through improvements in offshore wind turbine reliability. Unplanned maintenance levels can be reduced by increasing the reliability of the turbine. Particular emphasis is being placed on reliability issues from overall design improvements through to component level. Design for reduced maintenance might imply:

- Reduction in overall number of components and simplicity of design
- Modular design approach which facilitates the replacement of faulty modules
- Use of high reliability integrated components
- Re-siting of electrical units into an environmentally controlled section of the turbine
- Implementation of offshore corrosion protection technology
- Development of effective conditioning monitoring and remote control systems

Designing for reduced maintenance could drive wind turbine designs away from current onshore standards, such as towards two bladed configurations, direct drive technology or application of electrical actuators.

Electrical systems: There are many areas where technical developments in electrical systems are expected which will improve the economics and reliability of offshore wind farms. Some of these will arrive because of developments in other industries and in onshore wind, but others are specific to offshore wind and are therefore more risky. Developments will take place within the wind turbine (such as ABB's Windformer's concept) and with the wind farm electrical systems, regarding set-up of substantions, use of HVDC technology and cable technology

CONTENTS OF CHAPTER 2 : OFFSHORE TECHNOLOGY

2.1 INTRODUCTION

The OWEE project aims to *"define the maturity of the technology currently available for offshore wind farms"*.

This aim is to be achieved through collation and interpretation of relevant information in relation to the following key technological issues (a "state-of-the-art" summary):

- Size and configuration of wind turbines suitable for offshore installations
- Support structure design
- Installation, decommissioning and dismantling
- Operation and maintenance (O&M), reliability
- Electrical transmission and grid connection

Appendix 1 lists the companies who were involved in the work for preparing this chapter. Unlike the approach for the other chapters, it was decided that a trans-national approach rather than a country-by-country survey was more appropriate in view of the nature of the subject matter.

The task leader circulated a list of contents for the "state-of-the-art" summary in each of the above technical areas, with comments elaborating requirements, to form the basis of a draft report by the responsible party. The resultant reports have been collated and edited as input to Sections 2 to 7, below. The Contents List has been placed on the CA-OWEE website and some other members have also made contributions which have been used in assembling this chapter.

2.2 SIZE AND CONFIGURATION

2.2.1 Scaling Trends

2.2.1.1 Scaling laws

Considering all designs upwards of 30 kW (and not exclusively the largest which are demanded for offshore projects), there are approximately 75 commercially marketed wind turbine designs. This number counts as distinct designs of different scale and type of a particular manufacturer but excludes minor variations like the same having the same tower top system on alternative towers (higher or lower, steel or concrete, tubular or lattice type etc.)

Scaling trends need to be interpreted with great care. Data indiscriminately lumped together may suggest spurious trends or at least provide only superficial descriptions rather than insight into basic issues like the inherent specific costs (cost per kW or cost per kWh) trend with up-scaling. Some of the main issues are:

- ***Geometric similarity*** – with strict geometric similarity, volume, mass and cost of items will tend to scale as the cube of any characteristic dimension. Very small turbines (say < 30 kW output power rating) are generally too dissimilar to the larger turbines for valid interpretation of inherent scaling rules if all sizes are grouped together.

- ***Parametric similarity*** – designs basically similar in concept (e.g. 3 bladed, pitch regulated with glass epoxy blades and tubular tower) may have significantly different choice of key parameters. Tip speed is a key parameter that very directly influences the tower top mass and cost of a wind turbine. Different ratios of power rating or tower height to diameter will also clearly influence mass and cost. These influences can sometimes be effectively considered by normalisation processes allowing more data sets to be grouped together.

- ***Duty similarity*** – machine designs, mass and cost are influenced by the class of design site, i.e. the severity of the design wind conditions.

- ***Stage of development*** – the latest and largest wind turbines are at the most advanced state of knowledge of the manufacturers with ever increasing emphasis on cost and mass reduction inducing minor and sometimes more major innovations in the design. This can obscure intrinsic scaling trends that would apply if all sizes were at the same stage of technical maturity.

Needless to say there are also many other factors which complicate scaling comparisons like manufacturers prejudices for electric or hydraulic systems, for simple heavy structures or more lightweight optimised structures and more flexible blades etc. Finally in moving beyond technical issues to costs – and the main motive in addressing the technicalities of scaling is to get insight into how they will influence costs of large offshore wind turbines – a large number of non-technical factors are added (exchange rates, labour cost variations globally, marketing ploys, etc.)

It is not intended or appropriate to produce an extended technical discussion on wind turbine scaling issues which has been much addressed in the literature, but it is necessary to update information especially when this project is focused on offshore and the most relevant information is from the very latest machines. The foregoing preamble has therefore been offered as a health warning regarding scaling data presented herein and elsewhere.

2.1.1.2 Summary review of large turbines

In order to get a snapshot of the current maturity of wind technology especially as it affects large offshore wind turbines, summary information has been extracted (excepting Table 2.1) from [6] and from [7]. It represents in part an up-date of material provided [8] to the document [3].

Diameter
The upward trend in machine diameter is well illustrated by examination of the activities of rotor blade suppliers (Table 2.1).

Table 2.1 Large rotor blades

	Blade manufacturer	Largest blade size
1	Abeking & Rasmussen Rotec	Largest blade 40m for MBB, Aeolus II wind turbine.
2	Aerpac (recently purchased by Enron)	Size range up to 48 m
3	Borsig Rotor	39 m blade for Nordex 2.5 MW is the next prototype.
4	LM Glasfiber	Up to 38.8 m available– larger blades planned.
5	NEG Micon Aerolaminates	50 m blade about to be made and tested.
6	NOI Rotortechnick GmbH	Currently working on 39 m blades with 55 m blade for a 5 MW turbine planned this year.
7	Polymarin-Bolwell Composites	Latest blades up to 37 m length.
8	TECSIS	Currently supplying 34 m blades.

In addition to those companies specifically manufacturing rotor blades, companies like Enercon and Vestas who manufacture their own blades are clearly interested in large offshore machines and wind turbine systems with rotors up to 120 m diameter for 5 MW rating and perhaps as high as 140 m for 6 MW rating are under consideration.

Power rating

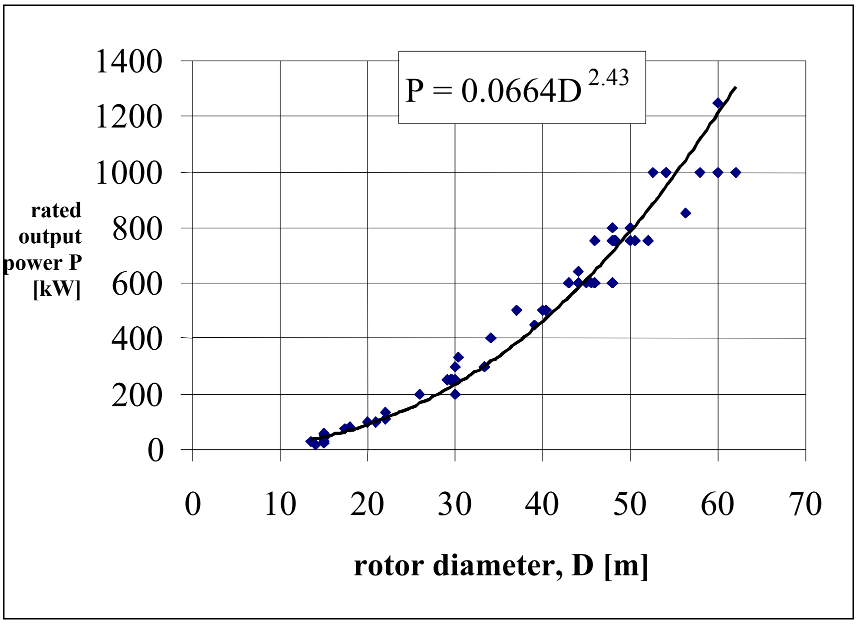


Figure 2.1 Power rating of wind turbines up to 62 m diameter

The power rating of wind turbines has typically been based on the assumption of a wind shear typical of European land based sites with a 1/7 power law applying to variation of wind speed with height above ground. This implies a rotor power variation as diameter to the power (2 + 3/7) i.e. 2.43, and it can be seen (Figure 2.1) that for a wide range of land based turbines up to 62 m rotor diameter there is an exponent of 2.4 in reasonable conformity with this.

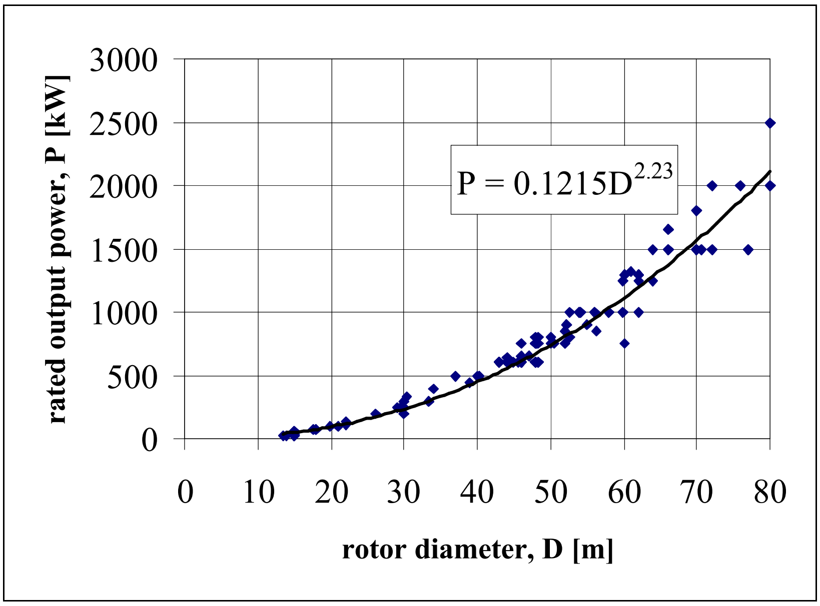


Figure 2.2 Power rating of wind turbines

It is apparent, however, (Figure 2.2) with the largest offshore wind turbines included, that the exponent in the rating trend has reduced. This is logical since there is reduced wind shear on offshore sites and certainly the 80 m turbines are targeted for such sites. It is also the case that unnecessarily high towers offshore will only exacerbate the problem of larger machines having low fundamental frequencies approaching the peak in the wave spectrum.

Tip speed

The tip speed of wind turbines is relatively constant (Figure 2.3) being limited on European land based sites primarily by acoustic noise.

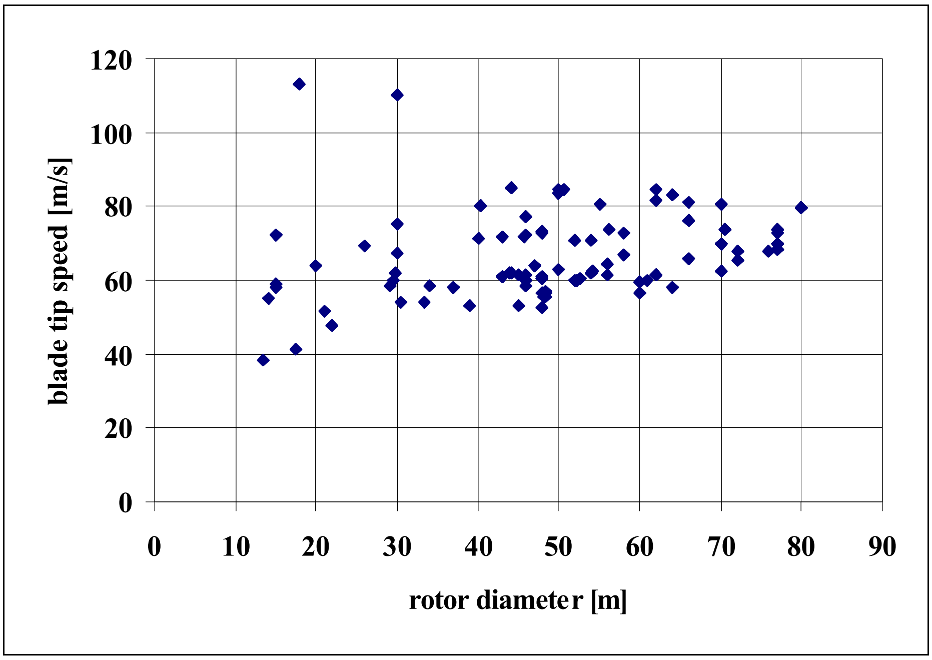


Figure 2.3 Design tip speed (maximum steady state)

Most machines of the leading manufacturers have tip speed lower than 70 m/s although a few machines, not generally market leaders, adopt high tip speeds above 100 m/s. Apart from acoustic considerations, a higher tip speed is advantageous, implying lower torque for a given power rating and lighter and cheaper tower top systems.

Table 2.2 Trends in tip speed comparing offshore and land based turbines

Design	Power [kW]	Control concept	Tip speed [m/s]	Ratio (offshore/land)
Vestas V66 (land)	1650	Pitch reg., variable slip	66	1.21
Vestas V80 (offshore)	2000	Pitch reg., variable speed	80	
Nordex N60	1300	Stall reg., fixed speed	60	1.33
Nordex N80 (offshore)	2000	Pitch reg., variable speed	80	
Bonus 1300 (land)	1300	Active stall, fixed speed	62	1.10
Bonus 2000 (offshore)	2000	Active stall, fixed speed	68	
NEG Micon 1000/60 (land)	1000	Stall reg., fixed speed	57	1.19
NEG Micon 2000/72 (offshore)	2000	Active stall, fixed speed	68	

The largest machines that are exclusively directed at the offshore market (Table 2.2) exploit significantly higher tip speed. Acoustic noise is probably much less of an issue for offshore projects. Table 2.2 indicates that, specifically in the offshore context, increase in design tip speed between 10% and 35% has already occurred. It is likely that this trend of rising tip speed for offshore designs will continue especially to reduce top weight and cost of machines in the 5 MW range.

Hub height

For land based wind turbines, hub height rises in proportion to diameter (Figure 2.4) with the caveat that, at any given diameter, there will often be a wide range of alternative tower heights available to suit the demands of specific sites.

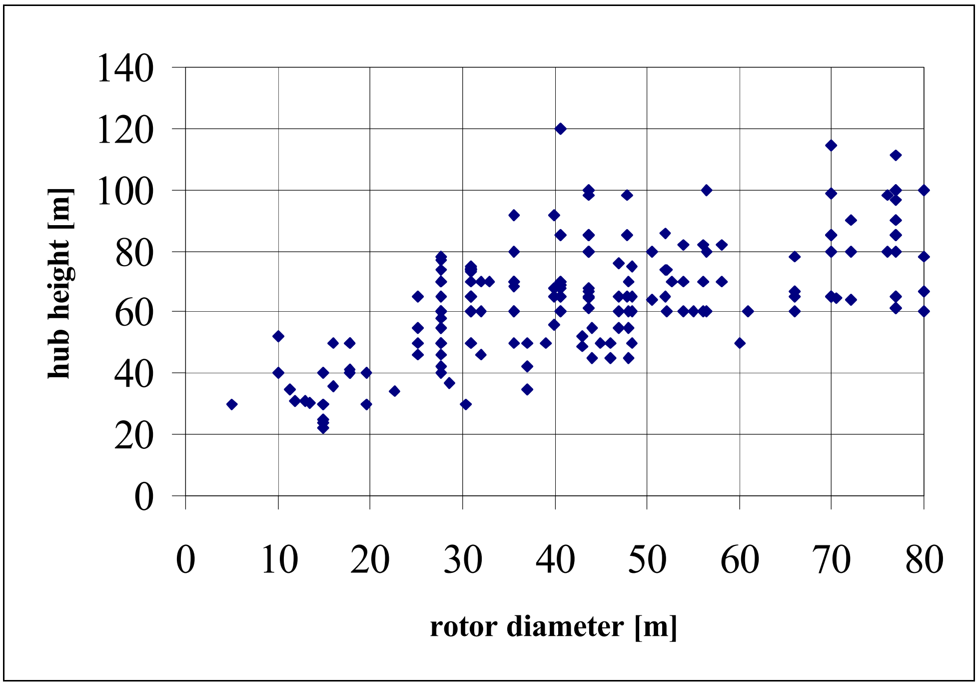


Figure 2.4 Hub height variation of wind turbines

The data (Figure 2.4) shows a levelling in the increase of hub height with diameter at the largest sizes. It is suggested that for best economics, offshore wind turbines in an environment with reduced wind shear will have hub heights that are minimal for safe clearance of the blade tips from extreme waves.

Safety and control
Pitch control (with independent actuators on each blade) in combination with variable speed predominates among the largest wind turbine designs. Of 16 distinct machine designs on or over 70 m diameter 14 adopt this configuration. The two exceptions are the designs of NEG Micon and Bonus which use stall regulation with dual speed operation.

Less than 10% of designs over the whole size range from 30 kW upwards are fixed speed. Many different options are exploited in order to achieve some degree of speed variation – dual speed with pole switching, high slip as with Vestas Optislip, doubly fed induction generators giving moderate range of variable speed and direct drive systems with wide range variable speed.

Over the whole size range there are still roughly equal numbers of pitch regulated and stall regulated designs but, as has been mentioned, pitch regulation dominates among the largest wind turbine designs.

2.2.1.3 Size and mass trends in offshore context

Onshore commercial, grid connected, wind turbines are today generally supplied in the rotor diameter range 45-80 m (rated power, 600-2500 kW). Semi-offshore wind turbines from 1990 up to now have been in the rotor diameter range of 30-45 m (rated power 220-600 kW).

Commercial offshore wind turbines, up-scaled from the onshore turbines, are today made by 10 manufacturers, in the rotor diameter size range of 65-80 m (rated power 1500-2500 kW). New offshore turbine prototypes are under design with rotor diameters up to 120 m. It remains to be seen however where the technical and economic barriers to further up-scaling exist, i.e. rotor diameters greater than 120m.

Offshore designs which exploit higher tip speeds than land based machines of similar diameter or rating should become less rather than more expensive even accounting for marinisation.

In Fig 2.5 the power ratings of onshore wind turbines, installed in Germany [7], are reported against year of installation (dots). For comparison in the same time scale, the power rating of existing turbines is shown (squares) for semi-offshore conditions up to 1998, while afterward the applications are real offshore. The much increased rating of the offshore designs is very evident.

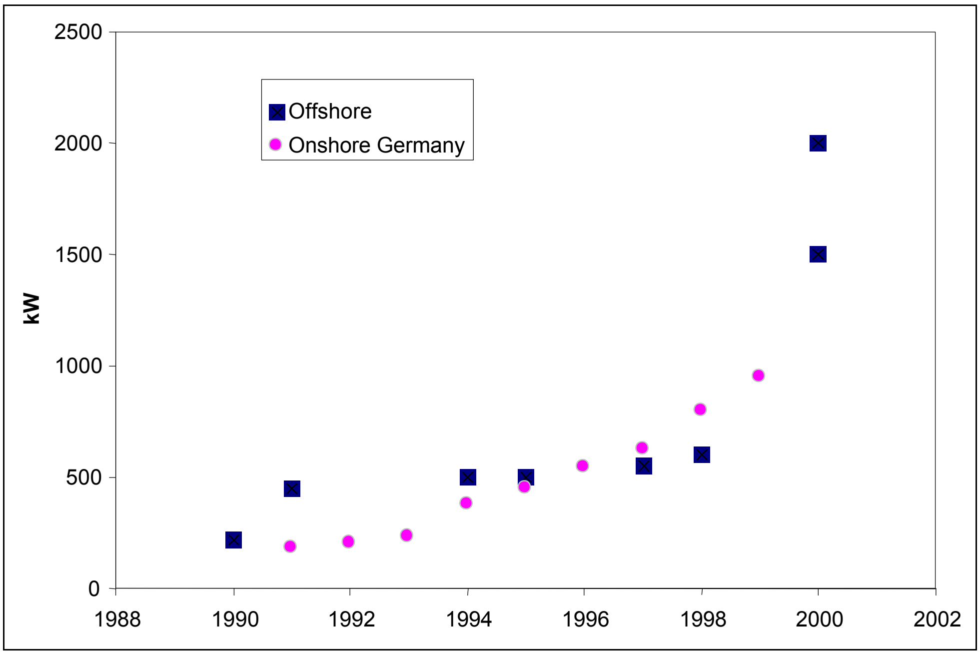


Figure 2.5 Rating trends in land based and offshore wind turbines

Fig 2.6 compares current commercial offshore turbines, derived by up-scaling and marinisation of onshore ones, with new prototypes most of which are still in the design phase. A further large increase in turbine size is evident with the new offshore models.

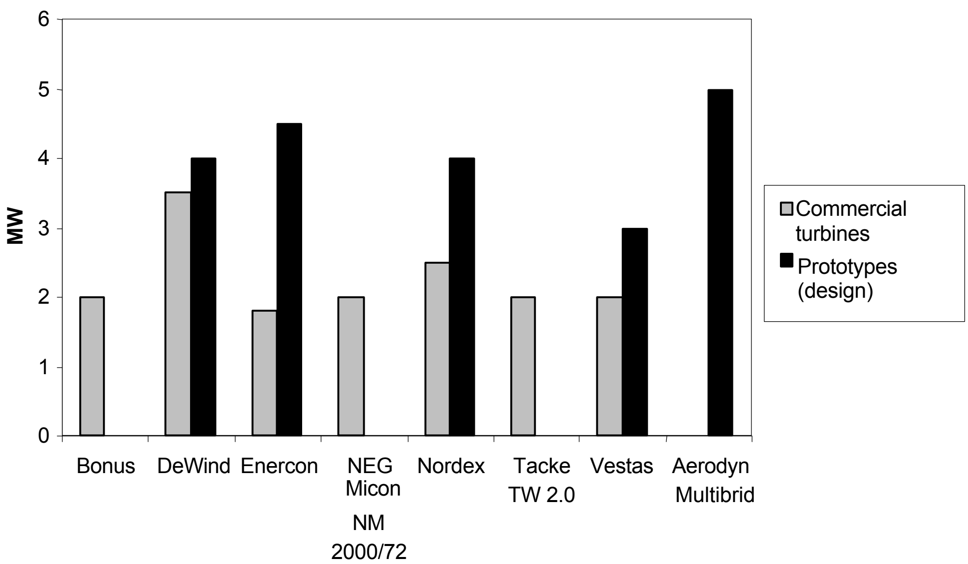


Figure 2.6 Commercial offshore turbines and forthcoming prototypes

Figure 2.7 shows substantial technology progress in reducing blade weight and cost. This inference comes from the trend line exponent being 2.3 rather than 3 as would apply from simple scaling rules relating design bending moment and structural material demands to rotor diameter. Higher tip speed of offshore turbines will result in relatively lighter rotors.

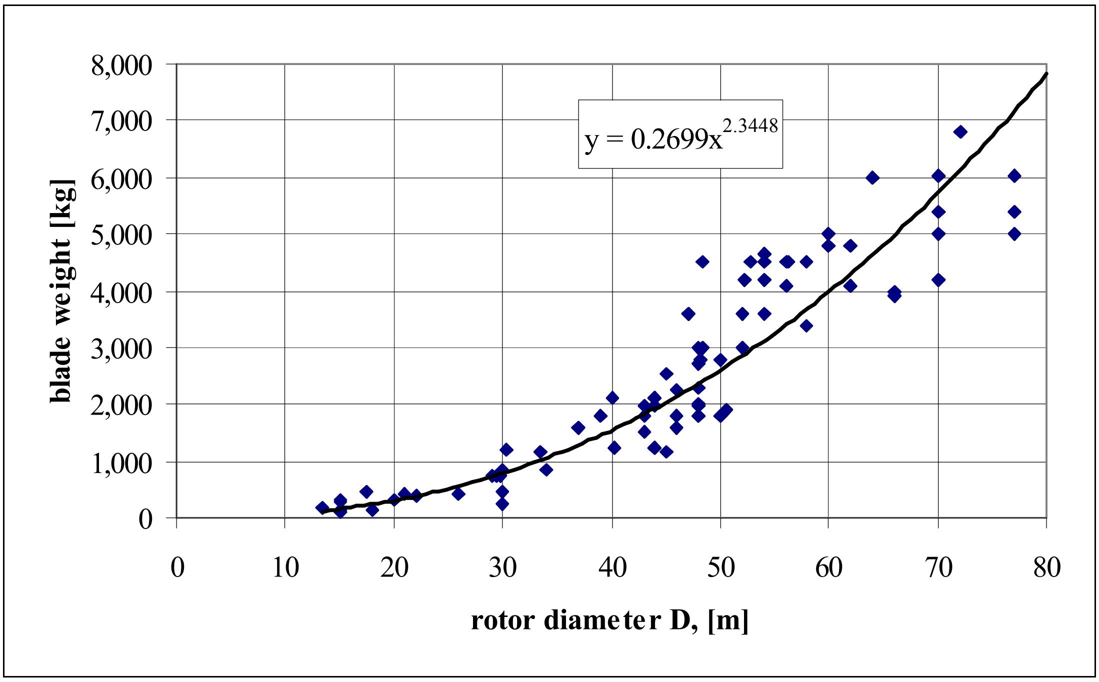


Figure 2.7 Blade mass related to rotor diameter

In Figure 2.8, the nacelle mass appears to increase as about square of diameter rather than diameter cubed as might be expected from a torque related component. This again reflects substantial ongoing technology progress and the trends already mentioned towards higher tip speed for the largest offshore wind turbines. It should however be noted that the data of Figure 2.8 includes both direct drive and gearbox based drive trains. Extrapolation of nacelle mass to large scale offshore wind turbines should treated with some caution.

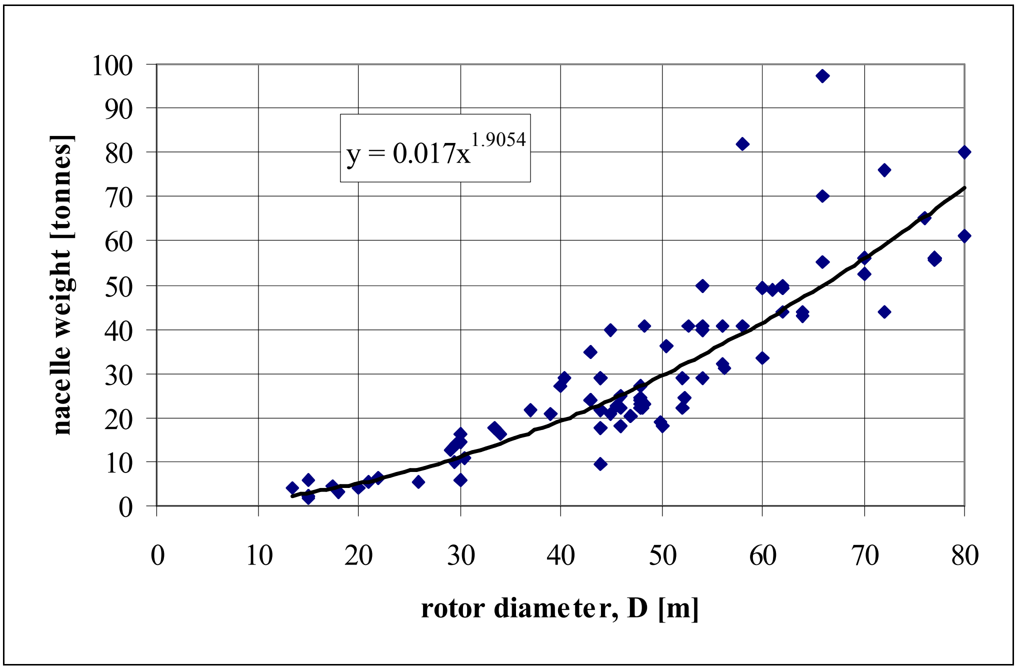


Figure 2.8 Nacelle mass v rotor diameter

In Fig 2.9, the ratio of blade mass to swept area is only slowly increasing whereas a linear increase would be expected from a mass or volume to area ratio. This is essentially an alternative presentation of the trend in Figure 2.7. The results depend on the blade number (almost always 3) and material used, generally glass composite. Lower specific rotor weights are expected from carbon fibre blades (especially in the context of increased tip speed of offshore machines) and two bladed turbines. The dispersion of data about the best-fit value is considerable but decreasing for the large size turbines, where design is better optimised.

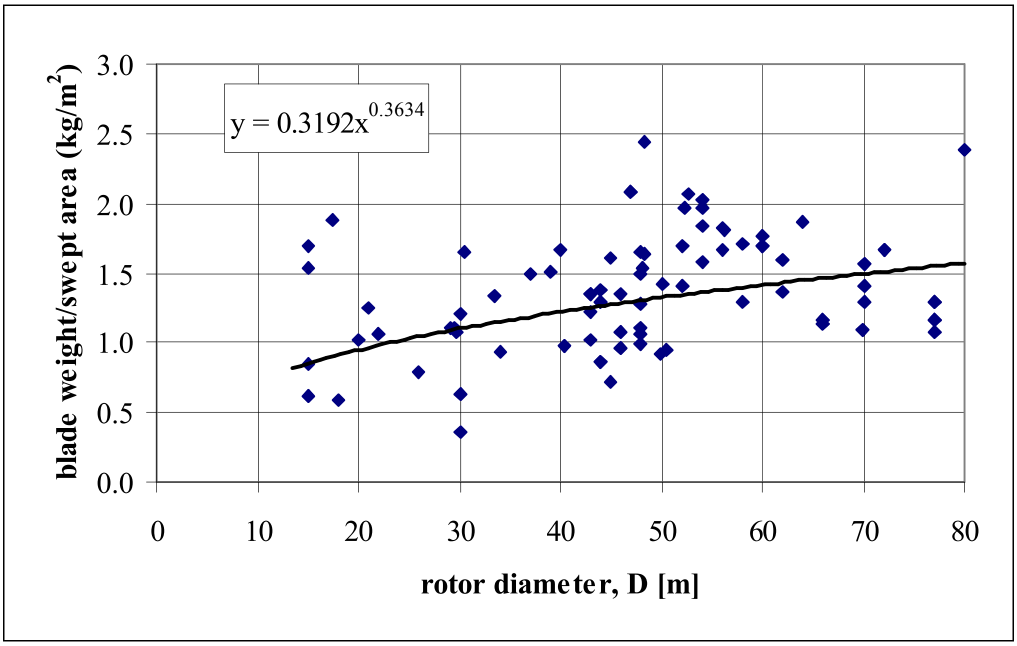


Figure 2.9 Rotor mass/ swept area ratio

In Fig 2.10, the hub height to rotor diameter ratio, for onshore turbines, is constant (about 1) above 40 m rotor diameter. With reduced wind shear offshore, the ratio may even decrease further depending on tip clearance in relation to extreme wave heights and tidal range.

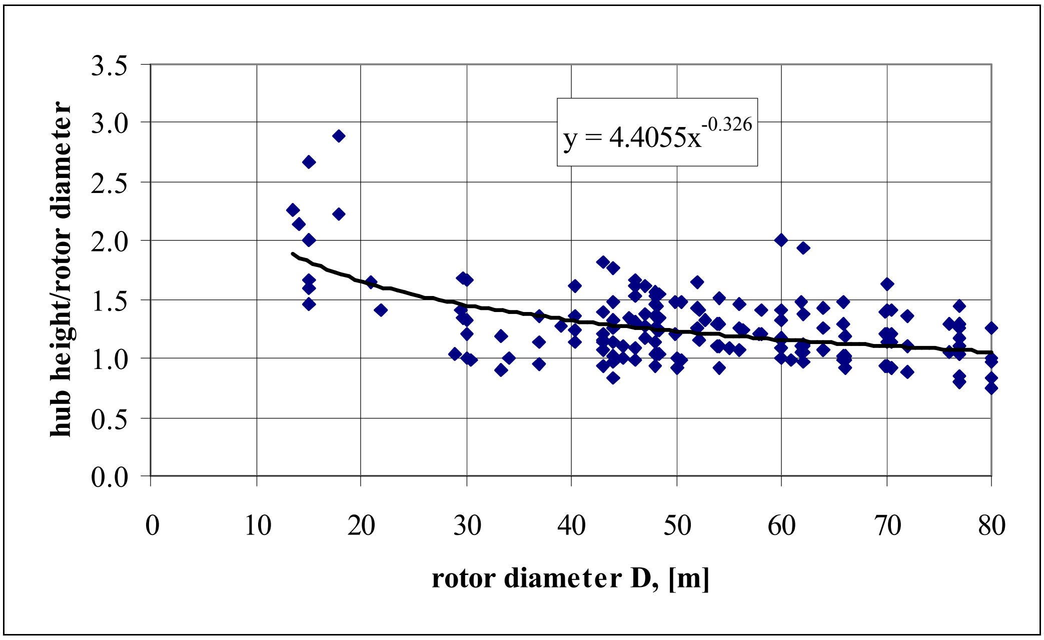


Figure 2.10 Hub height/rotor diameter ratio

2.2.1.4 Large wind turbine cost trends

Fig 2.11 from [4] shows the breakdown of capital cost of a typical offshore wind farm. In terms of CAPEX alone, turbines are about 40 ~ 45% of cost, much less than about 70% which is typical for land based projects, but clearly still a major item. Taking into consideration O&M costs, turbine costs are about 65% of total lifetime costs onshore and are expected to be about 30% offshore, [4].

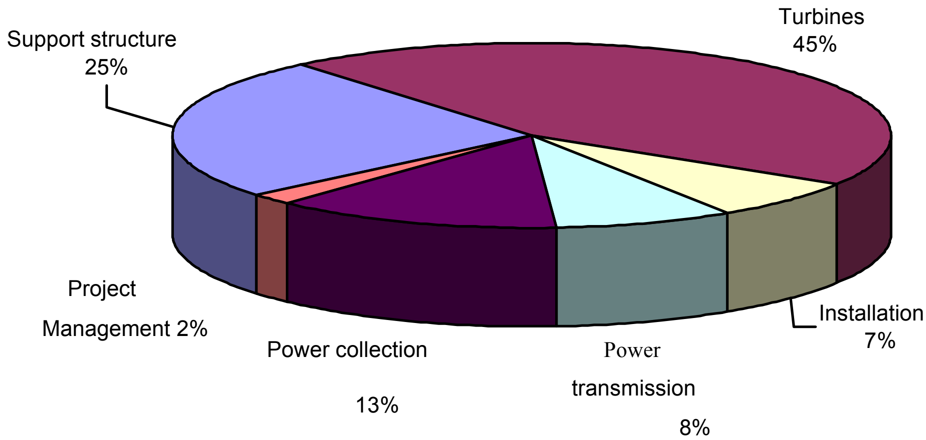


Figure 2.11 Breakdown of initial capital cost

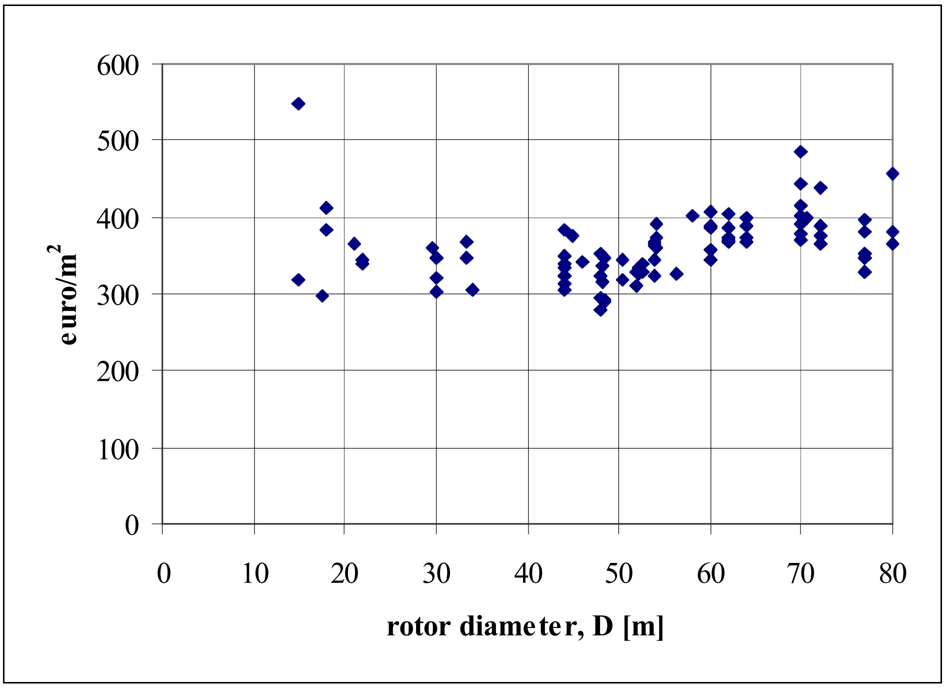


Figure 2.12 Cost per unit swept area v diameter

Figure 2.12 reveals a rising trend of medium and large size (30 – 70 m diameter) land based machines in cost/m^2 with increasing rotor diameter. This may not be immediately obvious, but the key is to discount the data above 75 m diameter which applies to the offshore designs with increased tip speed. It is expected that the offshore machines (at a given tip speed) will display the same rising cost trend but on separate curves related to design tip speed. Much of the vertical dispersion in Figure 2.12 and many other cost curves is due to the same turbines being offered with different tower heights.

Normalisation to take account of tower height and tower cost could considerably reduce the apparent scatter.

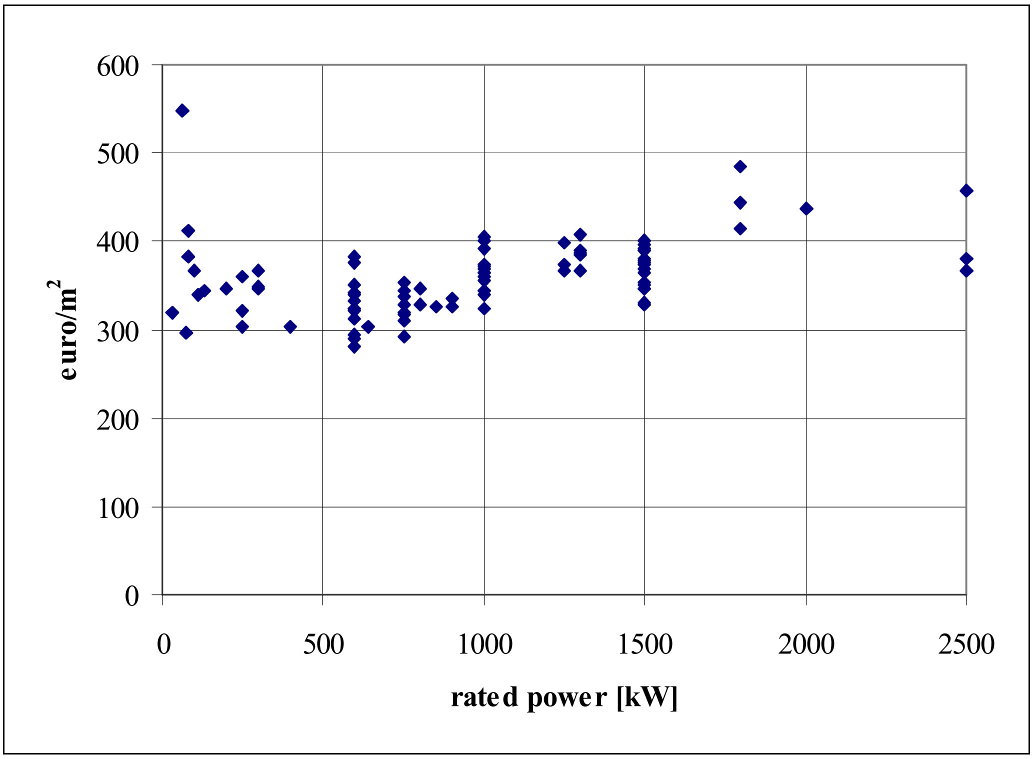


Figure 2.13 Cost per unit swept area v rated power

The same type of trend is apparent (Figure 2.13) in relation to rated power. The appearance of reduced costs of the largest offshore machines is even more striking in Figure 2.14.

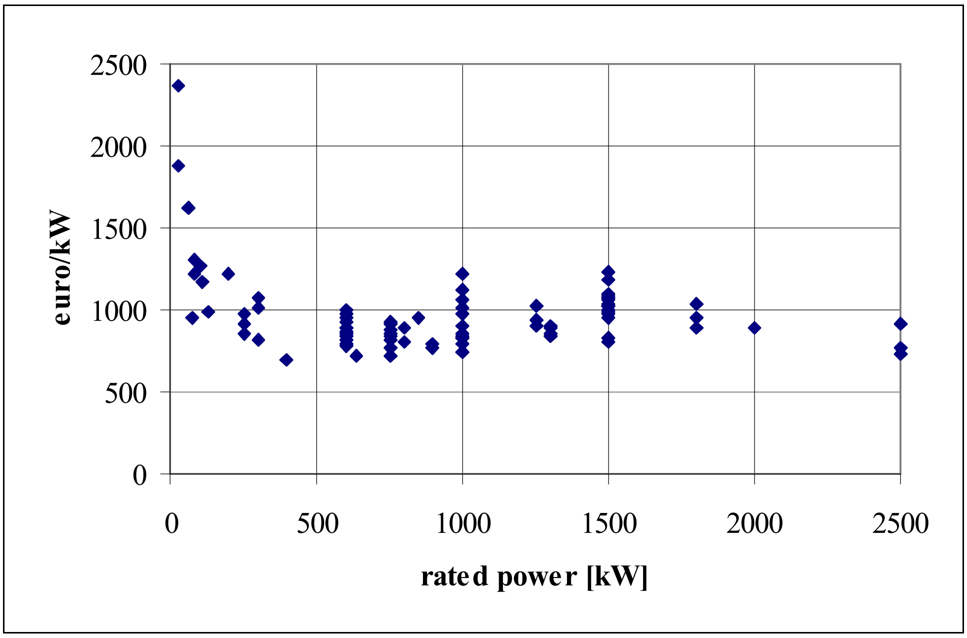


Figure 2.14 Cost per kW v rated power

The costs are based on list prices published in the same year [6, 7] and the 2 and 2.5 MW machines come out very well in terms of cost per kW because of the higher tip speeds (Table 2.2) and especially the higher ratio of rating to rotor diameter.

For onshore turbines the specific cost of foundation (ECU/kW) is decreasing with power rating as in Fig 2.15 (from [3]). A similar trend is expected in offshore projects especially when it is argued that a driver for having much larger unit turbines offshore is to have cost efficient foundations.

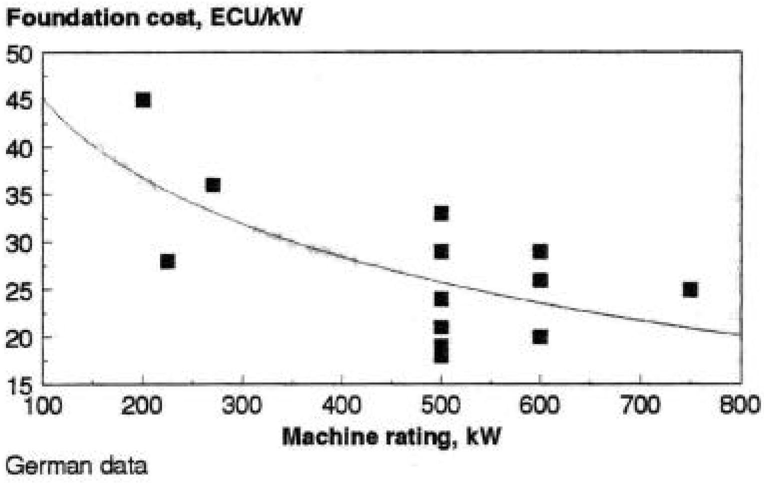


Figure 2.15 Foundation cost v rated power

Turbine availability is one of the most important parameters to be considered in the design of an offshore turbine. It connects directly to accessibility for maintenance and reliability. It affects the primary value, electricity production and Fig. 2.16, (from [4]), shows clearly that much improved reliability is demanded if reduced accessibility is not to impact strongly on availability. Current operational experience and offshore O&M is discussed in detail in Section 6. O&M demands will impact considerably on costs of offshore wind turbine systems and affect optimum scale for minimum cost of energy.

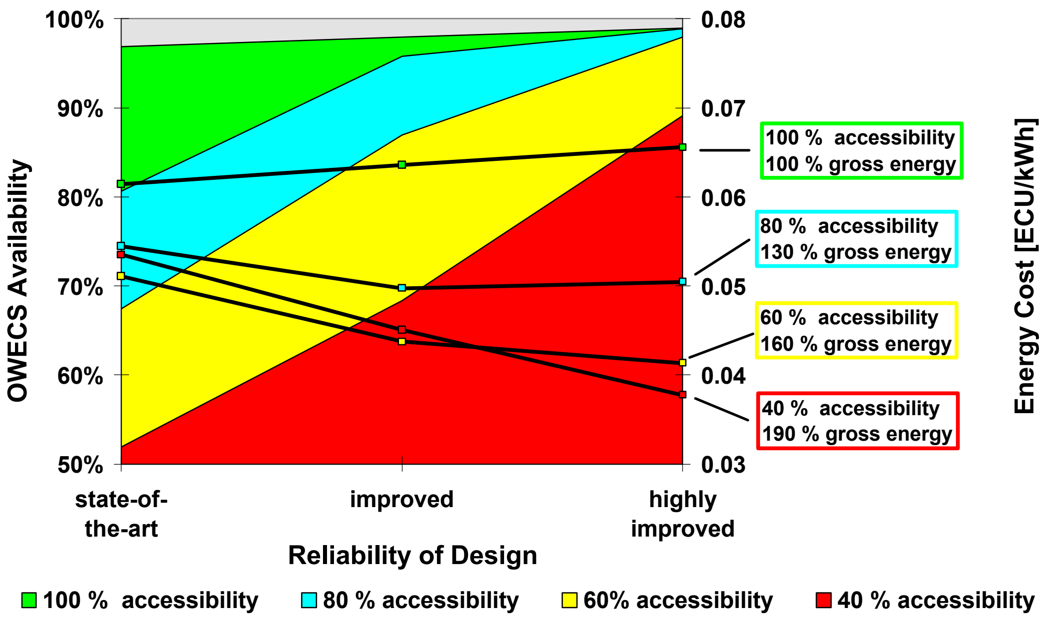


Figure 2.16: Availability vs. improved reliability

2.2.1.5 Summary of trends in offshore wind technology

Summarising the evaluations of size and cost trends;

- By turbine designers choice and reflecting wind shear conditions, rated power is generally scaling as $D^{2.4}$ on land and a bit closer to D^2 offshore. With lower wind shear offshore, specific power (W/m^2) is increasing up to around 500 W/m^2. It should be noted, however, that the choice of specific power (or rated wind speed) is also driven by the site annual mean wind speed, the breakdown of cost of energy and the predictability of power production in the future spot market.
- Under conditions of true similarity in design style, state of technological progress and design specification, it remains that costs of large turbines are expected to scale cubically with rotor diameter
- Considering historical data over the range of machine sizes, the cubic scaling law regarding system masses and costs appears closer to a square law with ongoing technology development
- The trends in published price data of machine for land based projects shows a gently rising cost/kW for rotor diameters of 40 m and greater. (This does not conflict with the circumstance, that after consideration of balance of plant and maintenance costs, the best overall project economics on land may come from utilisation of MW scale turbines)
- Offshore wind turbines are now essentially on different (lower) cost curves on account of tip speed increases in the 10 to 35% range,
- Rotor diameter and power rating is increasing. Commercial turbines are available in the diameter range 65 - 80 m and 1.5 - 2.5 MW. Prototypes are under development with respective values up to 120 m and up to 5 MW.
- The turbine cost is around 45% of initial capital cost of an offshore wind farm and, as a proportion of cost, is likely to be less on demanding sites with challenging wave climates.
- The increase of offshore turbine size is primarily driven by foundations and power collection costs. Very large unit size does not favour the inherent economics (cost/kW or cost per kWh ex factory) of the wind turbine in isolation.
- Reliability in parallel with accessibility are priority concerns for satisfactory economics of offshore wind turbines.

2.2.2 Manufacturers

2.2.2.1 General data sources on manufacturers

A list of most wind turbine manufacturers with contact details including web site references is available from [6,7]. Salient data on all commercial wind turbines above 52 m diameter, which are considered to be large enough for offshore use and some of which are specifically offshore designs, is presented in Table 2.3 (at the end of chapter 2)

2.2.2.2 Geographical regions

Some information relating to wind turbine and component manufacturers in southern European countries is given below.

Greece

Information on Greek manufacturers actively working in wind turbine manufacture as supplied by CRES is given below:

Table 2.5 Greek manufacturers

Manufacturer	
Pyrkal SA	Wind turbine manufacturer (up to 1-1.5 MW)
Geobiologiki SA	Wind turbine blade manufacturer (up to 19 m, up to 30 m under development) www.angelopoulos.gr
m.+g. tsirikos	Wind turbine gearing manufacturer
metal industry of arkadia – c. rokas SA	Wind turbine tower manufacturer & electrical systems www.rokasgroup.gr
biomek S)	Wind turbine tower manufacturer
metka SA	Wind turbine tower manufacturer www.metka.gr
viex SA	Wind turbine tower manufacturer

Italy

There is blade manufacture and Vestas turbine assembly by IWT, Taranto

Spain

Table 2.4, based on Wind Power Monthly, July 2000, indicates the status of the leading Spanish turbine manufacturers/developers.

Table 2.4 Spanish wind turbine manufacturers

Manufacturer	Installed capacity (MW)
Gamesa	1520.9
MADE	426.0
Ecotécnia	285.1
Desarrollos Eólicos	131.9
TOTAL	**2363.9**

2.2.2.3 Summary of blade manufacturers

Table 2.6 (at end of chapter 2) summarises the main players in the wind turbine blade manufacturing industry.

2.2.2.4 Current status of blade technology

There are a variety of design styles and manufacturing processes that are successfully in competition and no clear suggestion that a particular route of design or manufacture is definitely superior. Polyester resin is cheaper but inferior in preservation of final dimensional quality of a product and inferior in strength to epoxy resin. There has been a general move towards epoxy. New entrant blade manufacturers are using epoxy and Aerpac had switched to epoxy some years ago.

Large blades are requiring higher specific strength materials. This has undoubtedly driven the increasing use of epoxy resin and is also driving the widespread use of carbon reinforcements in large blades. The demand for high strength blades of low solidity in conjunction with diminishing carbon fibre costs may drive the industry in the direction of carbon epoxy. Carbon prices are falling and if it were used in significant quantities in blades for offshore machines, that could become by far the largest outlet for high quality carbon fibres and prepregs. This could then drive further cost reduction.

Wood composite blade manufacture is now a proven technology. Wood epoxy has good low temperature characteristics and is a cost effective blade material system. Wood may be more limited than other higher strength composites for very large blades. Wood is definitely unsuitable for very flexible blades. The spar and shell design, both manufactured using prepregs, is particularly favoured by Vestas. It has advantages in realising fast production with good quality control and suits manufacture of lightweight, flexible blades. These advantages are offset by a premium in the material components.

There are a number of interesting developments but no sign of any radical development in blade technology that would sideline present manufacturing technologies.

2.2.3 Offshore Prototypes

Nordex, Vestas and Enercon are known to be investigating designs in the 5 MW, >100 m rotor diameter range, and Aerodyn and NEG Micon are involved in a 6 MW design. (NEG Micon expect to install a 3 MW prototype in 2002). Parallel activities of the blade manufactures in development and testing of blades for rotor diameters above 90 m is noted in Table 2.6.

The ScanWind 3.5 MW, 90 m rotor diameter design utilising the ABB Windformer concept has been much publicised and a 500 kW system (generator only) has been laboratory tested. A 3 MW Windformer system is planned for Nasudden III (land based but coastal site) and it is expected that these developments will prepare the technology for offshore applications.

Offshore projects

A total of 8 offshore projects are currently operational worldwide: the early projects were relatively small scale and shallow or sheltered waters. Not until Blyth Offshore came online, exposed as it is to the full force of the North Sea, could any be described as truly offshore.

Table 2.7 Offshore Projects

Location	Country	Online	MW	No	Rating
Vindeby	Denmark	1991	4.95	11	Bonus 450 kW
Lely (Ijsselmeer)	Holland	1994	2.0	4	NedWind 500 kW
Tunø Knob	Denmark	1995	5.0	10	Vestas 500 kW
Dronten (Ijsselmeer)	Holland	1996	11.4	19	Nordtank 600 kW
Gotland (Bockstigen)	Sweden	1997	2.75	5	Wind World 550 kW
Blyth Offshore	UK	2000	3.8	2	Vestas 2 MW
Middelgrunden, Copenhagen	Denmark	2001	40	20	2 MW
Utgrunden, Kalmar Sound	Sweden	2001	10.5	7	Enron 1.5 MW
		Totals	**80.4**	**78**	

Ireland, Belgium, Germany and the Netherlands are also expressing serious intent in developing their offshore resource.

More details on existing and planned projects can be found in Chapter 9.

Utilising megawatt-plus class machines, future projects will generate higher volumes of electricity from the more constant wind regimes experienced at sea and are likely to play a major role in power generation in the future.

The EWEA have estimated that 5 GW of the 60 GW predicted for 2010 will be coming from the offshore sector.

2.2.4 Gearboxes in the Offshore Context

The majority of turbines currently supplied to the onshore market use a gearbox to increase the rotor speed to a speed compatible with the generator, ~1000 or 1500 rpm. Almost all gearboxes, regardless of power rating, tend to conform to a standard pattern for turbines up to the current maximum size of approx.● 2 MW. The gearboxes are three stage units, the first, input, stage is planetary and the two higher speed stages are parallel with helical gears.

It is not clear whether this current gearbox concept will be applicable for larger, offshore turbines. Gearbox design is generally determined by input torque and the required speed increase ratio. As power and, hence, rotor diameter increase the torque and ratio increase. In an offshore turbine the increases are offset to some degree by a relatively higher rotor speed compared to a land based machine. However, it is likely that for larger machines > 3MW an additional gearbox stage will be required. Therefore, the complexity of the gearbox may be increased beyond that currently being used or designs based on a lower generator speed (rpm) may be used to compensate for this effect.

Throughout the development of the modern wind turbine there have been periods when the frequency of failure of gearbox components has been above normal, acceptable levels. The gearbox is one of the more costly components and there is always a large incentive to reduce costs. As wind turbine technology has developed the loading calculations used to select gearboxes and other component have been refined. These factors mean that over time, the safety margins of gearboxes have reduced. This appears to result in a cycle of events. A period of stability is followed by an increased level of failures. The wind turbine and gearbox industries react to the failures, increase margins and a further period of stability ensues.

Gearboxes for use in offshore environments may be more complex. The increased complexity may lead to increased probability of failure. There are only a small number of failure modes that can be rectified in situ. Therefore, to repair a failed gearbox will entail the removal of the unit from the turbine with significant cost and time implications.

The above issues suggest that there is a reasonable possibility that direct drive technologies may prove more attractive than they currently appear to be in the onshore market.

These comments are based on GH engineers' experience in due diligence and are not attributable to any specific published source.

2.2.5 Future Trends

As has been discussed, there is direct evidence of the following trends; 1) tip speed increases, 2) up to 33 %, more use of carbon in blades, at least as reinforcement if not yet as a complete base material system, and 3) the appearance of more direct drive systems in new wind turbine designs, especially ScanWind as a large scale system targeted for offshore.

All these developments are logical from a technical/cost standpoint:

- **Higher tip speeds** gives lower torque and less mass and cost of tower top systems.
- **Carbon blades** or more carbon in blades – very large blades demand higher specific strength materials.
- **Direct drive with permanent magnet generator (PMG)** – direct drive does not have a cost or weight advantage over conventional geared systems but especially in the PMG type of design, it

constitutes a simpler power train than the gearbox/high-speed generator combination and may be more reliable.

Floating wind energy systems have major potential benefit in allowing utilisation of windy areas near population and electrical demand centres where there are no shallow sea water sites. A study (FLOAT) identified such sites off the east coast of Ireland and in the Aegean.

At present, costs of moorings and of the floating platform (with the need for some lengths of flexible transmission lines) would appear to be much greater than the cost of fixed sea bed foundations in shallow water. However, technical progress in these areas plus new system concepts including, for example, integration with an appropriate type of wave device may bring floating systems nearer to economic feasibility.

Other ideas which may warrant future work are multiple rotors fixed on a single pile.

2.3 SUPPORT STRUCTURE

2.3.1 Design Development – Piled Foundations

2.3.1.1 Operational experience

Piled foundations have been used throughout the world for supporting offshore oil and gas platforms and there exist well-established recommended practices and guidelines for the design of piles and grouted connections:

- API RP2A, American Petroleum Institute, Recommended Practices for Planning Designing and Constructing Fixed Offshore Platforms
- NORSOK N004 Design of Steel Structures.

Fixed offshore oil and gas platforms are generally supported by 3 or 4 legs with either a single pile driven through the leg or one or more skirt piles arranged around each leg, the piles connected to the leg by means of grouted sleeves. The piles are hollow steel tubulars ranging in diameter from 914 mm to 2743 mm.

In benign, shallow waters, a single pile has been used to support the topsides and as a conductor for drilling the well. In some cases, the conductor itself has been used to support the topsides. Conductors diameters are between 508mm and 914 and are normally either driven or drilled and cemented.

Nearshore marine construction of jetties and mooring dolphins has often used piles of greater diameter than those used offshore, but the depth of penetration and the means of installation have been different.

OWEC's have been supported on single monopiles, effectively a downwards extension of the tower and generally using methods developed from marine construction. They have ranged in diameter from 2.1 m at Bockstigen (Gotland) to 3.7m at Lely and have been installed by driving or by drilling and cementing (rock socket).

Large diameter tubular piles are a well-established design as indicated above. However, unlike an oil platform, the foundation supporting an OWEC is subjected to a much larger proportion of live load compared to dead load. This means that the foundation experiences larger shears and bending moments and relatively small axial compression. The design of monopile foundations should consider cyclic loading of near-surface soils and the potential for loss of soil contact at the surface (post-holing). Rock-socketed piles are unlikely to be susceptible to this effect.

2.3.1.2 Piling techniques

There are four main means of installing piles:
- Above-surface steam, hydraulic or vibration hammers
- Underwater hydraulic hammers
- Drill-drive
- Drill and grout

Pile driving is a faster and less weather sensitive means of installing piles than drilling and normally results in greater pile capacity than a drilled pile. There are however several disadvantages compared with drilling and grouting:
- The act of driving will sometimes damage the pile head and the pile may not be driven truly vertical. In order to connect the tower, this could entail cutting the head level and true and prepping it for either welding on of a flange or direct welding of the tower. This problem was overcome at Utgrunden by using a sleeve, incorporating the tower connection flange, that slid over the pile and could be adjusted to grade and level. Once in position, the annulus between sleeve and pile was grouted.
- During pile driving, accelerations both lateral and vertical of up to 50g will be observed. Any attachments to the pile will need to be designed for this or retrofitted. This would include access ladders and walkways, anodes, J-tubes etc.

Drill-drive would be slower than simply driving and would suffer all the disadvantages of driving. It is generally only used to assist driven piles in reaching target penetration in hard soils.

Drill and grout has been successfully used for some monopile foundations and is the only method if penetration of rock is required. The benefits of drill and grout are:
- More controlled placement of the pile without damage and to a tight tolerance is possible. This permits bolting on of the tower without top of pile preparation and eliminates the need to retrofit ladders, boat landings etc..

2.3.2 Design Development – Gravity Foundations

2.3.2.1 Operational experience

Gravity foundations or gravity base structures (GBS) have been used extensively in the Norwegian sector of the North Sea, mainly in deep water, for example Troll and Sleipner. The UK sector has also used gravity foundations in deep water, but more recently in shallower water: Ravenspurn and Harding.
GBS are generally buoyant for floatout, tow and installation and are then ballasted with water, iron ore or grout to provide sufficient on-bottom weight to resist overturning. The GBS normally consists of a series of open and or closed cells that form the base and one to four legs that are integral to the design, provide stability during temporary conditions and support the topsides.

To date gravity foundations for OWEC's have been similar in appearance to onshore foundations with the connection to the tower raised above Highest Astronomic Tide. Examples are Middelgrunden, Vindeby and Tuno Knob

The gravity foundation has advantages for installation over a monopile in that the complete OWEC can be assembled on-shore in a dry-dock as one unit and no drilling or piling equipment is necessary. However, the efficiency of the installation operation does depend on the dry-dock being located close to the OWEC's site, thus minimising transport times. Additionally, a specially modified transportation/installation vessel is needed.

2.3.2.2 Design configuration

A variety of different configurations have been used to date and it is likely that optimisation for particular site-specific developments would result in more solutions. The likely future of gravity foundations as water depths increase are discussed below.

Solid concrete plate foundation – Middelgrunden, Vindeby
These are extensions of onshore foundations and are likely to increase significantly in weight as water depths increase, although the plate could be made to contain additional heavy ballast as an alternative to simply adding concrete mass.

Concrete box caisson (filled) – Tuno Knob
The caisson does not rely purely on the mass of concrete to provide stability and would probably not increase in mass quite so significantly as the solid plate.

Steel caisson – proposed
This would be similar in form to the plate foundation with provision for the heavy ballast.

2.3.3 System Dynamics

The OWEC is dynamically sensitive to excitation caused by a complete rotation of the rotor and passage of the blades past the tower. This gives two periods that must be avoided to ensure that resonant response does not occur.

For example: for a three-bladed rotor with a rotation speed of 22 revs/minute the natural period T of the OWEC must be as given below.

- stiff-stiff natural period T < 0.8sec
- stiff-soft natural period 1.0sec < T < 2.4sec
- soft-soft natural period T > 3.0sec

It is normal to define the exclusion period as the calculated period +/- 10%

2.3.3.1 Sea bed conditions

The natural period of the OWEC is critical as discussed above and depends on the following:

- Mass of the system
- Stiffness of the tower
- Stiffness of the combined substructure and foundation.

(Note: substructure is defined as the element between the tower and the seabed, foundation is defined as the element at seabed and below.)

The monopile is potentially the least stiff of the foundations options and, particularly in slightly deeper water, is likely to be of the soft-soft type. However, it was observed at Lely that the behaviour of two of the OWEC's was stiffer than predicted, and that one was stiff-soft rather than soft-soft. It was fortunate that the exclusion period was avoided, although it must be noted that this was purely chance. Multi-pile substructures are likely to have more predictable natural periods, being less dependent on the lateral stiffness of the surface and subsurface soils.

For any design, sensitivity studies must be undertaken to ensure that, even with upper and lower bound soil properties, the predicted range of OWEC natural periods does not fall within the exclusion period.

Scour of the seabed can also significantly affect the foundation stiffness. Scour protection will be necessary where granular surface soils exist in areas where the seabed can experience high currents or wave particle velocities.

2.3.3.2 Wave excitation

Offshore structures generally have adequate fatigue resistance if their natural period is less than about 4 seconds. Above this level, design against fatigue is not impossible, but is more difficult.

Current demonstration OWEC projects: Middelgrund, Lely, Vindeby, Blyth are in very shallow and generally sheltered water (2m-10m) and the behaviour of the foundation is little influenced by wave dynamics.

In deeper water, and particularly with monopiles and monotowers, it is likely that the natural period of the OWEC will be greater than 3 seconds, a soft-soft foundation, and will be more susceptible to wave-induced fatigue damage. Aerodynamic damping is a result of rotor rotation and affects fore-aft first order motions. This will reduce the observed fatigue damage due to waves compared to that predicted using a theoretical undamped system.

2.3.3.3 Structure types

Up to 20m water depth, it is likely that the drilled and grouted monopile will be the most cost-effective solution, with the concrete plate foundation as an alternative.

Above 20m, it is likely that the natural period of an OWEC on a monopile will exceed 4 seconds, with potential problems for fatigue resistance, although aerodynamic damping would help to reduce the dynamic response.

A concrete gravity structure is theoretically suitable for depths greater than 20m although the weight and cost of such a structure could be prohibitive. It could be designed either to be self-floating or barge transportable. The former would require the structure to be constructed in a dry dock, although it is noted that the Middelgrunden structures were constructed in a dry dock and were not self-floating.

Steel structures would be suitable for these depths and would probably not be excessively heavy. It is likely that they would be supported by small (36-48in) piles rather than gravity or suction foundations, although a heavily ballasted steel caisson may be cost-effective. Such structures could either be of lattice tower or monotower construction. A lattice tower would probably be lighter than a monotower, but because of the large number of members and joints, would be more expensive to fabricate and would require significantly more inspection and maintenance, particularly in the splash zone. The lattice tower is likely to have a higher natural period than a monotower, and could therefore be more fatigue-susceptible.

A monotower is a large diameter central tube supported by three or four small diameter piles. The piles are connected to the tube by means of grouted sleeves and tubular braces. The benefit of the monotower is its simple construction, but it would still have a higher cost per tonne compared with a monopile. The turbine tower would be bolted to the monotower, just as for a monopile, thus the operational experience at Lely, Vindeby and Blyth regarding O&M, access, control rooms, workrooms would be transferable. Separate provision would be necessary if a lattice tower were to be used.

An alternative monotower concept is to use a large diameter tube with pile sleeves attached closely to the tube with shear plates – similar to a large offshore platform ‘leg bottle’. It is anticipated that three 36in-48in piles would be suitable for this purpose, and they could be driven, speeding up the installation process. The cost per tonne would be between a monopile and a braced monotower. Pile weight would be lower than the monopile so overall cost should be less.

The optimum concept for a particular site should be assessed by detailed analyses of all concepts and their site-specific costs:

- CAPEX:- engineering, fabrication and installation.
- OPEX:- inspection, maintenance, repair, visit intervals, support and/or accommodation vessel/unit requirements.

2.3.4 Icing

Sea ice is a consideration in the Baltic but not in the UK or Dutch sectors of the North Sea. However, since the sea ice is annual ice up to about 600mm thick, structures can be designed to resist it by providing sloping faces to the substructure at sea level. This reduces the ice pressure by inducing bending in the ice and breaking sheets into small pieces.

At Bockstigen, the monopiles have an octagonal form of ice protection made of stainless steel and filled with concrete.

2.3.5 Breaking Waves

Foundations could be designed using conservative assumptions of the effects of breaking waves compared with non-breaking waves and this would probably not be a significant cost item for a 1 or 2 OWEC development.

However, the economics of large OWECS rely on economy of scale and optimisation of all aspects of design to remain economically attractive. Better understanding of breaking wave phenomena for generic and site-specific wave environments is therefore necessary.

2.3.5.1 Operational experience

Breaking waves can cause both local damage to offshore structures and impose significant global forces. A single column structure such as a monopile or even a monotower is more susceptible to global forces compared with a multiple legged jacket structure because the wave force is applied instantaneously to a single discrete element rather than to an array of elements. A phenomenon known as ‘ringing’; a dynamic response to the high frequency components of a wave train, has been observed on a single column concrete gravity structure in the Norwegian sector(Sleipner). It has been suggested that a similar phenomenon can be observed with breaking waves acting on a monopile in shallow water.(Structural Dynamics of Offshore Wind Turbines subject to Extreme Wave Loading – N Rogers – Border Wind)

At the EPSRC OWEN workshop ‘Structure and Foundations Design of Offshore Wind Installations March 2000, NDP Barltrop discussed breaking waves and their effect on shallow structures. The effects of breaking waves upon the Bockstigen monopile structure are investigated in this study.

It should be noted that the occurence of breaking waves is not applicable for existing Dutch offshore windfarms as they are located in inland water.

2.3.5.2 Modelling

Because the behaviour of waves in shallow water is so dependent on local topology it may be difficult to predict whether waves would tend to break. There may well be local knowledge, existing model test information from coastal defence programmes or measurements that would indicate whether breaking waves had been observed.

Model testing would be a useful means of investigating the behaviour of waves at a particular site and with representative models of an OWECS give information on wave run-up, celerity, particle velocities and steepness. Current and wind can significantly alter the steepness of waves in shallow water, and should be considered in any testing programme.

2.3.5.3 Research for offshore wind

Direct research into breaking waves in relation to offshore wind energy is currently being undertaken under the Engineering and Physical Sciences Research Council (EPSRC) Renewable and New Energy Technologies (RNET) 'Dynamic Response of Wind Turbine Structures in Waves' NDP Barltrop University of Glasgow et al.

At the Bockstigen demonstration project the monopile and tower are strain gauged and measurement of the dynamic behaviour the OWEC and metocean and meteorological measurements are underway.

2.3.6 Design Developments

Garrad Hassan are further developing Bladed for Windows and Germanischer Lloyd have undertaken development under Joule 1 (Jour 0072) Study of Offshore Wind Energy in the EC

The OWEN / ESPRC Workshop April 1999 identified research priorities in this area as:

- A need to improve the prediction of environmental conditions for input to the design calculations, including:
    - The relationship between extreme winds and waves.
    - Improvement in metocean predictions for sites of interest
    - Improved models of boundary layer, turbulence and machine wakes in maritime areas
    - Predictions of wind and wave directions
    - The determination of loading due to breaking waves and other shallow water effects
- A decision as to whether components (namely turbine and support structure) are treated in an integrated way during design, reducing conservatism.
- To develop improved understanding of the structural dynamics of offshore wind structures
- To assess the reliability of existing spectral wave models
- To assess importance of wave-driven fatigue on offshore wind structures
- To investigate the suitability of different types of foundations for offshore wind energy applications, for example, their response under cyclic loads and their dynamic characteristics.
- To routinely monitor the performance of offshore anemometry masts and wind turbine structures – with the data used to refine models and designs
- To assess the available methods of determining and measuring dynamic soil properties
- To investigate the economics of off-the-shelf foundation designs

2.4 STANDARDS

2.4.1 General

The issue of building permits for offshore wind turbines will depend on a large number of different agencies and institutions. This is not only due to the different technical fields involved, but also due to the impact from the marine environment (navigation, national parks, pipelines, cables, defence areas, etc.). Many European countries have appointed one authority to co-ordinate the necessary involvement of the relevant organisations. In most countries this appointment is also different depending on the distance to the shore, i. e. local, inside 12 miles or outside.

In Europe the technical design of wind turbines shall be based on the relevant European Directives. Of special importance for wind turbines is the Machinery and the Construction Product Directives. However, the Low Voltage and Electromagnetic Compatibility Directives also need to be satisfied. All of these Directives are general purpose documents which ask for harmonised standards and requirements.

A European set of building codes are the Eurocodes 1, 2, 3 which are published as ENV 1991, 1992, 1993. The Eurocodes are based on the method of analysing limit states according to ISO 2394 and do require the use of partial safety factors. Eurocode 1 defines loads, Eurocode 2 contains requirements for concrete structures and Eurocode 3 those for steel structures.

In addition to the existing IEC-standards, the European Directives, Eurocodes and a number of national codes for wind turbines, Germanischer Lloyd's Regulation for the Certification of Offshore Wind Energy Conversion Systems [9, 10] and the Danish Recommendation for Technical Approval of Offshore Wind Turbines [25] give guidance on the special design requirements for offshore wind turbines. Further national and international codes and regulations for offshore structures may be applicable.

The design of offshore wind turbine foundations can be based on the long term experience gained in projects undertaken by the oil and gas industry. However, it has to be pointed out that for existing offshore structures, wind is generally not one of the dimensioning load components. The structural design of the offshore wind turbine has to take into account both wind loads and the structural response of the foundation which may result from waves, currents or ice.

Extended remote control is one of the design modifications for offshore wind turbines. Others are corrosion protection against marine atmosphere, boat or helicopter landing facilities and lifting gear for components.

Design rules for offshore wind turbines have been derived from codes for wind turbines and those for offshore structures. Although there is considerable experience for both of those structures their combination has revealed new load cases which need to be considered in the design, construction and operation of offshore wind farms.

2.4.2 GL Offshore Standard

Germanischer Lloyd's (GL) Regulations for the Certification of Offshore Wind Energy Conversion Systems (GL-OW) [9], issued 1995, are a result of the Joule 1 Offshore study [13] by merging the GL Regulations for the Certification of Wind Energy Conversion Systems (GL-W) and the Rules for Off-shore-Installations (GLO), [11, 12]. The structure and main components of these Regulations are described in [14].

In the meantime since the first issue of the regulation, new knowledge has been gathered on offshore wind and wave conditions and some pilot wind farms have been constructed. There is a strong requirement to bring the GL-OW Regulations in line with new developments.

Review of the Regulations is underway consisting of following points:

1) Resolve insufficiencies and errors found in planning and certification procedures: Several offshore wind farms are in the planning or design stage.. These include wind farms in Denmark, Germany and the Netherlands where Germanischer Lloyd WindEnergie GmbH (GL-Wind) is actively incorporated as a certification body.

2) Incorporate results from applications in pilot farms: GL-Wind is participating in the EU research project 'Offshore Wind Turbines at Exposed Sites' (OWTES), being undertaken by AMEC Border Wind, Delft University of Technology, Germanischer Lloyd WindEnergie, PowerGen Renewables Developments and Vestas Wind Systems under the leadership of Garrad Hassan and Partners [16].

The aim of this project is to improve the design methods for wind turbines located at exposed offshore sites in order to facilitate the gradual, cost-effective exploitation of the offshore wind energy resource available in the EU. This aim will be met through the achievement of a number of project objectives. These include to:

- establish a database of environmental and structural load measurements.
- evaluate the database of environmental and structural measurements in order to derive a thorough understanding of the aerodynamic and hydrodynamic loads and their influence on the dynamic response of the offshore wind turbine and its support structure.
- use the database of measurements to enable validation and enhancement of state-of-the-art-methods for computer modeling and design analysis of offshore wind turbines.
- undertake parametric analyses for investigation of the complex relationships between fatigue and extreme loading, the design characteristics of an offshore wind turbine and its support structure, and the site wind, wave, current and sea bed conditions.
- investigate the robustness of design calculations for offshore wind turbines with respect to variations in the environmental conditions, wind turbine and support structure design concepts and methods of analysis.
- provide a critical appraisal of present design procedures and certification rules for offshore wind turbines and to recommend changes where appropriate.
- catalogue the key design requirements for offshore wind turbines for sites where the environmental conditions are severe.

The database of measurements recorded at Blyth Harbour is evaluated in order to establish a complete characterisation of the environmental conditions at the site. The characterisation will identify the correlation of wind, waves and currents. In addition, the spectral characteristics of the wind turbulence and the wave heights will be established and compared with the standard models recommended by the certification regulations for offshore wind turbines.

The measurements of environmental data and structural response will be used to examine the extent to which the assumptions underlying the current GL certification regulations for offshore wind turbines are valid for the Blyth Harbour site.

A thorough review of the current GL certification regulations for offshore wind turbines will be undertaken. Based on a critical evaluation of the project results, the validity of the assumptions and guidelines offered by the GL regulations will be examined and, where appropriate, recommendations for revision will be made.

3) Update according to scientific / technological progress.
A number of research projects have provided valuable information on offshore specific issues. Specific subjects have been investigated separately e.g. wind resources, extreme wind and to some extent wave conditions, turbulence characteristics, joint-appearance (probability) of wind, waves, ice

and current and on operation and maintenance. Some of the results are now available [17, 18, 19, 20, 21, 22, 23] and the effort is to include these in future regulations updates.

4) Harmonization with IEC.
Considerable work has been performed by the IEC TC 88 committee, resulting in the second edition of the IEC 61400-1 in 1999 [15]. According to this standard, offshore wind turbines have to be treated as land based wind turbines of class “S”, considering marine environment. As most offshore turbines are “marinised” versions of land based turbines developed in accordance with IEC 61400-1, a harmonisation with the IEC code is of advantage. This task is scheduled for 2001-2002 and will be performed as a review of the regulations for land based wind turbines [10]. In Parallel GL-Wind is participating in the relevant national and international working groups of DIBt, CENELEC, IEC TC88 for offshore (WG03) and land based wind turbines (WG01) which will have influence on the regulation harmonisation.

2.4.3 Danish Recommendations for Offshore Wind Turbines

The Danish Energy Agency has issued Recommendations for the Technical Approval of Offshore wind farms in Denmark [25] . Generally the standard DS472 applies, with significant changes in some parameters. A short description of the recommendation is given here:

Part 1: Introduction, applicable standards. Wind turbines to be erected offshore Denmark have to fulfill the Technical Criteria for Type Approval and Certification of Wind Turbines in Denmark, The Danish Standard DS472 and other norms and regulations stated in the Technical criteria. For the analysis of wave loading, DS449 (Piled offshore structures) and for ice loading API 2N [26] have to be applied. Further Danish national construction norms (DS409 – DS415) to be considered are named.

Part 2: Climatic parameters and safety in relation to DS472. The changes of parameters relative to DS472 are described. Annual mean and extreme wind speed as a function from distance to shore, air density and safety factors for the loads to be used for offshore wind turbines are stated. Additionally a method to be used for the calculation of wind farm influence on wind speed turbulence intensity is given.

Part 3: Loads and load cases. The calculation methods and the nature of the dynamic model are described together with the loads acting on the structure. Depending on the system sensitivity some guidance on analysis methods and extent is given. Apart from the definition of the characteristic values (98% of the annual extreme value) and the coefficient of variation to be used together with safety factors, a list of load cases, based on DS472 and extended for offshore climate is stated. Recommendations on the combination of wind, wave, ice and current loading and the extraction of design loads from them are included.

Part 4: Foundations. Reference is made to DS415 (Foundation) and DS 449 (Piled offshore structures). The determination of the geotechnical category, the required pre-appraisals like measurements or laboratory experiments are considered together with inspection requirements.

Part 5: Materials and corrosion. This section refers to the protection systems and durability of the support structure up to the nacelle. Corrosion protection is considered. Regulations to be applied for concrete and steel structures are listed.

Part 6: Additional conditions such as occupational safety, lightening protection, marking, noise emission and environmental impact assessment are stated.

2.4.4 IEC Offshore Wind Turbine Standards

Review
According to the existing IEC 61400-1 standard, offshore wind turbines have to be treated as land based wind turbines of class "S". This is not a satisfactory solution and the Technical Committee 88 of the IEC set up a working group (WG03) to develop IEC 61400-3 specially dedicated to offshore wind turbines.

Objective of WG03
The objective of WG03 is to develop a standard for the engineering and technical requirements which should be considered during design in order to ensure the safety of systems and components of offshore wind turbines, inclusive of their support structures. This will be documented in IEC 61400-3.

IEC 61400-3 will cover only those issues relevant to offshore wind turbines, fully consistent with IEC 61400-1 and not duplicating the requirements defined in IEC 61400-1.

Contents
The contents of the document will be limited (at the beginning) to offshore wind turbines with support structures which are fixed to the seabed (not floating systems). It is proposed that a wind turbine be considered "offshore" if the support structure is subject to hydrodynamic loading. The main issues to be considered are: external conditions, design load cases, calculation methods, structural design, and assembly, installation erection, commissioning and maintenance.

The time schedule agreed in WG03 is shown in the following table:

Table 2.8 Time Schedule of WG03

Status of IEC 61400-3	Proposed Target Date
Availability of first WD (working draft)	December 2001
Circulation of first CD (committee draft)	June 2002
Submission of first CDV (committee draft for voting)	December 2002
Submission of FDIS (final draft international standard)	December 2003
Availability of IS (international standard)	June 2004

2.4.5 Offshore Environment

Apart from general rules and regulations on offshore wind turbine design, site specific environmental conditions are of interest. The influence of wind, wave, ice and soil conditions is covered by the standards for offshore, offshore wind turbine and land based wind turbine designs, together with procedures for site assessment. The certification procedure according to the site conditions is given in [9] and [24] and described in [14].

In addition to the standards normally applied for land based machinery, electrical machinery and buildings, the following may be of interest.

- Electrical conditions may have significant impact on wind turbine design, especially in conjunction with weak grid conditions. National standards or grid operator requirements will regulate electrical parameters to be fulfilled by the wind farm and the electrical installation up to the connected point on land. Additionally the grid loss probability and duration may (directly) influence load definitions in the standards.
- Operation and Maintenance and related labour safety issues are also covered by national regulations. They will have influence in access and rescue equipment and boarding platforms.

- The marine atmosphere must be considered for corrosion, as well as guidance relating to the materials to be used and electrical protection.
- Ship navigation will not directly influence turbine structural design except the collision case. National laws and international agreements determine the equipment to be installed (light marking, active and passive radar reflectors etc). The ship collision probability and load has to be considered.
- Installation, lifting and commissioning are generally covered by offshore regulation although national regulations may apply.
- Marine pollution, MARPOL, e.g. access visits must be minimised to reduce use of fossil fuels and disturbance on sea fauna.
- Dismantling. In most countries a full dismantling of offshore constructions is required by national law. In Germany by the mining law (§55(2) Nr3 Bberg).
- Air traffic markings in accordance with international and national regulations have to be installed.
- The noise problem cannot be neglected even offshore. Many large scale turbines can produce noise similar to sound levels generated from motorways.
- Site specific approach wind+wave+ice+soil conditions.
- Procedures on site assessment and certification according to GL and IEC.
- Electrical conditions – power supply power company, National O&M National Work safety influence on safety systems, accessibility, platforms etc.
- Shipping, navigation, air traffic national and international regulations and their influence on design e.g. collision, site spec. depth etc.
- Lightning protection requirements.

2.4.6 Offshore Industry Standards

Standards that will apply or assist in installation and erection procedures and in the design of special structures not included in wind energy related codes. These are listed in the following:

Offshore regulations

1. American Petroleum Institute, Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, API Recommended Practice 2A-WSD, 21st Edition 2000.
2. American Petroleum Institute (API), Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms –Load and Resistance Factor Design, 1993, (suppl. 1997), RP 2A-LRFD
3. American Petroleum Institute, Recommended Practice for Planning, Designing and Constructing Structures and Pipelines for Arctic conditions, API Recommended Practice 2N, 2nd Edition 1995.
4. Norwegian Technology Center (NTC), NORSOK Standard N-001, Structural Design, Rev. 3, Aug. 2000.
5. Department of Energy, (now Health and Safety Executive) 1990: Offshore installations: guidance on design, construction and certification (fourth edition) HMSO 1990 ISBN 011 4129614, replaced.
6. Det Norske Veritas, Rules for classification of fixed offshore installations 1998.
7. Germanischer Lloyd, Rules for Classification and Construction, III Offshore Technology, 2 Offshore Installations, Edition 1999
8. ISO 13819-1, Petroleum and natural gas industries -- Offshore structures -- Part 1: General requirements, 1995-12, 1st edition. To be replaced , ISO TC 67. (ISO 19900)
9. ISO 13819-2 Petroleum and Natural Gas Industries – Offshore Structures – Part 2: Fixed steel structures, 1995.
10. ISO 19903 (Draft), Offshore Structures – Fixed concrete structures.

Offshore Mobile Platforms

1. Det Norske Veritas, Rules for classification of mobile offshore installations.
2. Germanischer Lloyd, Rules for Classification and Construction, III Offshore Technology, 2 Offshore Installations, Guidelines for the Construction/Certification of Floating Production, Storage and Off-Loading Units, Edition 1999.
3. IMO, MODU-Code, Code for the construction and equipment of mobile offshore drilling units, 1989.
4. ISO 19904 (Draft), Offshore Structures – Floating systems.

Electrical Equipment

1. American Petroleum Institute, Recommended Practice for design and installation of electrical systems for Offshore.
2. IEC 60092-xxx (2000-02) Electrical installations in ships
3. IEC 60533 (1999-11) Electrical and electronic installations in ships - Electromagnetic compatibility
4. IEC 60654-2 (1979-01) Operating conditions for industrial-process measurement and control equipment. Part 2: Power
5. IEC 60654-4 (1987-07) Operating conditions for industrial-process measurement and control equipment. Part 4: Corrosive and erosive influences
6. IEC 61363-1 (1998-02) Electrical installations of ships and mobile and fixed offshore units - Part 1: Procedures for calculating short-circuit currents in three-phase a.c
7. IEC 61892-3 (1999-02) Mobile and fixed offshore units - Electrical installations - Part 3: Equipment
8. IEC 61892-6 (1999-02) Mobile and fixed offshore units - Electrical installations - Part 6: Installation

Materials and Corrosion

1. DIN EN 12495, Cathodic protection for fixed steel offshore structures, 2000.
2. DIN EN 10225, Weldable structural steels for fixed steel offshore structures, 1994.
3. Det Norske Veritas, R.P. B401, Cathodic Protection Design, 1993
4. Germanischer Lloyd, Rules and Regulations, II Materials and Welding, Part 1, Metallic Materials, Edition 1998.
5. Germanischer Lloyd, Rules and Regulations, II Materials and Welding, Part 1, Non-metallic Materials, Edition 2000.

Special Topics

1. IMO, Safety of Life at Sea Convention (SOLAS)
2. Marine pollution , MARPOL
3. International Association of Sea-Mark Administrators (AISM/IALA) Recommendations for the marking of offshore structures, Nov. 1984 /suppl. 1987).

Helicopter Platforms

1. Cap 437, Offshore Helicopter Landing Areas.
2. American Petroleum Institute, Recommended Practice for Planning, Designing and Constructing Heliports for Fixed Offshore Platforms, API Recommended Practice 2L, 4th Edition 1996.

Offshore Cranes

1. American Petroleum Institute, Specification for Offshore Cranes, API Spec 2C, 5th Edition 1995.
2. DIN EN 13852, Cranes – Offshore Cranes – Part 1: General purpose offshore cranes, 2000

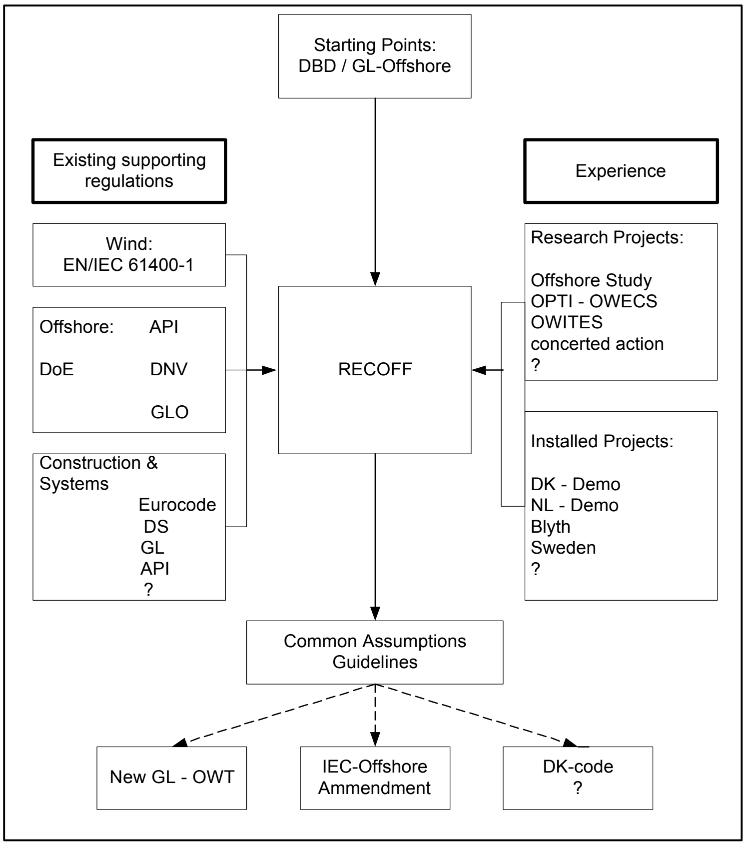
2.4.7 EU-Project Guideline for Design of Offshore Wind Turbine

The objective of this (RECOFF) project is to prepare guidelines and recommendations for design of offshore wind turbines. The main objective of these guidelines and recommendations is that they should serve as a basis for development of European and national standards and certification rules for offshore wind turbines. The recommendations will be addressed directly to the two standardisation bodies: the International Electrotechnical Commission (IEC) and the European CENELEC.

The existing offshore standards, mainly written for offshore oil and gas exploitation, are not suitable to cover the offshore wind energy technology. Particular review of health and safely issues for offshore work on OWECS must ne a priority. A combination of these offshore standards and the existing onshore wind energy standards is in process but technology gaps exist. In the project, readily available information will be utilized to the extent possible, and where a need is identified, research and development will be performed. The project is structured in accordance with the typical components of a standard. The main tasks are reflected in the project work packages:

1) External conditions: identification and description of wind, waves, ice etc.,
2) Computational tools: generation of loads from external conditions,
3) Design load cases: identification of a suitable number of representative load cases,
4) Probabilistic methods: new models for decision-making on load cases,
5) Structural integrity: specification of e.g. partial safety coefficients,
6) Operation and maintenance: labor safety and standard method for data collection.
7) Project management and communication: management, preparation and execution of seminars for external parties such as manufacturers.

The proposed work (3 years duration) will aim to bring together available information and expert knowledge from the wind power (Riso (coordinator), CRES, ECN, GH and GL) and offshore engineering industries. The overall methodology of the project is summarized in Figure 2.17.



Abbreviations:
IEC61400-1: International standard on wind turbine safety; GL-OWT: GL regulation for the certification of offshore wind energy convertion systems (1995); API: American Petrol institute – recommended practice for planning, designing and constructing fixed offshore platforms; GLO: GL rules for classification and construction, III offshore technology (1999); DoE: UK Dept. of Energy; GL: regulation for certification (1999); DBD: design basis for Danish demonstration offshore projects; DS: Danish Standard; DNV: Det Norske Veritas, EN: European Norm, OWITES: Offshore Wind Turbine at Exposed Sites.References

Figure 2.17: Overview of the Methodology used in the Project.

2.5 PROJECT EXPERIENCE

2.5.1 Methods Used

The installation sequence of an offshore wind turbine depends on the foundation structure chosen. An offshore wind farm requires much closer integration of the design and construction activities than an onshore wind farm because of the additional challenges of operating at sea. Some basic principles, including construction, for typical offshore foundations are given in Table 2.9.

Table 2.9 Basic principles of typical foundations for offshore wind turbines

Foundation type	Size (diameter)	Weight	Construction sequence
Gravity base	12 – 15 m	500 – 1000 tonnes	1. Prepare Seabed 2. Placement 3. Infill Ballast
Monopile	3 – 3.5 m	175 tonnes	1. Place Pile 2. Drive Pile
Multipile	0.9 m	125 tonnes	1. Place Base 2. Drive Pile
Bucket (caisson)	4 – 5 m	100 tonnes	1. Place Base 2. Suction Installation

Each type of foundation will be subject to construction constraints. A gravity base foundation requires the seabed to be prepared in advance and the toe of the structure to be protected against scour. An advantage is that the structure can be constructed onshore, thereby reducing offshore operations. The monopile is easy to install (drive) with proper equipment but large stones in the seabed can make it difficult or even impossible. If the pile needs to be driven into the bedrock (granite), expensive site works have to be undertaken. A comparison of the construction differences for monopile and gravity base foundations is summarised in Table 2.10.

Table 5.10 Construction differences for monopile and gravity base foundations

Construction phase	Gravity base foundation	Monopile foundation
Onshore construction	Local to site	No constraints
Transport offshore	More complex	Lift onto barge
Pre-placement activities	Seabed preparation	None
Placement	Lift or float-over	Lift
Fixing	Grouting	Pile driving
Installation of tower / turbine	Potential obstruction to lift	No hindrance to lifting

2.5.2 Problems Encountered

Time delay at sea is the most significant problem related to offshore project engineering. As hired equipment is used for installation, all downtime will prove costly. Project developers try to minimise delays by pre-assembly and onshore testing of installation procedures. Any problem or design error detected at sea causes time delays and equipment downtime.

- At Middelgrunden some of the interconnecting cables were damaged when the foundations were installed. The problem was foreseen with spare cables available and a covering insurance.
- At Bockstigen downtime was caused by high winds preventing the jack-up barge from being operated. Jack-up barges cannot be safely deployed during heavy sea conditions.

Construction time for a driven pile foundation from a floating barge was initially shown to be less costly than using other methods. Due to weather downtime, the overall installation durations have been similar for gravity base foundations and driven pile foundations installed either from a jack-up vessel or floating barge.

The weather downtime allowance required for a 50 unit wind farm is considerable, approximately doubling the floating barge installation duration. It has been proposed to install the structure in two pieces (first the foundation unit followed by the assembled support tower, nacelle and rotor as one unit) compared to three pieces (installing each of the foundation, support tower and nacelle and rotor units in a separate operation) to save in construction time.

2.5.3 Design Options

2.5.3.1 Assembly design

Offshore wind turbines are most likely to be installed from either a jack-up barge or a floating crane vessel. The choice will depend on the water depth, the crane capability and vessel availability. The crane must be capable of lifting the structures, with hook heights greater than the level of the nacelle to enable the tower and turbine assembly to be installed. Existing crane vessels have not been specifically designed for installing offshore wind turbines. For large offshore wind farms, greater than 50 units, significant time (and therefore cost) savings could be made by using an installation vessel purpose built for the task. This philosophy has been adopted elsewhere in the civil engineering industry.

So far, the installation process had held two phases. First the foundations are build and then the turbines are installed on top of the foundation. Usually turbines are erected as on land, i.e. first the tower in segments and then the nacelle and the rotor.

In the case of Middelgrunden, the first tower segment was pre-installed and transported on the foundation. The control board, switchboard and the transformer were located at the bottom of the tower during transportation and lifted in place, at intermediate floors, on site.

The total build duration for a multi-unit wind farm is likely to take several months. All installation operations will be subject to weather constraints and there will inevitably be periods of non-operation/weather down-time. This can be minimised by scheduling installation operations during the relatively calm summer months, when both wind speeds and wave heights are most frequently within safety limits.

2.5.3.2 Transportation

The monopile foundation, i.e. a steel cylinder, is usually transported to the site on barges. Alternatively it can be capped and sealed at the ends and floated to the site.

At Vindeby and Tunø Knob, the caissons were floated to the site and filled with ballast. At Middelgrunden, the foundations were transported with a barge, that lifted the foundations several meters from the seabed and transported them one by one to the site.

The Opti-OWECS report [4] suggests transporting the whole turbine in one piece. Two alternative tower and wind turbine transportation orientations were considered, i.e. a vertical and a near horizontal orientation. In the near horizontal orientation the barge space requirements govern the size of the barge required whilst in the case of the vertical orientation, the transportation stability requirements govern. Transportation in the vertical orientation is not regarded as feasible without substantial bracing to limit the bending moments at the base of the tower.

An amphibian vessel for transporting, installing and maintaining assembled wind turbines has been patented in the Netherlands [28].

2.5.3.3 Erection

All installation methods have their advantages as well as disadvantages. The decision will depend on assembly design, foundation structure, site conditions and to some part on the approach adopted for maintaining the structures.

It is often anticipated that tower units complete with the nacelle and rotor could be installed as a single unit at a rate of two per day (24 hour working) during the summer months (May-August). Under these circumstances vessel downtime of around 50% is anticipated i.e. a rate of 1 tower per day accounting for downtime with a total installation period inclusive of mobilisation of 4 months. However, the temporary storage of the turbines to be installed may constitute a problem.

The Opti-OWECS report [4] presents a good summary of the options available for installation of the tower (inclusive of nacelle and rotor etc.):

Jack- up Installation
Jack-up lift appears at first glance to be the obvious method of installing the tower, nacelle and rotor. It forms a stable base from which to carry out the operation and is the preferred choice for carrying out the piling operation. However, its inherent stability and hence lack of manoeuvrability poses problems for the installation of the tower. Offloading tower elements from a floating barge and lifting them into place will most likely require a form of piecemeal construction with the tower, nacelle and rotor all installed as separate items. The same jack-up barge can be used for driving the monopile and for installing the turbine.

Semi-Submersible Installation
Lifting from a vessel is in principle most straight forward method of installation. Semi-submersible crane vessels represent the most stable floating platform from which to carry out offshore construction work. Existing vessels, however, are designed for more remote offshore operation and have difficulties operating in shallow water depths.

Ship Shaped Vessel, Flat Bottom Barges and Land Based Cranes
Ship shaped vessels and flat bottom barges offer appreciably less stability for carrying out construction work and are consequently subject to weather delays. Ship shaped vessels with rotating cranes offer the best performance. As a result, they are in heavy demand and are attracting appreciable day rates. Flat bottom barges with sheer leg cranes of a suitable size are in far greater supply and offer a cost effect approach to tower installation despite weather delays. One way of combining the benefits of rotating crane with adequate reach but at a lower day rate is to use land based cranes. Such a system is adopted quite satisfactorily in sheltered locations.

Float-Over Installation
The Opti-OWECS report presents a float-over installation, where the tower is erected and floated out in the vertical orientation before being floated-over then lowered down onto the pre-installed pile. The tower is erected at the quay side on a dummy pile and is stabilised by a pin which is housed in the tower and lowered into the pile. The tower is secured to a barge in the vertical orientation ready for transportation. The vessel required for this operation may need to be specially built although modifying an existing vessel is also an option. The vessel takes-on the tower at the quay side where it is moored adjacent to the tower and securely seafastened. Then, possibly on a rising tide, the barge is deballasted allowing the tower to be detached from the dummy pile. Once in a safe water depth, the barge is ballasted for the tow. On arrival at the site the vessel is deballasted, if necessary, and safely moored over the offshore installed pile. Then follows the operation of ballasting the vessel down so as to safely transfer the support for the tower onto the pile. The sea-fastening is then released leaving the vessel to be towed away.

2.5.4 Other Sources, Further Area of Work

Offshore wind energy structures and their foundations must be designed to accommodate exposed weather and equipment workability, with support towers designed to be compatible with the available construction equipment. Additional work is required in:

- Improved dissemination of knowledge of offshore marine related construction procedures and techniques amongst designers/developers.
- Optimise the cost-effectiveness of offshore wind structure installation operations by making use of novel construction sequences and scenarios.
- Investigation of reducing fatigue loading by introduction of inherent flexibility, i.e. flexible towers, compliant couplings, etc.
- Reduction of fatigue loading through more sophisticated control. (Benefits of greater sophistication to be balanced against potential reliability problems.)
- Investigation of the technical and economic feasibility of 're-useable' foundations.
- Identification of suitable European test sites with offshore type conditions, e.g. islands.

2.5.5 RTD Priorities

The highest uncertainty in offshore installations relate to time delays and costs in use of rented equipment. Also, it is important to minimise the time needed for offshore operations as any unscheduled downtime. There is a clear need for installation vessels that can withstand more severe weather conditions and operate for longer periods of the year. Special installation vessels, designed for installing offshore wind turbines are possible, and perhaps a necessity, when offshore wind energy installation becomes a continuous all-year activity. Cost control efforts should be focused on the overall installation process, and dissemination of areas for economic improvements identified.

A longer term objective should aim for an integrated design, where the foundation and the turbine is installed as one piece. The installation procedure should at least be simplified and include a minimum of operations offshore.

The projected overall cost for an offshore wind farm should account for decommissioning costs which include an allowance for shifts in environmental ground rules or other fluctuating cost factors. The offshore oil and gas industry is currently facing the issue of decommissioning offshore installations and subsea wellheads, the cost of which exceeds previous conservative estimations.

2.6 OPERATION AND MAINTENANCE

2.6.1 Introduction

Operation and maintenance of offshore wind farms is more difficult and expensive than equivalent onshore wind farms. Offshore conditions cause more onerous erection and commissioning operations and accessibility for routine servicing and maintenance is a major concern. During harsh winter conditions, a complete wind farm may be inaccessible for a number of days due to sea, wind and visibility conditions.

Even given favourable weather conditions, operation and maintenance tasks are more expensive than onshore, being influenced by the distance of the OWECS from shore, the exposure of the site, the size of the OWECS, the reliability of the turbines, and the maintenance strategy under which they are operated.

Offshore installations require specialist lifting equipment to install and change out major components. Such lifting equipment can usually be sourced locally and at short notice for onshore wind farms.

The severe weather conditions experienced by an OWECS dictate the requirement for high reliability components coupled with adequate environmental protection for virtually all components exposed to sea conditions.

Consequently, the requirement for remote monitoring and visual inspection becomes more important to maintain appropriate turbine availability levels.

2.6.2 Land Based Comparative Data

Operational information for onshore wind turbines has been compiled for a number of years which is directly relevant for operation and maintenance issues.

"WindStats" newsletter is a quarterly international wind energy publication with news, reviews, wind turbine production and operating data from over 12,000 wind turbines in Denmark, Germany, Belgium, USA, Sweden, Spain and The Netherlands.

However, WindStats provides very limited information for 1 MW plus turbines. A more relevant source of operating information is provided by turbine manufacturers who either have data in their publicity material or will usually provide data on request.

The overall picture of turbine availability is very good for all major manufacturers who have turbines in full production. For instance, Vestas V66, Enercon E66, Bonus 1.3 MW, Nordex 1.3 MW, Enron/Tacke 1.5 MW all have fleet-average availability of at least 97%. Information on maintenance effort to achieve this is practically unavailable, except through fault reports published in Germany and Denmark (summarised in WindStats).

Monthly wind turbine statistics for Sweden are published by SwedPower AB, and are available on the internet at www.elforsk.se/varme/varm-vind.html.

Published statistical information on the availability, accessibility and reliability of offshore wind turbines is presently limited to site specific information released at the discretion of wind farm operators. Therefore we are dependent on published data from the few existing truly offshore wind farms constructed since 1991. Current offshore wind farms are mostly small in comparison to onshore wind farms, although large scale wind farms, typically around 100 machines, are anticipated.

Operation and maintenance data for onshore wind turbines are readily available as detailed above. However, the environmental conditions associated with offshore installations renders this current machine data inadequate.

2.6.3 Offshore O&M Models

Maintenance strategies have been developed in the Opti-OWECS project using Monte Carlo simulations. A simple expert system has subsequently been developed based upon analytical trend curves determined from a large number of Monte Carlo simulations [29].

In the Monte Carlo model, the site accessibility as well as the failures of the wind turbines in the OWECS are simulated stochastically on an hour to hour basis. The response in terms of deployment of maintenance and repair crew, and equipment, is simulated simultaneously in the model. This results in the determination of the instantaneous and overall availability of the OWECS and of the instantaneous and overall costs associated with the adopted maintenance strategy under the assumed site conditions

As mentioned above, 'expert systems' [30] have been developed which represent the trend lines found from the far more comprehensive Monte Carlo simulation model. This simple approach enables the assessment of availability and O&M costs for a given OWECS with its O&M strategy as a function of distance to shore and site (wind) conditions. The analytical functions used in this expert system have also been used for the concept evaluation. With them, the OWECS availability and O&M costs could then be determined and optimised for a range of scenarios. [31].

2.6.4 Maintenance Strategies

The availability of a wind turbine largely depends on the O&M strategy adopted by the operators of a wind farm. Given the limited amount of offshore O&M data, strategic planning is in its infancy, however a number of options were developed in the Opti-OWECS study [4]:

1. No maintenance: Neither preventative nor corrective maintenance are executed, and major overhauls are performed every five years or so. One of the few alternatives is exchanging a whole turbine if availability drops below a predefined minimum or after a certain amount of operational hours. Given the current level of turbine failure rates, this option is not presently viable.

2. Corrective maintenance only: Repair carried out soon after a turbine is down, or, alternatively, wait until a certain number of turbines are down. No permanent maintenance crew is needed

3. Opportunity maintenance: Executing corrective maintenance on demand and taking the opportunity to perform preventive maintenance at the same time. No permanent maintenance crew is needed

4. Periodic maintenance: Scheduled visits performing preventative maintenance, and corrective actions performed as necessary by a permanent dedicated maintenance crew.

The Opti-OWECS study concluded that O&M strategy should be optimised with respect to localised energy production costs rather than pure capital or O&M costs. Further, the availability of OWECS with commercial offshore wind turbines without significantly improved reliability and without optimised operation and maintenance solution may be unacceptably low, e.g. 70% or less.

In conclusion, given current reliability and failure modes of commercial offshore wind turbines, which have been adapted from onshore models, a reduced level of preventative and corrective maintenance is not a viable option at this stage in the development of the offshore wind energy industry.

2.6.5 O&M Offshore Experience

2.6.5.1 Availability

Onshore wind turbines are now enjoying availability levels in excess of 97% with appropriate routine servicing and responsive maintenance actions. However, in practice, this typically equates to visiting a wind turbine four times a year, either for regular service or for repair tasks. [29].

Vestas cite a comparison between availability rates for the Fjaldene onshore wind farm and Tuno Knob offshore wind farm [32]. Average availability for Fjaldene is quoted as 99.3% mainly due to the proximity of this windfarm to Vestas' Central Service Department.

Tuno Knob average availability is quoted as; 97.9%, 98.1%, and 95.2% for the years 1996 to 1998 respectively. [35].

2.6.5.2 Operational expenditure

As stated above, operating expenditure for offshore wind farms is considerably higher than the equivalent onshore facility. Offshore operations are in the region of five and ten times more expensive than work on land, and these costs are exacerbated by inflated prices prevalent within the offshore oil and gas industry. For example, the day rate for an offshore lifting vessel, which will be well over capacity for the wind industry, will typically cost at least ten times that of an appropriate land based crane.

Also, onshore equipment can be sourced and mobilised within a short period of time, usually within hours, and available on site within a day. Offshore lifting cranes are uncommon, and will generally have to travel a considerable distance to an offshore wind farm site, hence the requirement for careful scheduling of such vessels movements. The economics of a large wind farm (e.g. 100 machines) may justify the purchase of a dedicated purpose built lifting vessel which would be available during installation and for maintenance throughout the wind farms lifetime. However, it is commercially expedient to dispense with the need for expensive lifting vessels after installation and hire lifting equipment during scheduled major overhaul. Given relatively calm sea conditions, it is possible to use a floating barge to transport and operate a land based crane offshore. The floating barge need only be a crude construction incurring minimal expenditure, hence be procured and stored for and at a dedicated wind farm.

General maintenance tasks are carried out using less specialised equipment which is generally purchased for the design life of the wind farm.

Operation and maintenance costs mainly related to the wind turbine can account up to 30% and more of the energy costs. [4]. Recent discussions with leading wind turbine manufacturers have indicated that O&M costs, given 95% availability warranties (excluding weather constraints, and dependent on the scale of the project), is approximately £30,000 per turbine per annum for the UK market. The cost of operation and maintenance for the first year of operation may be higher.

2.6.5.3 Serviceability

The service demand of the present generation of offshore wind turbines in terms of man-hours is in the order of 40 to 80 hours [34]. Service visits are paid regularly, (except in the more demanding first year) about every six months. A more major overhaul will be undertaken every five years, and will take around 100 man hours to complete. [29].

Experience from Tuno Knob show that the total number of service visits have been about 35 to 70 visits per year, an average of approximately 5 visits per turbine per annum. The number of cancelled visits (last moment cancellations due to weather) makes up about 15% relative to the number of service visits realised. [35].

2.6.5.4 Access for maintenance

Gaining access to an OWECS for routine servicing and emergency maintenance is difficult or impossible in harsh weather conditions due to wave heights, wind speeds and poor visibility. The traditional and obvious method for transporting personnel and equipment is by boat, which is limited to relatively benign sea states. Wave heights above one metre present serious concerns for health and safety issues and damage to equipment.

Since the beginning of offshore wind farm development, suggested methods for gaining safe access have included:

- Helicopter
- Underwater tunnels
- Wheeled platforms for turbines in close proximity to the shoreline
- Amphibious vehicles where caterpillar tracks transport a platform over a firm and stable seabed
- Small hovercraft or ice roads for frozen seas.

For the present discussion, only the principle advantages and disadvantages of boat (plus jack-up) or helicopter access will be considered:

Boat Access

Advantages:

- well proven method of inshore transportation
- relatively cheap equipment expenditure

Disadvantages:

- impractical for wave heights greater than 1m (dependent on vessel)
- transfer of personnel and equipment difficult in rough conditions

Jack-up

Advantages:

- vessel can be raised above waves to provide a stable access platform
- heavy equipment can be transferred

Disadvantages:

- requires firm seabed conditions
- existing jack-up vessel designs are too large, hence purpose built designs are necessary
- high capital cost of vessel
- installation sequence must be previously defined (cable installation later on)
- sensitive to wave conditions during deployment and retraction of legs

Helicopter Access

Advantages:

- sea state is not a major issue
- quick transfer of personnel and equipment from land to turbines

Disadvantages:

- cost of equipment and qualified operating staff
- turbine must be shut down and locked prior to boarding, and flying is restricted to good visibility and wind conditions
- not possible to use for certain wind turbine fault conditions (for instance yaw bearing failure)
- expensive and cumbersome (landing platforms needed on each turbine)

Helicopter access is routinely used for oil and gas installations and offshore lighthouses, however it is unlikely that this mode of transportation can be reasonably considered for OWECS.

From recent reported experience, it has not been possible to access Vindeby turbines in heights of more than 1 metre using an 8 metre launch, but nevertheless turbines reportedly had an accessibility of 83% for the time during the first 12 months of operation in 1992. However, during the worst month accessibility fell to 45%. It was found that the conical foundation amplified the waves, making boat landing more difficult especially in winds from the north or north-west. Access was limited to wind speeds of less than 7-8 m/s from the north or north-west and 12 m/s from other directions. Solid ice around the foundations and blocking the boat's nearby home harbour also prevented access for several weeks, although this amount of ice was unusual. The travelling time of approximately 30 minutes in each direction also affected availability and maintenance. [36].

At Tuno Knob a 32 foot fibreglass boat (forward control fishing boat with flat stern) .is used for the service rounds The boat weighs about 11 tonnes and is equipped with a 185 hp diesel engine. [35].

In conclusion, there are a number of current projects addressing the issue of improved access to offshore wind turbine installations. Most focus on maintaining existing boat access methods with emphasis on addressing the issue of motion compensation or complete removal of the vessel from the water at the turbine location. The potential for using small purpose built jack-up vessels with integral craneage is also a possibility assuming a sufficiently large wind farm is to be serviced. However, access using small purpose-built landing craft continues to present the most pragmatic and economic solution.

Improvements made to the base of OWECS to facilitate safe personnel access include:

- Fixed platforms fixed to tower above splash zone with fender posts to absorb vessel impact
- Flexible gangways extended from the vessel and held in the lee of the OWECS base.
- Installation of friction posts against which the vessel maintains a forward thrust during transfer
- Facility for winching the vessel out of the water during harsh sea conditions
- Winch / netting for personnel and equipment

As mentioned above, there are significant advantages in eliminating the need for specialist lifting vessels currently necessary during overhaul or major component replacement. For a number of current offshore wind turbines, craneage facilities (either permanent or temporary) within the nacelle are capable of lifting some of the heaviest components. At Tuno Knob, special electrical cranes were installed in each Vestas V39 turbine to allow replacement of major components, such as rotor blades or generators, without using a large and expensive floating crane. However, all other currently available turbine models require external cranes for the more demanding lifts, although Vestas claim to be able to change rotor blades with on-board cranes on their V80 2 MW machine.

2.6.6 Designs for Reduced Maintenance

The issue of accessibility can also be addressed by improvements in offshore wind turbine reliability. Both planned and, more importantly, unplanned maintenance levels can be reduced by increasing the reliability and hence availability of the turbine. Particular emphasis is being placed on reliability issues from component level through to overall design improvements such as corrosion protection and component siting.

NEG Micon's new 2 MW turbine has a fibreglass cabin within the nacelle which encloses the transformer, power and control cabinets within a controlled nacelle environment.

2.6.6.1 Component reliability

Rotor blades
Current OWECS utilise a three bladed configuration, and it appears that this will continue to be the popular choice of turbine manufacturers. However, two bladed configurations incorporating alternative hub structures may see a rise in popularity given the opportunity to operate turbines at higher rotor speed and without visual constraints. The main advantages from a reliability perspective are the reduction in the number of components, reduced complexity of the hub and easier rotor lifting. The track record of teetering mechanisms is not favourable, and for this reason these may be avoided for offshore use.

Gearboxes
Onshore turbine manufacturers, notably Enercon and Lagerwey, specialise in direct drive generators therefore eliminating the need for a gearbox. Current offshore turbines manufactured by leading manufacturers favour geared drive transmissions. Being the widely recognised as the number one item for mechanical failure and servicing supervision, it would appear a progressive step to move to direct drive systems.

Aerodyn who are currently designing the 5MW Multibrid Technology favour a drive-train consisting of single stage planetary gears, combined with a slow rotating generator, therefore eliminating fast-running components which are prone to wear. [37]

Generators
In general, induction generators require less maintenance than synchronous generators. They do not require a DC source and being inherently more simple and robust are the most common generators in onshore wind turbines.

To protect standard induction generators from marine environments, the generators is totally enclosed with integral insulation to protect the internals from salt and high levels of moisture.

Onshore generators rely on air cooling, which is not recommended for offshore applications. Closed system water cooling or air-to-air heat exchange prevent the risk of corrosion from maritime cooling air.

Direct Drive Systems
Ring type direct drive systems have been developed for onshore wind turbines, primarily by Enercon and Lagerwey. Direct drive systems dispense with the historically problematic gearbox, where the drive train, generator and rotor rotate at the same speed of around 20 rpm for a 2 MW OWECS.

The advantages of direct drive generators are obvious; no gearbox with associated high speed rotating parts, no gearbox oil contamination and leakage, and less routine servicing, to name a few. However, the direct drive generator for megawatt turbines is extremely heavy, bulky and the large diameter required changes the visual appearance of the nacelle. The added tower top mass coupled with increased wind loading increases tower stresses and hence tower dimensions.

The ring generators developed by Enercon are multipole synchronous machines with the copper windings impregnated with resin for environmental protection. Heat is dissipated by conduction via the high surface area steel structure.

ABB's Windformer is a large diameter gearless generator using permanent magnets rather than coils or electromagnets. No transformer is required as the power is produced at 25 kV DC, compared with AC at less than 1 kV for most turbines. Halved lifetime maintenance costs as well as arguable benefits of up to 20% higher power conversion efficiencies have been claimed [38].

Electrical & Electronic Components
Electrical and control system failures account for the highest percentage of failures. For the year 2000, failures of electrical and controls systems accounted for exactly 50% of the need for wind turbine repairs [39]. Typically, failures of this nature occur due to the number of components, poor electrical connections, corrosion, lightning strikes, etc.

Potting of electronic printed circuit boards and reduction in the number of components are necessary for offshore conditions.

Hydraulic Systems
Elimination of problematic hydraulic systems employed in yaw damping, blade pitching and breaking systems should be realised wherever possible. Electrical actuation is preferable and eliminates the possibility of oil leakage leading to secondary component failure and potential fire risks.

2.6.6.2 Corrosion protection

The main methods of marine corrosion protection for offshore installations, recently developed within the offshore oil and gas industry, are selection of corrosion resistant materials, two-pack epoxy coatings, cathodic protection, and creation of controlled environments for sensitive equipment.

The potential wind farm sites being considered in the North and Baltic Seas present harsher maritime conditions in terms of severe sea conditions and higher salinity levels.

More work is needed in developing support structures which can withstand stresses caused by wind and wave loading, together with reductions in material fatigue strength caused by corrosion. Cathodic protection technology of subsea structures is integral in the front end engineering design, with due consideration of state-of-the-art paint systems and metal spray coatings particularly for application within the splash zone.

2.6.6.3 Control and condition monitoring

Surveys of machine outages reveal that around half the unplanned shutdowns on onshore turbines are caused by faults and trips in the electrical and electronic control systems. To reduce the number of unplanned visits to an OWECS, automatic re-set and remote re-set facilities are now becoming common in all new turbines. Increasing numbers of sensors and monitoring equipment are being used, and the signals categorised to register; data, minor faults requiring notification only, or major faults which shut the turbine down automatically.

Using SCADA (System Control And Data Acquisition) systems, monitored signals and alarms are transmitted between the turbine and the onshore control station. Control personnel can interact with the monitoring system to over-ride the turbine controller if necessary.

Internet connections, webcams and sophisticated vibration monitoring for example can now be utilised to detect a limited number of pending failures prior to their occurrence.

2.6.6.4 Back-up power

Power for the turbine controller, electrical actuators, monitoring and communications systems are drawn from the turbines gross output, or imported from the grid system.

In the event of loss of turbine power generation or lost electrical grid connection, there is no power at the isolated turbine for maintenance work or to keep turbine systems running. At Horns Rev, it is intended to have a back-up diesel generator sited on the substation platform to provide power should the electrical connection to shore be broken.

2.6.6.5 Conclusions

An important aspect of future wind turbine development is the requirement to adapt existing onshore designs to cope with harsh maritime environments

As indicated in the previous sections, reductions in the lifetime O&M costs of OWECS will require the following to be addressed:

- Development of appropriate maintenance strategies for scheduled and unscheduled maintenance, reflecting the constraints on OWECS in terms of access.
- Improvement of access methods for unscheduled and scheduled maintenance.
- Development of access methods which are less sensitive to wind/wave conditions.
- Reduce time required for offshore working
- Designs for reduced maintenance by:
    - Reduction in overall number of components and simplicity of design
    - Modular design approach which facilitates the interchange of faulty modules
    - Use of high reliability integrated components
    - Re-siting of electrical units into an environmentally controlled section of the turbine
    - Implementation of offshore corrosion protection technology
    - Development of effective conditioning monitoring and remote control systems

2.7 ELECTRICAL

The aim of this section is to establish the state of the art, in the wind industry and in research, in offshore wind electrical technology. In particular, it summarises important technology developments that are in place, foreseen, or considered necessary or beneficial. Network connection is excluded from this chapter, as it is covered in chapter 3. Transmission to shore is included in this document.

2.7.1 Electrical Systems within the Wind Turbine

2.7.1.1 Variable or fixed speed

Recent developments in operational strategy, variable or fixed speed, show a tendency towards variable-speed designs as can be seen in [40]. Despite this, some big manufacturers, such as Bonus or NEG Micon, still make use of fixed speed (often two-speed) technology in their large designs (≥2 MW) for future offshore applications.

A list of the operating philosophies is given in [40]. Some principal manufacturers of variable-speed machines and the technology used are outlined below:

Wide range variable speed operation – conventional
Several manufacturers have followed this route. It appears that Vestas are moving to this option in place of Optislip (see below) as converter costs reduce.

Wide range variable speed operation - direct drive

- ENERCON - direct-driven synchronous generator with wound rotor.
- LAGERWEY – direct-driven synchronous generator with wound rotor.
- JEUMONT – direct-driven synchronous generator with a permanent magnet rotor.
- SCANWIND - direct-driven synchronous generator with a permanent magnet rotor and high-voltage winding stator. (see Section 2.7.1.3)

Limited range variable speed

- NORDEX - 'doubly-fed' induction machine.
- ENRON - 'doubly-fed' induction machine plus optionally a dynamic VAR control system (DVAR).

Narrow band variable speed operation

- VESTAS – Induction generator with variable slip of as much as 10% by an electronically controlled resistance in series with the rotor resistance (OPTISLIP).

Wide range variable speed has well known benefits [40]. A further advantage offshore is the ability to avoid damaging resonances. This is important for offshore turbine structures, where the resonant frequencies have proved difficult to predict accurately, particularly for monopile structures, and also due to different seabed conditions. As a result such frequencies may change over the lifetime of the structure [43].

However, looking at operating statistics from wind turbines using power electronics according to the German ISET Institute [42], it also seems that availability rates for these machines tend to be somewhat lower than conventional machines, probably due to failures in the power electronics.

Therefore, special attention must be paid to the electronic converter required to interface the synchronous or induction generator to the utility grid. At the moment, wind turbine manufacturers are pushing the wind energy market with larger and larger turbine rotor diameters, which are specially suited for offshore developments. Wind turbines up to 2 MW are currently being sold as commercial products on the market. There is competition between Insulated Gate Bipolar Transistor (IGBT), Gate

Turn-Off Thyristor (GTO) and integrated gate-commutated thyristor (IGCT) in the market for powers around 1 MW. However, IGBT may be favoured because of their use in motor drives of this size. For offshore applications, technologies which have demonstrated reliability with many units in industrial locations onshore will be attractive.

All the options used onshore will probably be used offshore, with the possible exception of Optislip. The only important factor in this area that is different offshore than onshore is availability, which would appear to favour fixed-speed machines, and direct-drive (because of the omission of the gearbox). It is not clear whether power electronic converters can be made reliable enough at suitable cost.

Future developments in this area are therefore expected to be:

Reliability
Work on converter design and remote monitoring to reduce downtime.

Benefits of variable speed
Work to establish whether the different conditions offshore (particularly turbulence) affect the pros and cons of variable speed.

Progress with device characteristics
Power electronic devices will get larger, cheaper and more efficient, and these may change the balance in favour of variable-speed.

Voltage and power factor
Research to optimise the converter in terms of control of power factor and voltage is likely to be useful [41].

Housing of equipment onshore
An ideal situation is to employ simple turbines offshore generating unregulated electric power as 'raw-material' in terms of voltage, frequency etc. Cables are laid to shore where the electricity is refined prior to grid connection. However, poor 'quality' of the generated electricity, in other words, a wide voltage and frequency range, will add cost to the electrical system within the wind farm and to shore. It is also possible to reduce the equipment required offshore (i.e. offshore transformer station) by accepting increased electrical losses in the connection to shore. However, any decision to locate complex items offshore rather than onshore must be supported by detailed analysis of the failure mechanisms and expected downtime.

There has to be a compromise between the simplicity of the electrical equipment offshore and the cost and efficiency of the transmission system to shore. It is not clear where the best compromise lies. The Scanwind/ABB Windformer concept assumes that for large distances to shore, an offshore converter station may be required to step up the DC voltage to a more economic level.

2.7.1.2 Direct drive

Direct-drive generators are considered above. There is scope for incremental improvement, particularly to suit the offshore environment. The principal aims are to make direct-drive cheaper, and with smaller diameters. Other types of machines may also be considered, like axial-flux and transverse-flux generators [41].

2.7.1.3 Scanwind: Windformer concept

The Windformer uses advanced cable technology developed by ABB's Powerformer high-voltage generator. Powerformer is capable of generating electricity at up to 400 kV, allowing it to be connected directly to the transmission system.

This has been achieved by changing the conventional stator windings consisting of mica-epoxy insulated rectangular conductor-bars to windings with circular conductors insulated with conventional solid dielectric high-voltage cable insulation materials. As a result of this, the conventional generator, the generator surge arresters, the medium-voltage generator breaker and busbars, and the step-up transformer are all replaced by one single component, as can be shown in Figure 2.18. However, this new design will also have the relatively high top mass and large torque levels typically of large direct drive systems, which can be a potential problem for future 4-5 MW concepts.

The Windformer generator operates at voltages ranging from 18 to 25 kV depending on the rotor speed. A directly connected diode rectifier is used to rectify the AC voltage from the generator. This option is taken to maximise the reliability and minimise the losses. The high voltage characteristic of the generator rectifier system facilitates the connection within the cluster of wind turbines with minimum losses. The wind turbines are all connected to a common DC node from which the energy is transmitted to a converter station.

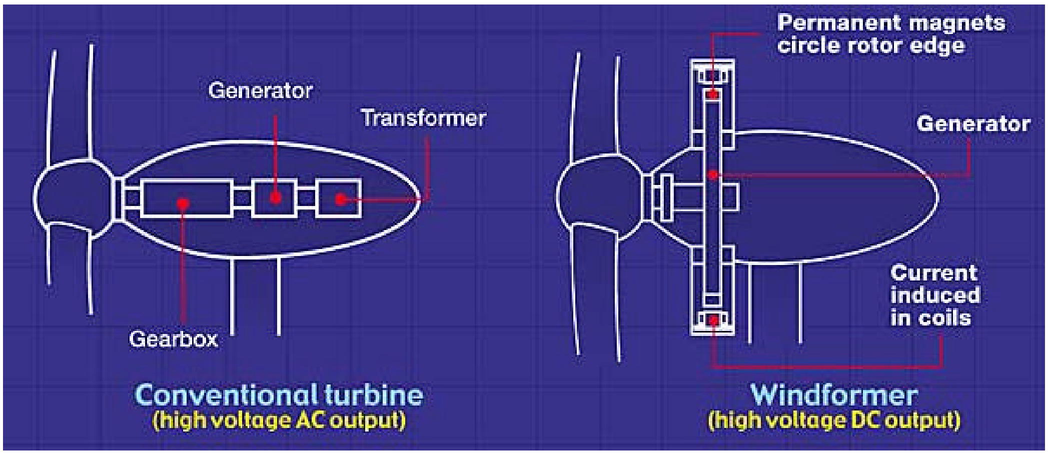


Figure 2.18 Diagram comparing conventional and Scanwind concepts
(Source http://www.newscientist.com/news/news_224335.html)

The principal claims for this concept are:

- **Higher energy production (see below):** Control of reactive power in order to control steady-state voltage and voltage fluctuations (flicker): this is also possible with most variable-speed concepts in principle, and with all turbine concepts if HVDC is used for transmission to shore.
- **Simple integration with HVDC transmission to shore, saving cost and losses:** Low maintenance / high availability, due to the omission of the gearbox and power electronics (except for the diodes, which are very reliable).

There are no published figures regarding the high energy production so this claim cannot be quantified. However, there are some positive factors which are likely to lead to higher energy production:

- Losses in the DC-transmission cable vary with the DC-level, which varies with the rotational speed of the turbine.
- Mechanical losses associated with the gearbox are avoided.
- The generator is likely to have high efficiency due to the permanent magnet rotor and its design.
- Losses related to the step-up transformer are avoided (typically 1% of annual production).
- The diode rectifier has lower losses than the active rectifiers habitually used in variable wind turbines.

GH estimate that the most that can be saved from gearbox, generator and transformer losses is probably about 10%.

2.7.1.4 Voltage level for output

The Scanwind concept has a benefit in avoiding the turbine transformer. This benefit is available to all design options if the generator is designed for a voltage sufficiently high (probably above 10 kV) to be suitable for interconnection of the turbines within an offshore wind farm. The technology exists to do this, but the effect on generator cost is significant. No commercial turbine manufacturer uses high-voltage generators, onshore or offshore. There would be advantages in studying the technology and the costs of high-voltage generators (up to 35 kV) in volume production.

2.7.1.5 Control system and SCADA

Turbine control systems are not expected to be different in principle offshore. However there is likely to be considerable effort to improve reliability, as control systems are a significant source of downtime. This effort will cover:

- formal techniques for estimation of reliability;
- redundancy of components (principally sensors) and complete subsystems;
- condition monitoring:
  - remotely via the SCADA system;
  - locally within the turbine controller;
- increased numbers of sensors to allow improved remote diagnosis, either manually or automatically by the SCADA system (perhaps by an expert system).

2.7.1.6 Robustness

This is a vague term, but it is intended to cover the need offshore for items of equipment to cope with a wider range of conditions. Principally these are environmental conditions, although temperature range is expected to be more benign offshore than onshore. In particular, it is likely that in the life of any offshore wind turbine, there will be periods when, due to cable failures, there is no power on the turbine for heaters and dehumidifiers for periods of several weeks or months. Is it cheaper to accept an extended recommissioning phase after such an event, or to design the turbines to allow generation to recommence after restoration of supplies without maintenance? This question can only be answered by studying the likelihood of cable failures, the restrictions on access to the turbines, and the effect of extended outages on individual components.

Electrical conditions, such as voltage range and voltage steps, could also be allowed to become more extreme if it resulted in an overall system (wind turbine to network connection point) which produces lower cost-of-energy. It is no longer necessary or perhaps even desirable to design turbines as though they will be connected directly to the distribution system.

2.7.1.7 Earthing and lightning protection

Earthing and lighting protection is an issue that should be addressed as offshore structures may be more exposed to positive polarity lighting strokes. Positive downward lightning is more destructive than the more common negative strikes, due to higher peak currents and charge transfers. This should be further investigated in order to establish and improve protection arrangements for offshore structures. It would be useful to have the same understanding of lightning phenomena offshore as is now available onshore.

2.7.2 Electrical Systems within the Wind Farm

2.7.2.1 Voltage level

This issue has been partly addressed above. In the Middelgrunden offshore wind farm, 30 kV XLPE cables dug into the ground are used within the wind farm. The idea of using oil-insulated cables was also carefully considered, but the tenders showed that the XLPE cable solution was by far the cheapest. Eventually authorities decided due to environmental concern not to allow oil-cables anyway. On the other hand, for the Horns Rev offshore wind farm to be built in Denmark [45] with an initial capacity of 150 MW, the cables within the wind farm will be operated at 22 kV nominal voltage and then a transformer station will increase the voltage up to 150 kV for transmission to shore.

A voltage of 36 kV within the wind farm is thought to be the highest which is acceptable, due to the cost of switchgear for higher voltages.

There may be a benefit in development of switchgear at these voltage levels specifically for offshore wind turbines. Such switchgear would ideally be highly reliable, able to withstand humidity and salt, and require no maintenance.

2.7.2.2 Cable laying techniques

Conventional cable laying vessels are expensive and may have too large a draught to operate in relatively shallow waters. There is a need to develop new techniques for installing the relatively short cables within the wind farm (~ 1000 m lengths). Hauling the cables within the wind farm could be relatively straightforward and could be handled by winches temporarily mounted on the foundations, or on simple barges.

There is also a need to consider new techniques for cable recovery and repair, which can be carried out in most sea states.

2.7.3 Transmission to Shore

2.7.3.1 Voltage level

Three possible options could be used for connecting an offshore wind farm:

- (a) multiple medium voltage links (up to 35 kV)
- (b) single high-voltage link (100 to 200 kV)
- (c) HVDC link.

According to [52]:

- the first option appears to be the cheapest for distances offshore of a few kilometres and relatively small wind farm size (say up to 200 MW);
- the second option is appropriate for longer distances offshore and larger wind farms;
- the final option is appropriate for distances to shore above 25 km and for power levels of more than 200 MW.

In the Middelgrunden wind farm, (40 MW and 3 km to shore), the first option has been selected. Each turbine contains a 690 V/30 kV transformer in the bottom of the tower. From the central turbine of the wind farm two 3 kilometres long parallel 30 kV XLPE cables connect the wind farm to the national grid at the nearest point on shore. At this point 500 MW coal-fired power plants are situated, and provide an excellent point of connection for the wind farm. The tenders showed that two parallel cables, equal to the cable used between the turbines, are the cheapest solution.

However, higher installed capacity is expected for future offshore developments. Possible technical solutions will range from 150 kV or 400 kV for multiple wind farms to one 150 kV cable for a wind farm alone. HVDC is discussed below. In the Horns Rev Wind Farm [45], the solution finally chosen is one 150 kV cable for this wind farm alone. Later expansion of the site may result in a ring system. Three single-conductor cables or one three-conductor cable will be used to connect the wind farm to shore. Both types can be made with XLPE insulation and the three-conductor with fluid filled (oil/paper) insulation as well, although as seen before, environmentally-speaking oil insulation presents disadvantages.

2.7.3.2 Offshore substations

If voltages greater than 33 kV are used for the links to shore, then an offshore substation will be required, containing a step-up transformer. Unfortunately, there is no precedent for a small substation located at sea. It is likely that offshore transformer stations would be a three-legged steel structure with all the equipment necessary and supplied as a "turnkey" solution. Packaged substations are available, but these are usually used as emergency replacements or for quick installation in remote areas. The manufacturers are cautious about offering these for offshore installation. The reticence may disappear if a sizeable market appears.

For any site, there is some optimisation required to decide the number and size of offshore substations. A single large substation is likely to be cheaper due to the structure costs, but a failure results in the loss of the output from the entire wind farm. The same argument applies to the cable link to shore. It is likely that offshore wind farm design will include formal assessment of these risks, in order to select the optimum configuration.

The main item in the offshore substation will be the transformer, but there will also be medium-voltage switchgear and possibly high-voltage switchgear.

An emergency diesel generator may be included in the equipment. Due to the rough weather conditions and difficulties with access, electricity supply cuts for prolonged periods are possible. It may be justified to equip the station with a diesel generator in order to keep all essential equipment, such as climate conditioning, control and safety systems operating during these periods. The diesel generator could also supply the auxiliary loads in the wind turbines.

For large onshore wind farms, it is likely that on-load tap changers on the transformer would be required for voltage control. There is the same need for offshore wind farms, but maintenance requirements would be excessive. Table 2.11 summarises failures in substation transformers, where it can be seen that mechanical failures, and in particular on-load tap changer failures, are the most common cause of outage [50].

Table 2.11 Substation transformers.

Origin	Less than 1 day	1 to 30 days	More than 30 days	Total
Mechanical	24.3	20.5	8.3	53.1
Dielectric	7.1	7.9	15.8	30.8
Thermal	2.3	4.6	2.3	9.2
Chemical	1.1	-	-	1.1
Unknown	5.8	1.4	1.6	2.8
Total	36.2	34.6	29.2	100

Failures with forced and scheduled outage, as a percentage of total number of failures.

Solid-state load tap changers for medium power transformers (15 kV to 34 kV) with conditioning monitoring are being investigated, and it is claimed that they could reduce maintenance costs by 50-80% while increasing safety, reliability and power quality. This could be a line of research for higher voltage applications in conjunction with capacitor and reactor compensation [46].

The alternatives to on-load tap-changers are:

- specifying the turbines to be able to operate with a wide voltage range, so that voltage control is unnecessary;
- fitting off-load tap-changers, which are cheaper and smaller, and accepting that occasionally it will be necessary to shut down the wind farm for a few minutes in order to adjust the tap position.

The conclusion is that there is a need for detailed consideration of offshore substation design. It is likely that there will be a substantial market for such products, and there is substantial scope for detailed design to produce high availability and low cost.

2.7.3.3 HVDC

Since the establishment of the HVDC industry over 40 years ago, the technology and its application has undergone dramatic transformation. Nowadays, fast progress in the field of power electronics devices with turn off capabilities such as IGBT and GTO, makes Voltage Source Converters (VSC) more attractive for HVDC applications. To date, there are three manufacturers that have developed the state-of-the-art HVDC technology suitable for offshore wind farms; ABB, Alstom and Siemens.

As an example case, Siemens Power Transmission and Distribution Division has outlined a preliminary version of a possible 675 MW offshore DC/AC-Converter Station as can be seen in Figure 2.19 [49]. The dimensions of this station would be approximately 50 m in length, 50 m deep and 28 m in height. As shown, it would be designed with a platform for helicopter access for maintenance operations.

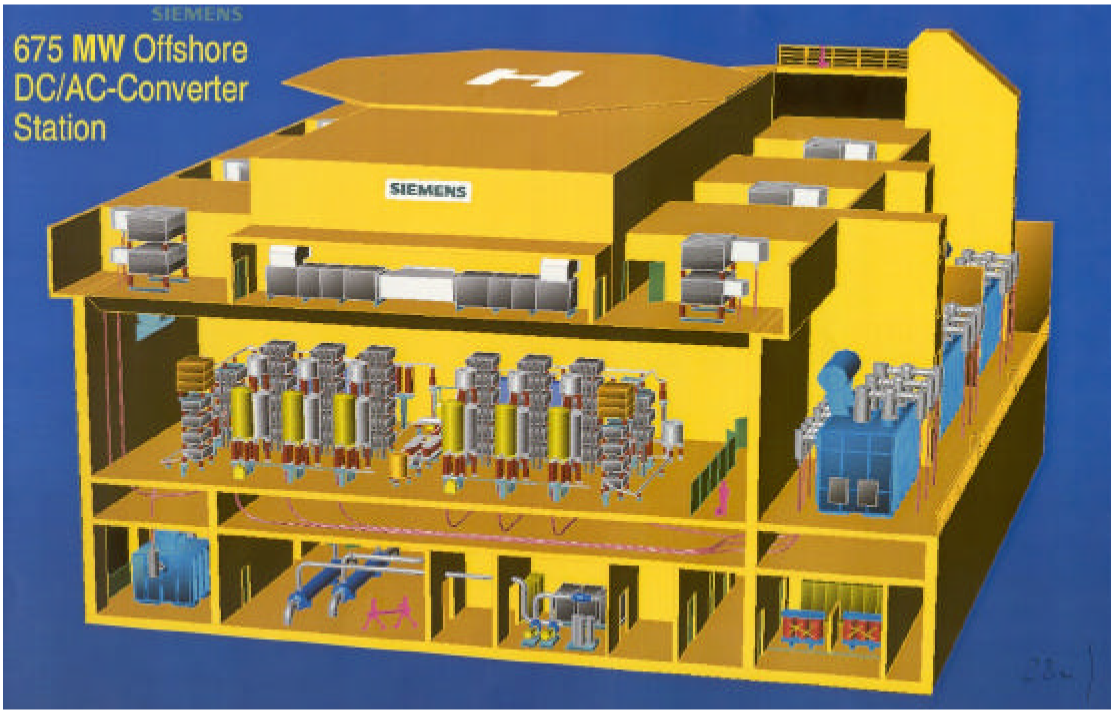


Figure 2.19 675 MW Siemens Offshore DC/AC-Converter Station

HVDC by ALSTOM [47]

Alstom makes use of conventional technology based on thyristor devices. Thyristor converters in conventional HVDC always require reactive power. Additional power components such as switched capacitor banks or Static Var Compensators (SVC) must be used in order to supply the reactive power demand of the converter station.

HVDC-Light by ABB [48]

The technology uses IGBTs as opposed to the thyristors used in traditional HVDC systems. The IGBTs are characterised by switching very fast between two fixed voltages. PWM and low pass filtering are used to achieve the desired AC waveform. Active and reactive power can be controlled by the PWM switching technique. As less components are required than conventional designs, the area required for a converter station is 20% lower.

HVDC^{PLUS} by SIEMENS [49]

The HVDC^{PLUS} converter is also equipped with IGBTs, and the important characteristics are similar to HVDC-Light. The technology can deal nowadays with up to 200 MW offshore capacity through a single sea cable. Future developments, with Light Triggered Thyristors (LTT), will be able to cope with up to 600 MW capacity. Recently, SIEMENS has been awarded the contract for the HVDC converter stations of a 500 MW submarine cable link between Northern Ireland and Scotland. For the first time in a commercial HVDC system, direct-light-triggered thyristors with integrated overvoltage protection will be used for the AC/DC converter stations.

Published cost information is not available to allow a comparison of the technologies, but it can be concluded that for the distances and power levels being considered for offshore wind farms, HVDC is more expensive than a conventional AC solution. Nevertheless, HVDC may well be used for offshore wind, because:

- Restrictions in building new overhead power lines onshore may require underground cables onshore, which narrows the gap between AC and HVDC.
- HVDC allows the entire offshore wind farm to operate at a variable frequency, which can give some benefit in energy capture.
- HVDC provides independent control of reactive power at the shore converter station, which could be of great benefit to the network operator, and could allow the network connection point to be on a weaker section of network, closer to the landfall.
- HVDC provides almost no contribution to fault currents, which in many areas are a major limitation on the connection of new generation of any type.

2.7.3.4 Cable installation

Submarine cables are vulnerable to damage by shipping, unless buried or otherwise protected. Burial is often the preferred method, although in some conditions other techniques are appropriate. Available information on actual likelihood of this sort of damage in the likely sites for offshore wind farms is sparse [51].

The major risk of damage is from ships' anchors and trawl equipment. The risk therefore varies greatly with location. It is also affected by seabed conditions. In areas with a hard bottom, anchors and trawl gear will not penetrate: therefore, the cable could be buried to a shallower depth than in areas with soft soils. Consequently, in a softer sea bottom, the cable would need deeper burial to have adequate protection, though the cost of burial would be lower.

To date, there are no developments on minimum standards for cable route surveys. There are several industry standard techniques for subsea cable route surveys:

- Multibeam bathymetry is for developing seafloor topography along a proposed route and enables large swaths to be surveyed with a single pass of the survey vessel. Various systems are available on the market. Basically the higher the system frequency, the greater the resolution and data density, but the shorter the system range.
- Side scan sonar is for seabed imaging. Side scan provides excellent target detection and seabed classification capabilities.
- Sub-bottom profiling is for the collection of data concerning shallow geological and sedimentary conditions. The technique is an essential component in pre-installation surveys for buried marine cables.

There may be scope for development of new techniques and equipment suitable for route selection and installation of cables for offshore wind farms, particularly as the water depths will generally be shallower than for cables for other applications.

2.7.3.5 Energy storage

The connection to shore forms a greater fraction of the project cost than for the equivalent grid connection for onshore wind farms. This connection to shore will have a capacity factor of 0.3 to 0.4, depending on the site wind conditions. In other words, it is approximately three times larger than it needs to be, in terms of the energy it transmits per year. There is therefore some scope for examining techniques for storage of energy offshore, one benefit of which would be to reduce the size and cost of the connection to shore. Recent developments in fuel cells may possibly lead to energy storage which is cheap, reliable and small enough to be located offshore. This is considered a ‘long shot’, but worth investigation [53]. There may also be benefits in electricity trading, and in reducing the adverse effects of large wind penetrations on national electricity systems. The planned Laesø offshore wind farm in Denmark will include a small installation onshore, to investigate these latter benefits [54].

2.7.4 Conclusion

In conclusion, it can be said that there are many areas where technical developments are expected which will improve the economics and reliability of offshore wind farms. Some of these will arrive because of developments in other industries and in onshore wind, but others are specific to offshore wind and are therefore more risky.

There are also several areas where the risk is too high for commercial wind farm developers or turbine manufacturers, and which are therefore suitable for pre-competitive or collaborative investigation.

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Table 2.3 Wind turbines above 52 m diameter

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Nordex N-80	2500	60	5026	80	19		80,000		736.3	366.2	1,840,651
Nordex N-80	2500	80	5026	80	19	179,000	80,000		766.9	381.5	1,917,345
Nordex N-80	2500	100	5026	80	19		80,000		920.3	457.8	2,300,813
AN Bonus 2 MW/76	2000	80	4,536	76	17	162,000	65,000				
AN Bonus 2 MW/76	2000	98	4,536	76	17	162,000	65,000				
NEG Micon NM 2000/72	2000	64	4072	72	18	113,000	76,000	6,800	889.6	437	1,779,296
NEG Micon NM 2000/72	2000	80	4072	72	18	130,000	76,000	6,800			
Vestas V80/2.0 MW	2,000	60	5,027	80	19	110,000	61,200	12,000			
Vestas V80/2.0 MW	2,000	67	5,027	80	19	130,000	61,200	12,000			
Vestas V80/2.0 MW	2,000	78	5,027	80	19	170,000	61,200	12,000			
Vestas V80/2.0 MW	2,000	100	5,027	80	19	200,000	61,200	12,000			
Enercon E-66/18.70	1800	65	3848	70	22	122,000	101,000	4,200	886.2	414.6	1,595,231
Enercon E-66/18.70	1800	85	3848	70	22	191,000	101,000	4,200	950.2	444.5	1,710,271
Enercon E-66/18.70	1800	98	3848	70	22		101,000	4,200	1036.8	485	1,866,215
Vestas V66/1.65 MW	1,650	60	3,421	66	19	87,000	55,000	4,000			
Vestas V66/1.65 MW	1,650	67	3,421	66	19	102,000	55,000	4,000			
Vestas V66/1.65 MW	1,650	78	3,421	66	19	141,000	55,000	4,000			
BWU/Jacobs MD 70	1,500	65	3,850	70	19		56,000	5,400			
BWU/Jacobs MD 70	1,500	80	3,850	70	19		56,000	5,400			
BWU/Jacobs MD 70	1,500	85	3,850	70	19		56,000	5,400			
BWU/Jacobs MD 77	1,500	61.5	4,656	77	17		56,000	5,400			
BWU/Jacobs MD 77	1,500	85	4,656	77	17		56,000	5,400			
BWU/Jacobs MD 77	1,500	90	4,656	77	17		56,000	5,400			
BWU/Jacobs MD 77	1,500	100	4,656	77	17		56,000	5,400			
Enercon E-66/15.66	1500	67	3421	66	22	130,000	97,400	3,900			
Enercon E-66/15.66	1500	85	3421	66	22	191,000	97,400	3,900			
Enercon E-66/15.66	1500	98	3421	66	22		97,400	3,900			

Table 2.3 continued

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Enron EW 1.5s	1500	64.7	3904	70.5	20						
Enron EW 1.5s	1500	80	3904	70.5	20						
Enron EW 1.5s	1500	85	3904	70.5	20						
Enron EW 1.5s	1500	100	3904	70.5	20						
Enron EW 1.5sl	1500	61.4	4657	77	18.3						
Enron EW 1.5sl	1500	80	4657	77	18.3						
Enron EW 1.5sl	1500	85	4657	77	18.3						
Enron EW 1.5sl	1500	100	4657	77	18.3						
Enron Wind 1.5 sl	1,500	61.4	4,657	77	18				1090.8	351.3	1,636,134
Fuhrlander MD 77	1,500	65	4,655	77	17.3	93,000	55,500	5,000	1022.6	329.5	1,533,876
Fuhrlander MD 77	1,500	85	4,655	77	17.3		55,500	5,000	1073.7	346	1,610,569
Fuhrlander MD 70	1,500	65	3,850	70	19	93,000	52,500	5,000	947.6	369.2	1,421,391
Fuhrlander MD 70	1,500	85	3,850	70	19		52,500	5,000	1005.5	391.8	1,508,311
NEG Micon NM 1500/72	1500	98	4,072	72	17.3	89,000	44,000	6,800	1056.7	389.2	1,585,005
NEG Micon NM 1500/72	1500	64	4,072	72	17.3	132,000	44,000	6,800	988.5	364.1	1,482,746
NEG Micon NM 1500/72	1500	80	4,072	72	17.3	201,000	44,000	6,800	1022.6	376.7	1,533,876
NEG Micon NM 1500C-64	1500	68	3217	64	17.3	113,000	43,000	6,000	801	373.5	1,201,536
NEG Micon NM 1500C-64	1500	80	3217	64	17.3	148,000	43,000	6,000	835.1	389.4	1,252,665
PWE 1566 (Pfleiderer)	1,500	65	3,421	66	22	220,000	70,000	3,900			
Sudwind S-70	1,500	65	3,848	70	19	95,000	56,000	6,020	971.5	378.7	1,457,182
Sudwind S-70	1,500	85	3,848	70	19		56,000	6,020	1027.7	400.6	1,541,545
Sudwind S-70	1,500	98.5	3,848	70	19		56,000	6,020			
Sudwind S-70	1,500	114.5	3,848	70	19		56,000	6,020			
Sudwind S-77 = MD77	1,500	61.5	4,657	77	17.3	80,000	56,000	6,020	1022.6	329.4	1,533,876
Sudwind S-77 = MD77	1,500	85	4,657	77	17.3		56,000	6,020	1078.8	347.5	1,618,239
Sudwind S-77 = MD77	1,500	90	4,657	77	17.3		56,000	6,020			
Sudwind S-77 = MD77	1,500	96.5	4,657	77	17.3		56,000	6,020	1094.2	352.4	1,641,247
Sudwind S-77 = MD77	1,500	100	4,657	77	17.3		56,000	6,020	1227.1	395.2	1,840,651
Sudwind S-77 = MD77	1,500	111.5	4,657	77	17.3		56,000	6,020	1182.8	381	1,774,183
Made AE-61	1,320	60	2,922.50	61	18.8	89,500	49,000				
AN Bonus 1.3 MW/62	1300	68	3019	62	19	80,000	50,000		896.7	386.1	1,165,745

Table 2.3 continued

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Nordex N-60	1300	60	2828	60	19		49,200	4,800			
Nordex N-60	1300	65	2828	60	19		49,200	4,800			
Nordex N-60	1300	69	2828	60	19	98,400	49,200	4,800	837.7	385.1	1,089,052
Nordex N-60	1300	70	2828	60	19				845.6	388.7	1,099,278
Nordex N-60	1300	85	2828	60	19	154,000	49,200	4,800	884.9	406.8	1,150,407
Nordex N-60	1300	120	2828	60	19		49,200	4,800			
Nordex N-62	1300	60	3020	62	19		49,200	4,800			
Nordex N-62	1300	65	3020	62	19		49,200	4,800			
Nordex N-62	1300	69	3020	62	19	98,400	49,200	4,800	853.5	367.4	1,109,503
Nordex N-62	1300	70	3020	62	19						
Nordex N-62	1300	85	3020	62	19	154,000	49,200	4,800			
Nordex N-62	1300	120	3020	62	19		49,200	4,800			
DeWind D6	1250	68	3217	64	24.8	72,000	44,000		944.8	367.1	1,181,000
DeWind D6	1250	91.5	3217	64	24.8	116,000	44,000		1026.4	398.8	1,283,000
DeWind D6	1250	65	3019	62	26.1	72,000	44,000		900	372.6	1,125,000
AN Bonus 1 MW 54	1000	50	2300	54.1	22	54,000	40,000	4,650	828.3	360.1	828,293
AN Bonus 1 MW 54	1000	60	2300	54.1	22	60,000	40,000	4,650	859	373.5	858,970
AN Bonus 1 MW 54	1000	70	2300	54.1	22	90,000	40,000	4,650	899.9	391.2	899,874
DeWind D6	1000	68.5	3019	62	25.2			4,100	1120	371	1,120,000
DeWind D6	1000	91.5	3019	62	25.2			4,100	1222	404.8	1,222,000
Enercon E-58	1000	70	2642	58	24	130,000	82,000	3,400	1060.9	401.6	1,060,931
Fuhrlander 200/1000	1000	70	2180	52.7	22				741.4	340.1	741,373
Fuhrlander FL 1000	1,000	70	2642	58	22	95,000	40,500	4,500			
Fuhrlander FL 1000	1,000	82	2642	58	22	120,000	40,500	4,500			
Fuhrlander FL 1000	1,000	70	2463	56	22	95,000	40,500	4,500			
Fuhrlander FL 1000	1,000	82	2463	56	22	120,000	40,500	4,500			
Fuhrlander FL 1000	1,000	70	2290	54	22	95,000	40,500	4,500	741.4	323.7	741,373
Fuhrlander FL 1000	1,000	82	2290	54	22	120,000	40,500	4,500	833.4	363.9	833,406
MWT 1000 (Mitsubishi)	1,000	60	2,463	56	21	63,000	32,000	4,100			
NEG Micon NM 1000/60	1000	70	2827	60	18	114,000	33,500	5,000	971.5	343.6	971,455
NEG Micon NM 1000/60	1000	80	2827	60	18	114,000	33,500	5,000	1007.2	356.3	1,007,245

Table 2.3 continued

TYPE	RATED POWER kW	HUB HEIGHT m	SWEPT AREA m^2	DIA. M	SPEED rpm	TOWER WT kg	NACELLE MASS kg	BLADE WT kg	EURO/ kW	EURO/ m^2	PRICE EURO
Nordex N-54	1000	60	2290	54	22	90,200	50,000	4,200	833.4	363.9	833,406
Nordex N-54	1000	70	2290	54	22	105,000	50,000	4,200	843.6	368.4	843,632
Nordic 1000	1,000	60	2,290	54	25	45,000	29,000	3,600	787.4	343.8	787,389
Enron Wind 900s	900	60	2,206	55	28						
NEG Micon NM 900/52	900	60	2,140	52.2	22	72,000	24,500	4,200	772.6	324.9	695,357
NEG Micon NM 900/52	900	74	2,140	52.2	22	97,000	24,500	4,200	795.3	334.5	715,809
Frisia F 56/850 kW	850	70	2489	56.3	25	74,000	31,000	4,500	956.4	326.6	812,954
Fuhrlander FL 800	800	70	2,180	52.7	22	88,000	40,500	4,500	894.8	328.4	715,809

Table 2.6 Summary of wind turbine blade manufacturers

Company	Capacity	Technology	Comment
Abeking & Rasmussen Rotec	Largest blade 40m for MBB, Aeolus II wind turbine.	Glass epoxy and glass polyester	Best established of the German manufacturers having mainly supplied German wind turbine manufacturers.
Aerpac	Over 8000 blades supplied, 620 from their new Scottish factory since 1997. Size range 7 m to 48 m	Employing resin infusion system for glass epoxy blades.	Major blade manufacturer, second to LM in market share. Recently taken over by Enron.
ATV	All carbon blades up to 14 m length. Hybrid blades using carbon reinforcement up to 32 m length.	Carbon and hybrid epoxy. The only company making one piece all-carbon blades.	Recovering their market position after significant technology problems in production of medium-sized blades for Tacke Windtechnik. Now owned by Caterpillar.
Borsig Rotor	A new company founded end 1999. 31 m prototype blade manufactured (March 2000) 850 blades anticipated production in 2001. 39 m blade for Nordex 2.5 MW is the next prototype.	Glass epoxy.	Manufacturing plant in Rostock. Technical input is from Walter Keller who had founded Aero Construct which later became LM Aero Construct. Supplier for Nordex and Südwind.
Enercon	Large number of blades for their E40 and E66 turbines especially.	Glass epoxy.	Manufacturing blades exclusively for their own projects. Have also sourced blades in quantity from Aerpac.
Euros	24.5 m (Sept. 1999) and 27.5 m (March 2000) blades load tested. Blades first in operation (June 2000)	Glass epoxy	Aerodyn designs. Euros started in 1997 supplying blades for machines in 600 kW – 1.5 MW range.
LM Glasfiber	Around 36,000 blades supplied. LM claim a 49% world market share. Blade supply from 11 m to 38.8 m. Blade manufacture on 12 sites world wide.	Glass polyester. Carbon tubes in tip brakes and carbon reinforcement in largest blades.	Long established as the world's leading supplier of wind turbine blades. Have always been more diverse than rotor blades. Leading supplier of lightweight composite parts for the European rail industry.
MFG	They claim to be the leading US producer of large rotor blades over 20 m.	Glass epoxy.	Manufacturing blades primarily for Enron Wind Corporation.
NEG Micon Aerolaminates	Over 1000 large blades manufactured. 15 m to 31 m. 50 m blade about to be made and tested.	Wood epoxy – the only major supplier of wooden blades.	Principally supplying NEG Micon. Recent major expansion of manufacturing capability. Set up on the Isle of Wight with direct shipping facilities.
NOI Rotortechnick GmbH	Currently working on 39 m blades with 55 m blade for a 5 MW turbine planned this year.	Glass epoxy	Aerodyn designs. Founded in 1999, first blade produced October 1999.
Polymarin BV	Around 2000 blades supplied. Blade lengths up to about 26 m..	Glass epoxy primarily and limited carbon epoxy	Started in 1982.
Polymarin-Bolwell Composites	Over 800 blades for 600 and 750 kW wind turbines. Latest blades up to 37 m length.	Glass epoxy.	Canadian offshoot of Polymarin now 50% owned by Australian Bolwell Corporation. Set up in 1995 to supply large blades to US market.
TECSIS	70% export production to US and Europe. Hundreds of 25 m blades supplied. Currently supplying larger blades (34 m) for EWC projects in US.	Glass epoxy construction.	Brazilian manufacturer. Their main market is in the US for Enron Wind Corporation. Have also supplied Enercon.
Vestas Wind Systems	Thousands of blades produced for own turbines. World market leader in wind turbine supply.	Glass epoxy, spar/shell construction using prepregs.	Well established in-house blade manufacturing technology producing low mass flexible blades.
NEG Micon Aerolaminates	Over 1000 large blades manufactured. 15 m to 31 m. 50 m blade about to be made and tested.	Wood epoxy – the only major supplier of wooden blades.	Principally supplying NEG Micon. Recent major expansion of capability. On the Isle of Wight with direct shipping facilities.

CHAPTER 3

GRID INTEGRATION

SUMMARY

The objective of chapter 3 is to analyse the current state of the art in grid integration of offshore wind farm. Grid integration issues are discussed against the EU target of 10.000 MWe of large wind farms.

In principle, large-scale offshore wind power results potentially in increased unbalance between production and consumption. Cross-border power transmission limitations prevent a geographical smoothing of the production/consumption imbalance. Solutions to deal with this unbalance discussed in the paper are: Demand Side Management, increased flexibility and dispatching capability of conventional plants, the use of energy storage, application of wind power forecasting techniques and increasing the controllability of wind farm output. It is concluded that, although all options could eventually contribute to the solution (requiring much more RTD), the most promising immediate step is to increase the accuracy and reliability of wind power forecasting techniques.

The impact of large-scale offshore wind power on power systems performance (power quality) requires special attention since coastal connection points will often be relatively weak. Flicker, harmonics and interharmonics and static stability are not considered as limiting factors but dynamic grid stability may be a limiting factor, in particular in relation to wind farm correlated sudden shut-down of wind turbines. These problems may eventually lead to modifications in wind turbine control philosophies at high wind speeds.
Large scale offshore wind power will further impose an increase of primary control (response time of the order of seconds)) and secondary control (response time of the order of minutes) requirements of the conventional production components of the system; such requirements could also be imposed on large wind farms, although it remains unclear how such requirements could be efficiently implemented.

The connection technology between offshore wind farms and the grid is characterised by large power (> 100 MW) and potential large distances. The paper addresses the potential advantages of using HVDC links, which could also contribute to power quality management problems mentioned above.
Access of large offshore wind farms to the grid must be in accordance with national grid codes. Current requirements imposed by national grid codes are in general not considered to be a limiting factor for the development of large-scale offshore wind power, although these requirements are not particularly suitable for non-predictable, highly variable energy sources. Project developers may have to take additional measures to comply with the grid codes, such as: use of variable speed wind turbines, special purpose remote control systems (with individual power set points for the wind turbines, etc). In the long term, HVDC transmission and/or on-site large storage facilities with controllable reactive power output, might present interesting opportunities allowing Large scale offshore wind power plants to meet grid access requirements more easily.

CONTENTS OF CHAPTER 3 : GRID INTEGRATION

3.1 INTRODUCTION

3.1.1 Interaction between production and consumption (EMS)

3.1.1.1 Production and Consumption patterns

In all electrical systems, the production and the consumption should always be in close conformity as it would otherwise be physically impossible to keep the system frequency within allowable tolerances. This balance is the main reason why continuous production planning is necessary.

In the EU white paper on Renewable energy, 40000 MWe installed capacity is targeted by 2010 (delivering about 80 TWh/y). If 25% should be delivered by 10000 MWe capacity from large wind farms, preferentially offshore, then this would lead to an annual production of over 20 TWh/y. Concentration of such large production capacity could lead to a large penetration in the existing network and the problems of balancing production and consumption becomes then important.

Load forecast aims at an economic and reliable adjustment of the production to the load, from seasonal, daily down to 15 minutes level. Load forecast handles prediction of the load with all stochastic aspects involved. Analysis tools include probabilistic generation simulation and generation costing models and reliability analyses in generation/transmission based on Monte Carlo simulations.

The temporal production from wind parks, with a substantial stochastic character, will require new sophisticated methods to forecast the production capacity, and to mobilise conventional generation capacity to continuously meet the consumption. What is the state of the art in short term resource forecast for offshore wind parks?

Prognosis tools: At European level, an annual wind turbine production of about 20 TWh in 2010 would require a number of changes in the EMS practices and tools. Especially the prognosis tools currently available for this variable production concept need to be further developed and optimised. When the local penetration of wind energy is large, it is very important – technically and financially – to be able to forecast the expected production from such a large installed capacity. In some electricity markets (e.g. the UK NETA balancing market system) it is also very important for individual wind farms. Furthermore, the capacity cannot be equally distributed throughout Europe as the wind resources and the available sites are concentrated in certain areas, e.g. Northern Europe. Experience has demonstrated that the uncertainty of the present prognostic tools is in the vicinity of 30-40% for a 36-hour forecast. The accuracy of the prognostic tools should be improved to less than 10% to reduce the costs for regulating power to an acceptable level. There is another issure related to forecasting periods (‘look-ahead’ period). In conventional systems, it is relatively easy to forecast generation and demand for periods of a day or more ahead. It may be suspected that look-ahead periods of 24 hours and more are chosen for administrative convenience rather than real need. The costs this imposes on the system or on generators is small in conventional systems, but is much higher when there are variable sources such as wind in the generation mix. There is a need to establish the costs and benefits of longer look-ahead periods, in order to determine the optimum. This optimum is likely to be different for different systems.

3.1.1.2 Utility operation and energy management systems

In spite of the improvements made in the prognoses tools, it will remain difficult to forecast the power gradients arising in the wind power production within a quarter of an hour. The Transmission System Operation (TSO)will be under an obligation (i.e. the grid code) to keep the **Area Control Error (ACE)** within limits to avoid penalties for too large imbalances and to ensure that these **power gradients** are compensated for via the secondary control, either by central production facilities or cross-border exchange. This gives rise to a number of important questions, for instance: Who will be establishing and financing data acquisition and remote control facilities as such? Who will be paying for the lost production and other system costs? Who will be refunding the loss if the production margin is lowered before a particular time of operation – resulting in the wind turbine owner being unable to deliver the production offered to the exchange? How will the priority between several wind farms be administered – whose production is going to be restricted? Is this need best met by requiring wind farm operators to install more expensive equipment in order to appear more like conventional generators?

3.1.1.3 Means to face production-consumption balance

Demand Side Management. An improved agreement between consumption and production would also improve the real-time operation.
Energy storage : Means to face imbalance between consumption and production: operation and EMS in situations with imbalance between consumption and production within a certain area must be investigated in-depth in order to ensure operation with a high penetration of wind energy. A number of solutions must be developed, such as:

- *Electricity storage facilities*. Regenerative fuel cells, pumped storage are important technologies for storing large quantities of electrical energy. While pumped storage is already been fully exploited for peak shaving with a limited possibilities for extension, the regenerative fuel cells would offer a flexible means for storing energy. If this technology could reach technical and commercial maturity this would significantly improve the real-time operation in systems with high penetration of fluctuating wind energy.
- *Energy Conversion.* The feasibility for conversion of (surplus) electricity into Hydrogen should be investigated.
- *Possible modifications on conventional power plants*. The present control possibilities including response time for the existing thermal power plants should be analysed.

3.1.2 Design and operation of the transmission grid : Connection technology for LSOWE

3.1.2.1 Technical feasibility limits for LSOWE grid connection

Grid integration of large-scale offshore wind wind farms may be constrained by the technical limits of state-of-the-art grid connection equipment. The number of (parallel) cables between the wind farm and the onshore grid connection point will often be limited for economic or environmental reasons.

Operating conditions : Rapid technological progress is made in the areas of sea cable technology and offshore electrical equipment. Questions to be answered are : What are the maximum (power, voltage,) ratings for state-of-the-art sea cables, transformers and switchgear.

Maximum distance from shore : For offshore wind farms at a large distance from the shore losses and reactive power production in the sea cable(s) may become important. A question to be answered is : what is the maximum distance from the shore for which grid connection using current technology remains technically and economically feasible ?

3.1.2.2 Reliability and maintainability of offshore electrical equipment

There is currently little experience with high-capacity transformers and switchgear installed on offshore platforms. The environmental conditions in an offshore environment may significantly reduce equipment reliability (e.g. marine corrosion). Access for maintenance will not always be possible. Design changes to improve reliability and maintainability may yield significant benefits for the development of large-scale offshore wind farms.
The same issue becomes even more important when it is considered to install power electronics (frequency converters) offshore.
Information is required regarding the behaviour of electrical equipment in a highly aggressive offshore environment, and regarding developments aimed at improving reliability and maintainability.

3.1.2.3 AC/DC conversion technology

Whereas most of the current offshore wind energy projects use an AC link for the grid connection, the possibility of using DC links has never been excluded, and due to technological progress in the field of AC/DC conversion technology, DC links may become the preferred choice for future offshore wind farms.
Questions to be answered are: What performance can be expected from state-of-the-art AC/DC conversion technology (in particular, capital cost and electrical losses)?

Economic Break-Even Distance for DC connection.
Another important question to be addressed is from what distance may DC links be considered as being economically more interesting than AC links, taking into account the current state-of-the-art in AC/DC conversion technology. This distance will be a function of MW capacity.

Ease of connection
HVDC may offer control benefits which allow connection to a weaker part of the network, so saving costs. If underground cable is required for the onshore section, for environmental reasons, HVDC may be cheaper than AC.

3.1.2.4 Improving LSOWE grid connection reliability

Redundant grid connection systems.
By increasing the redundancy in the grid connection system it is expected to improve the availability and the reliability of the system. On the other hand, increasing redundancies will also increase the system complexity and cost. Given the limited available information on the reliability of offshore electrical equipment, it is not excluded that increasing redundancy will effectively decrease the overall system reliability. Some questions to be answered are therefore : What is the optimal degree of redundancy to be used in LSOWE grid connection systems ? How must emergency (back-up) power for equipment in the wind farm be provided ?

Internal Wind Farm Grid Lay-Out
Many different designs have been considered for the internal grid of large-scale wind farms. The lay-out adopted for the internal wind farm grid may have an important impact on the global wind farm availability and on investment costs. A question to be answered is therefore : What is the optimal internal grid lay-out ?

3.1.2.5 Innovative solutions

New wind turbine concepts have been proposed which might significantly alter the cost and the feasibility of grid connection of large scale offshore wind farms. For instance, systems using DC generation in the wind turbines, combined with IGBT-based DC/AC conversion onshore have been announced. The impact of these new designs on grid connection must be analysed.

3.1.3 Impact of LSOWE on power system performance

3.1.3.1 Power Quality issues

Various factors contribute to voltage fluctuations at the terminals of a wind turbine generator: aerodynamic phenomena (wind turbulence, tower shadow effect, etc) short circuit power at the grid connection point,(?), number of wind turbines, and the type of wind turbine control systems. Under particular connection conditions, this may result in a significant flicker level. As a consequence, some limitations for installed power could be recommended in case of a weak network or particular polluting devices. This is especially valid for offshore wind farms, as the grid connection point may be a weak point of the grid and the building of a reinforced transmission line may not be feasible for environmental reasons.

- Required grid characteristics (Installed power versus short circuit power)
- Impact of long-distance power cable to shore on power stability
- Suitability of existing guidelines for Power Quality Assessment

However typical power quality issues, like flicker, harmonics, voltage fluctuations and variations (during normal operation and during switchings of the wind turbines) is a less problem for LSOWE due to the soothing effect of the number of wind turbines within the wind farm and due to the improved power quality behaviour of today's wind turbines. This problem will be treated in chapter 3.2.3.

3.1.3.2 Impact of wind turbine generator type and power electronics on power quality

The impact on voltage control depends primarily on the connection point and the generating plant power output. Present day onshore wind parks have a relative low power output and are connected to the Medium Voltage grid system, which means they rarely have a significant impact on voltage control. But in the event of substantial power increase or wide-scale connection to the High Voltage grid, existing specifications might be changed to account for the impact on voltage control.

Until some years ago, generator technology for wind turbines used to be mainly based on fixed speed induction generators. For several years however, variable speed induction generators (using IGBT rectifier - DC link - inverter technology) have consistently won an increasing share of the market.). The main advantages of the variable speed wind operation are to reduce drivetrain requirements and to optimise the energy conversion. The power quality such as flicker, harmonics, voltage and frequency variation can be controlled by variable speed wind turbine generators using a power electronics interface. The type of interface used for connecting the wind park unto the network has a determining impact on harmonic interference. Thyristor technology for inverters generates low frequency harmonics (250 Hz to 1 kHz), whereas IGBT technology generates high frequency harmonics (1 kHz to 1 MHz) depending on interface power rating.

3.1.3.3 Dynamic grid Stability analyses

The large installed capacity combined with long transmission distances to the net may create problems of instabilities and excessive reactive current transmission. It may be advisable to perform dynamic analyses to understand the nature of the unbalance and to correct the situation.

Incident conditions (short circuits, voltage dips,..) may have to be simulated with models which incorporate the interface technology (direct coupling, inverter interface, power electronics interface,..) since the interface technology appears to have a determining impact on the system behaviour under incident conditions. For fixed-speed wind turbines, the drive-train characteristics must also be simulated. What is the state-of-the-art in dynamic grid stability analysis tools? Are suitable models available?

3.1.3.4 Secondary Control requirements

Secondary control is the system-wide adjustment of the production in the neighbouring zone to a new operating situation to maintain balance between production and consumption with a time constant of the orders of 10-15 minutes. The introduction of LSOWE may have an impact on the required dispatchable power. How can this be done ? With hydro power or pumped storage? What is the additional cost to guarantee the needed dispatchable power? In a free market, will this cost increase the cost of ancillary services ? Can the wind farm or wind turbines be controlled satisfactorily to control power, power gradients, and voltage? What does a TSO really need?

3.1.3.5 Contribution to ancillary services

Ancillary services are the services needed to transmit the energy from generation plants to end users with guarantees concerning power system dependability. The main ancillary services concern active power and frequency regulation, reactive power and voltage regulation and system restoration after collapse (blackstart capability). We may notice the fact that in terms of quantities, wind turbine generators are expected to take a large part of renewable generation in the future (EU target 11.9 % of the total Renewable energy production in 2010). As a consequence, we should pay great attention to the ancillary services capability of this energy production. Is it sufficient to rely on a market approach, or are firm technical requirements necessary?

3.1.4 Power system planning and grid access

In a fully liberalised market, the power utility context moves from a monopolistic structure, with technology driven developments, towards an open production competition with market driven developments. The collegial interaction between former geographical monopolies disappears completely.

Superimposed on this trend are some policy driven developments in the field of Renewable Energy, which cannot be handled by the open market as such.

The TSO will remain in hands of geographical monopolies, however subject to “strong” national supervision.

This new situation poses a series of challenges in the power system planning for satisfactory operation of the system as a whole and in particular for the large connecting large offshore wind parks , such as:

- Impact of the **grid code** (connection code) on generating investments (and profitability). The grid code contains the national requirements for the user of the network with strict procedures for connection and information exchange.
- **Technical requirements** for small scale generation and impact in case of substantial penetration of these small scale units. The criteria have been fixed as for conventional onshore wind farms and may not be flexible enough to handle large offshore wind park connections.(e.g. Belgium : Operational reserve should at least be 10% of the total production of the park, with the possibility to recover lost capacity within 15 minutes).
- Impact of **geographically concentrated generation** (particularly large wind parks) on national and interconnected grid development. Special attention should go to investigate the grid capacity along the coastline. Note also that the coastal areas are mostly located at the end of the transmission line, which is not conceived to transmit power in the reverse direction.
- Stability of the context (ruling) in order to perform reasonably long term planning, particularly for large offshore wind parks, which is necessarily policy (and not market) driven. The EU proposal to force **priority access** for Wind energy to the grid is an example.

3.2 STATE-OF-THE-ART SUMMARY

3.2.1 Interaction between production and consumption – Energy Management Systems

Energy Management Planning is described in [1] as follows :
In all electrical systems *the production* and *the consumption* should always be in close conformity as it would otherwise be physically impossible to keep the system frequency within the allowable tolerances. This balance is the primary reason why continuous production planning is a necessary activity for all utilities. In addition, production planning is of course contributory to the economic and environmental optimal operation of the electrical network.
Focus on the economic optimisation including risk management is increasing with the liberalisation of the electricity markets in the EU and the subsequent competition between the utilities.
It is a precondition that the overall long-term planning ensures the availability at all times of the necessary production and transmission capacity.
Energy Management Planning can be split up into the following activities:

- Load Forecast / Unit Commitment :
- Primary and Secondary Control
- Security Analysis
- Training
- Emergency Control.

3.2.1.1 Production and consumption patterns

Consumption patterns
Generic and national information regarding diurnal and seasonal variations of consumption patterns is systematically collected by national grid operators. Well-proven load forecast tools are available. These tools are used on a daily basis for generating unit commitment. In most countries generic information on consumption patterns is publicly available.

LSOWE Production patterns
Generic information on diurnal and seasonal variation of wind energy production can readily be derived from measured wind data eg. [30,31]) Also, production statistics are available in several countries from utility companies or other organisations.

Short-term variability (i.e. variability on a time-scale of 10 minutes) and long-term variability (i.e. variability on a time-scale of 12 to 24h) of the power production of the existing onshore wind farms has been analysed for Germany [2], Denmark and the Nordic Countries [21]. The applied methodology can easily be extended to LSOWE applications.

Worst-case power gradients typically occurring in large wind farms in normal operation are of the order of 10 to 15% of rated power in 15 minutes. It is however expected that much larger variations in the power production of LSOWE can be caused by passing weather fronts and thunderstorms, which could possibly cause a nearly simultaneous shut-down of all wind turbines in the wind farm (though not in several wind farms at once). Quantitative investigations into these power gradients are not publicly available.

An important question to address is this: is it better to cope with variability of output by:

- curtailing wind production during critical periods (in the worst case, ceasing production entirely during storms or other critical periods);
- technical measures to reduce the variability (storage, power gradient limits, VAR control etc.);
- utilising (and paying for) the ability of conventional thermal and hydro plant to compensate for variability of wind production.

Production/Consumption Imbalance
In principle the existing information should be sufficient to assess the unbalance between consumption patterns and consumption patterns. The result will however depend largely on local circumstances. Generic assessments (e.g. On a European scale) are only meaningful if cross-border transmission capacity limitations are taken into account.

Since the development of LSOWE has a concentrating effect on wind energy production (i.e. a larger proportion of the total wind energy production is concentrated in some specific areas), it may be expected that the development of LSOWE increases the production/consumption unbalance. Part of this unbalance may be compensated by a geographical smoothing effect (if cross-border transmission capacity is sufficient). For the remaining part however, additional energy management measures are required.

Spatial correlation
A study of equalising effects from wind energy in Northern Europe [6] has shown that wind power from sites with a separation of more than 1500 km is nearly uncorrelated. This leads to a smoothing of the wind power production. Change on a time scale of 12 hours can reach ca +/- 30% about once a year. The existing study only considers existing onshore wind farms. An extension of the study based on LSOWE plans in the different EU countries, would yield valuable information regarding the impact of LSOWE development on Energy Management .

3.2.1.2 Energy Management

Demand side Management
By means of currently available information technology, existing demand side management systems (e.g. Double or dynamic tariff systems during night hours and switching of interruptible loads) could be extended to take into account the availability of power from wind energy.

Such measures, although not specifically taking into account wind energy production, are now standard practice with most electricity suppliers for managing peak demands.

RISOE has published a study on the possibility to recharge electric cars with LSOWE by using a tariff signal. The electric cars are in standby in the garage and when the signal is present (thus when there is offshore energy) they charge. RISOE indicates that the cars are often in the garage and that it would be the best way to use clean energy in transport (technology H2 is in gestation).

Increasing flexibility of conventional plants
The increased unbalance between production and consumption created by the development of LSOWE can to some extent be covered by increasing the flexibility of conventional power plants. Conventional power plants have some flexibility allowing them to participate in secondary control and to compensate for load variations by modulating their power output. The extent to which conventional power plants can be modulated depends on the type of plant. Hydro-power plants are among the most flexible, even if pumped hydro-power plants often can only be modulated in turbinating (power producing) mode. Fossil-fuel fired plants also have some modulating potential, although modulating is significantly more difficult for coal-fired plant which have a relatively high start-up lag time, and a much higher thermal inertia than for instance gas-fired plants.

In all cases, increasing the flexibility of conventional power plants inevitably decreases their efficiency (due to operation at a sub-optimal working point, and due to increased start-up and cool-down losses). Therefore the extent to which conventional plants can be modulated, may in practice be largely determined by economical constraints. It should also be noted that the modulating potential of co-generation plants is often very small due to constraints imposed by the heat demand. The increased penetration of co-generation plants effectively reduces the modulating potential of the existing conventional power plants.

Few studies are known in which a detailed assessment is performed of the potential and the cost of operating conventional power plants in a modulating mode to compensate for the variability of large-scale non-dispatchable wind energy [27]. However, pilot projects (e.g. Hybrid generation consisting of wind power in parallel to a gas-fired power plants) are underway in some countries. There has been various studies on this subject in Ireland (ESB uses also Prediktor; see www.prediktor.dk).

Compensation of power gradients via fast dispatching
Power output from LSOWE plants may rapidly decrease when storm fronts pass, and all wind turbines in the wind farm are nearly simultaneously shut down (when the wind speed exceeds the cut-out speed).

In some countries, it is a requirement from the TSO that the (negative) power gradient caused by the LSOWE plant should never exceed a reduction from 100% of rated power to below 20% in 2 seconds. Even so, with a large penetration of LSOWE plants, a significant amount of rapidly dispatchable power may be required to compensate for the LSOWE power gradients.

However, in countries where the power system comprises large units (such as 1000 MW nuclear power plants), rapidly dispatchable power of some kind should already exist to cover an unexpected shut-down of one of these large units. Mostly, (pumped) hydropower plants will be used for this purpose. For many countries the existing capacity of rapidly dispatchable plants will be sufficient to cover for the power gradients occurring in their offshore wind farms.

Notice that in [28], it is stated that the Danish requirements for transmission-connected wind farms will make them the fastest-responding generating plants on the system (power ramp rates of 5 MW/minute in controlling mode).

3.2.1.3 Energy Storage

Technically, storage is a perfectly viable solution for the unbalance between production and consumption. The cost of energy storage may however often be prohibitive, either due to low efficiency (eg. Pumped hydropower) or due to high investment cost.

Although energy storage should be investigated at the level of the entire electricity system (and not only in relation to offshore wind energy), research efforts aiming to decrease the cost of energy storage will definitely be beneficial to the development of LSOWE.

Pumped Hydropower
Pumped Hydropower Technology is technically mature, and can in many cases be implemented without unacceptable environmental consequences. However the cost of pumped hydropower is high, mainly due to low efficiency and high investment costs. Typically, the COE[1] for electricity from pumped hydropower ranges between 0.02 and 0.1 EUR/kWh.

Hydrogen
Hydrogen technology is often considered promising for use as an energy vector and for energy storage. Research activities in this area are ongoing. The technical maturity of hydrogen technology however remains very uncertain.

Regenerative fuel cells
According to [1], a technology which looks promising for maturity by 2010 is the so called Regenerative Fuel Cell(=RFC) under development by Innogy [32]

[1] Cost of Energy (COE) calculated assuming an economical life-time of 40 years and an actualisation rate of 7%.

The principles of the technology are verified on small-scale laboratory tests and are based on the electrochemical conversion process such as is used in the fuel cell technology. The RFC comprises two compartments separated by an Ion-selective membrane, separating the electrolytes flowing through each compartment. Electrodes are immersed in the electrolyte as electron transfer surfaces, but do not take part in the electrochemical process and so do not limit the energy storage capacity. The energy storage capacity (MWh) is determined by the size of two external reservoirs containing the two different electrolytes which are pumped through the fuel cell, while the capacity (MW) is determined by the surface area of the ion-selective membrane.

Plans are to build a demonstration plant to provide 120 MWh of energy and up to 15 MWe power rating. The authors claim a full conversion cycle (Electricity-chemical-electricity) of about 70%, with interesting dynamic operating capability including quick start (response time of the order of 0.02 s), quick switching from charge to discharge mode, and can be modulated by a control system. Such system would be able to store the total electrical energy from a 5 MWe wind farm during 24 hours. Such storage system combined with adequate wind prediction models could to a large extend compensate for the supply/demand forecast errors.

This technology promises to be a good alternative to pumped storage power plants, because they have a short response time, are flexible in MW and MWh and independent from dedicated sites. Furthermore, this new technology could become interesting in the future for the delivery of ancillary services, in general.

The Regenesys system should be tested in Laeso (Denmark).

Other solutions
Smaller scale techniques are available such as batteries, flywheels, superconducting magnetic storage and super-capacitors, but do not have the power and energy storage capacity needed for storing large quantities of intermittent energy such as produced by LSOWE feeding into the main transport grid.

Long distance storage
Long distance storage (using for instance the large Scandinavian hydropower capacity) could in principle be a viable energy management option. Currently however, long distance storage on a European scale is not feasible due to technical restrictions on cross-border electricity transmission, reinforcement costs, and due to the organisation of the electricity markets in Europe.

3.2.1.4 Forecasting tools

According to [1], energy management of electrical systems implies that the production is adjusted to the inevitable load variations throughout the year, all the way down to day level – even down to hourly or quarter of an hour level - by following the prognoses for the load. The load forecast is at first based on statistical data for consumption during previous years adjusted to the expected development in consumption and on a day-to-day basis corrected for temperature conditions, other climatic factors and the actual consumption on the previous days or weeks. On basis of these prognoses a Unit Commitment Plan is prepared showing which production plants should be in operation, and the output which they are to feed to the network within given intervals. In this planning process considerable consideration is paid to the operating costs of the various plants as the base load should be covered by those plants which have the lowest production costs inclusive of net losses. Consideration should also be made to start-up costs, which may vary greatly.
Pumped-hydro plants are very suitable to cover peak loads, which normally occur a few times a day. If such plants are not available other production plants must be scheduled for these situations.
The producers on the power market must also consider the expected price level on the Power Exchange and any constraints in the network when their Unit Commitment Plan for the following day is prepared.

Obviously any electrical system can absorb a certain amount of unregulated and stochastic production from LSOWE as the system must be designed and operated in order to accommodate the changes in the consumption, a trip of a conventional production unit or a fault on a transmission line. However, the exact amount of LSOWE that can be accepted without any modifications of the procedures or tools for system operation must be carefully analysed in each case.
For systems with a high penetration of LSOWE, the most significant difference is that in addition to prognoses of the consumption, prognoses are also to be prepared of the unregulated wind power production. Such prognoses are necessary both for the TSO and for the players on the power market that own significant wind power production sites as well.

Development of forecasting tools for wind energy production
In recent years wind energy forecasting tools have been developed in countries such as Denmark or Germany (e.g. [12],[13],[14],[24]). These tools are being applied by utilities for trading and unit commitment purposes. Also, some forecasting tools are available on a commercial basis. Projects are currently underway to merge some of the existing forecasting tools.

Suitability for balancing requirements
Currently available forecasting tools are in general not considered sufficiently reliable for assessing balancing requirements, i.e. to dispatch other power plants to compensate for the short-term variability of wind farm output. It is not expected that this will change with the development of new models. Other short-term energy management solutions (e.g. Energy Storage or Modulation of Conventional Power Plants) remain necessary to compensate the short-term variability of wind power.

Suitability for trading requirements
Currently available forecasting tools are to some extent considered sufficiently reliable for use in electricity trading (i.e. for day-ahead planning of purchase and sales bids on the power exchange). This means that, with careful risk management methods, the average accuracy of forecasts is sufficient to limit financial losses due to erroneous forecasts to an acceptable level. However, trading based on forecasting tools is currently applied to the average wind power from many different wind farms dispersed in a certain geographical region. With LSOWE it may be expected that wind power will be geographically more concentrated, and more advanced forecasting tools may be required.

3.2.2 Design and operation of the transmission grid : A. Connection technology for LSOWE

Overviews of currently existing electrical connection technology for LSOWE technology haven been presented in e.g. [18, 25]. Special workshops dedicated in particular to HVDC transmission for offshore wind farms have also provided a useful discussion forum on this subject.

3.2.2.1 Feasibility limits

Cable length
For large distances to shore, cable losses become important, and cable cost may become excessive. The maximum distance from shore for which grid connection is technically and economically feasible depends on the choice between AC and DC transmission. With state-of-the-art AC technology the maximum distance is in the order of a few hundred km [29]. With DC technology the maximum distance has no practical upper limit.

Operating conditions
Using state-of-the-art technology, the maximum (active) power which can be transmitted by a single three-phase AC cable between wind farm and shore is about 30-40 MVA for a transmission voltage of 30 kV, and about 140-150 MVA for a transmission voltage of 150 kV. This implies that very large offshore wind farms (with an active power larger than 100 MW) would require more than one cable at a 150kV transmission voltage. Cables may run in parallel tracks, but safety distances are required between the cables, which causes an increased use of sea surface often in vulnerable areas close to the cost. [Due to electric interference or to installation requirements??]

It should also be noted that advanced power cable technology would allow transmission up to 450kV for single-phase cables, and that DC transmission of about 600 MW should be possible through a single cable operating at 500 kV.

AC/DC conversion technology
Very important developments have been made recently in forced commutation AC/DC conversion technology (Voltage Source Converter based HVDC), which could possibly make DC grid connection of offshore wind farms economically attractive in the near future (eg. [26]).

Whereas conventional (natural commutation) has been in use for more than 50 years, it is still unclear whether the new forced commutation systems are sufficiently mature for large-scale application in offshore conditions.

Even if the economical analysis of different grid connection options is very much project-specific, it is estimated that HVDC-based links may become more attractive than AC links starting from distances of about 50km from the shore.

It should also be noted that the HVDC-technology offers additional benefits regarding transmission network and power quality management (e.g. STATCOM functionality) (cfr. 3.2.2.3).

3.2.2.2 Reliability / Maintainability

Component Reliability
With adequate design measures (protection levels, sheltering, use of gas-insulated closed switchgear, …) state-of-the-art electrical equipment is considered sufficiently reliable for offshore installation.

Component Maintainability
Maintenance requirements for offshore electrical equipment are expected to be similar to requirements for land-based installations (about one service visit per year). Maintenance costs are however very difficult to estimate, since they highly depend on accessibility and work conditions. This uncertainty can only be reduced by feed-back from test and demonstration projects.

Grid connection lay-out
Whether or not a redundant grid connection lay-out (e.g. Two separate cables between wind farm and shore, or an interconnected internal wind farm grid) is necessary to assure a sufficiently reliable grid connection, is project-specific. The question can be answered by straightforward risk analysis, provided that adequate cable failure data and cable repair times are available.

3.2.2.3 Innovative solutions

The development in recent years of power electronics equipment to the point at which it can be used in electricity transmission is a major development in electrical engineering. According to [1], the most important features of this development are, firstly, reliable application of thyristor equipment in High Voltage Direct Current (HVDC) equipment and in Static Var Compensators (SVC) and, secondly, the more recent advent of IGBT or GTO devices with a controlled on/off capability at power levels compatible with the necessary rating for transmission. This technological advance opens new possibilities for power equipment permitting better management of transmission networks through rapid, continuous and flexible control of reactive and active power flows. Such techniques are of interest to those faced with new challenges in their transmission activities, such as increasing environmental pressure and deregulation, both resulting in a less predictable future. In fact, this electronic equipment enables more extensive use of the thermal capacity of power lines, without decreasing the stability margin.

3.2.3 Design and operation of the transmission grid : B. Impact of LSOWE on power system performance

Power quality
Electricity is supplied at a specified quality level, expressed (as regards voltage characteristics) in terms of standard thresholds for the following (ref. [1]) :

- voltage imbalance;
- slow voltage fluctuations;
- rapid voltage fluctuations and flicker;
- harmonics.

The voltage quality rules governing network access for generating plant operators define minimum network characteristics at the connection point[2], plus minimum technical conditions for the plant (for existing producers or new incomers). These rules are determined to ensure that consumers enjoy supply quality within applicable standards.

Various factors contribute to voltage fluctuations at the terminals of a wind turbine : aerodynamic phenomena (wind turbulence, tower shadow effect, etc), short circuit power at the grid connection point. Under particular connection conditions, this may result in a significant flicker level. As a consequence, some limitations for installed power could be recommended in case of weak network or particularly polluting devices.

Special attention should be paid for LSOWE since the grid connection point may be a weak point and correlatively the building of a new onshore transmission line, in opposition with environmental politics, may be required.

Flicker
Experience from onshore wind farms shows a noticeable impact on flicker levels on small island grids (e.g. [19]). Similar effects might be expected from large offshore wind farms.

However, in general flicker emission is not considered to be a limiting factor for the development of LSOWE for the following reasons :

- Flicker emission of wind turbines is highly dependent on the wind turbine technology. Modern variable or semi-variable speed wind turbines show relatively low flicker emission levels.
- High frequency fluctuations of power output from wind turbines in a wind farm are not correlated. Increasing wind farm size does not cause an equally important increase of the flicker level.
- Large offshore wind farms need to be connected at a sufficiently high voltage level to limit transmission losses. Typically at high voltage level (e.g. 150 kV) the short-circuit power of the grid at the point of common coupling is sufficiently high to limit flicker to an acceptable level.

[2] The supply terminals mark the limit of the properties defined in the connection agreement between power system administrator and generating plant operator.

Harmonics and interharmonics
Harmonics and interharmonics are not considered to be a limiting factor for the development of LSOWE. Even if inverters used in modern variable speed wind turbines or HVDC systems generate harmonics and interharmonics, standard filter techniques can be applied to limit the emission of harmonics and interharmonics to an acceptable level.

Impact of long-distance sea cable on power quality
A particular feature of offshore wind farms, compared to onshore wind farms, is the influence of the power cable between the wind farm and grid connection point on power quality. The power cable generates reactive power which may need to be compensated. Some voltage control problems may be expected, e.g. due to severe inrush transients when switching on transformers.

It should also be noted that the power cable may have a beneficial impact on power quality by acting as a harmonics filter.

Power quality assessments
Current assessment methods for flicker, harmonics and interharmonics (e.g. Draft IEC 61400-21, which is expected to be issued as an international standard in 2001) are considered suitable for application to large scale offshore wind farms.

Power quality measures
It is expected that variable speed wind turbines will in general augment the power quality of large scale offshore wind farms. Additional measures which may be taken are : installation of filters for harmonics, VCS-controlled switching to reduce switching transients.
In severe cases STATCOMs or SVCs may be installed to reduce or eliminate flicker. The same functionality is obtained from state-of-the-art HVDC-links.

3.2.3.2 Grid Infrastructure

Grid requirements
There are no generic or firm requirements regarding grid characteristics at the grid connection point for connecting large scale offshore wind farms. The required voltage level will be dependent on the wind farm active power output. Typically wind farm sizes in the range of 100 MW would require connection at the 150kV level. The required Short-Circuit Power Level also depends on the wind farm nominal power. Some countries and grid operators limit the allowable ratio of wind farm nominal power to short-circuit power at the grid connection point. However the limiting ratio appropriate for small wind farms is likely to be inappropriate (conservative) for large wind farms.

Grid suitability
In general the transmission grid is not very strong in coastal areas, except for areas with significant industrial or harbour activity, or in cases where nuclear power plants have been built close to the seafront. Therefore onshore grid connection (i.e. covering the distance from the shore to the nearest substation where the grid is sufficiently strong) may represent a significant part of the total offshore wind farm cost. This is especially true when the use of overhead lines is not acceptable for environmental protection reasons, and cables must be used instead.
.
Grid reinforcements
The strength of the currently existing grid in coastal areas may become a limiting factor to the large-scale development of offshore wind energy. The impact of this limiting factor has until now not been taken into account in offshore wind energy potential studies.

Connecting large-scale offshore wind farms will require some grid reinforcements in coastal areas (cables and switchgear) . There seems to be a need for studies into the relationship between the technical-economical offshore wind energy potential, and the investment cost required for grid reinforcements. There is also no clear view on whether grid reinforcements should be born by the project developers, or by the grid operators (see 3.2.4.1).

3.2.3.3 Grid stability

(Static) stability
Slow voltage variations can be eliminated by means of tap-changing transformers and/or reactive power control, and should therefore not become a limiting factor for the grid connection of large scale offshore wind farms.

Set points of grid protection equipment should in principle not be affected by the presence of offshore wind farms. Neither will the control system set points of other power plants be directly affected (although the introduction of large amounts of wind power will increase the control effort to be performed by these control systems).

Loadflow-analysis
Load flow analysis is required to assess the feasibility of connecting large-scale offshore wind farms to the grid. Traditional load flow analysis methods are suitable, although some stochastic features need to be taken into account due to the variability of wind power production. Load flow analysis should cover all realistic scenarios. As a minimum, four scenarios must be analysed, comprising minimum and maximum wind farm output, combined with minimum and maximum 'system' demand, taking into account possible shut-down of conventional plants.

Dynamic grid stability
Dynamic grid stability issues may be a limiting factor to the grid connection of large offshore wind farms. In particular, the dynamic impact on the transmission grid of a nearly simultaneous shut-down of all wind turbines due to high wind speeds (above cut-out wind speed) should be taken into account. The importance of dynamic grid stability issues depends to a large extent on the imposed specifications for connecting wind farms to the grid Most specifications imposed until now (mainly intended for dispersed wind power generation connected to the medium voltage grid), simply allow wind farms to disconnect in case of grid faults (and to reconnect when normal grid conditions are restored). A similar requirement cannot be imposed in case of large-scale, geographically concentrated wind power generation. For example, the Eltra specifications imposed in Denmark, require the wind farm to withstand three-phase grid faults without attempt to reclose, and two-phase faults with an unsuccessful attempt to reclose [28]. These requirements may lead to modifications in the wind turbine control systems. Dynamic grid analyses are required to demonstrate that the specifications can be met.

Dynamic Grid Analysis
State-of-the-Art Dynamic Grid Simulation Codes in use in many countries (such as EUROSTAG, NTUA, INETI) are suitable for the analysis of dynamic grid stability of offshore wind farms. In general these codes have standard models for synchronous generators, and even for standard asynchronous generators. However, further development of wind turbine/generator models is required to take into account the particular dynamic behaviour of advanced (variable speed) wind turbine generators and their power and speed control systems.

3.2.3.4 Impact on national grids

Primary and Secondary Control
According to [1], by primary and secondary control is meant the production control which is necessary to handle the inevitable difference between prognosis and the actual load including of losses. The turbine controllers in the controlled units are to engage automatically and increase the production in case of frequency drop or reduce the production in case of frequency increase. This is called primary

control and is as such part of the Automatic Generator Control (AGC), acting with a time constant in the range of 1 sec.

The primary control is defined by the following two parameters :

- Spinning Reserve (MW);
- Droop (%).

Sufficient and fast primary control ability is necessary in all electrical systems and must be very well co-ordinated to avoid instability. The co-ordination embraces both the geographical dispersion and the above mentioned primary control parameters.

The control possibilities including response time are highly dependent on the type of plant as hydro plants have far better control possibilities than thermal plants. Within the framework of NORDEL, among others, so-called ”Power Station Specifications” have been prepared which set up specific requirements to the utilities’ capability of participating in the primary control.

The primary control ability is at the present not commercially available on the deregulated power market.

Secondary control is the subsequent system-wide adjustment of the production to a new operating situation in order to maintain the frequency to its nominal value, e.g. 50 Hz. There is a desire in order to keep the exchange of power across borders within the planned programmes. The time constant of the secondary control is roughly 10-15 minutes from the time that the intervention of the primary control is achieved.

In some cases, e.g. in large nuclear power plants, the secondary control is automatic. In other cases, the secondary control is performed manually at the power plants on request from the regional dispatch centre.

LSOWE plants – at least with today’s technology – do not constitute reserves of primary or secondary control.

Therefore, a high share of unregulated production causes a markedly higher need for secondary control on conventional units in order to compensate for the stochastic production from, e.g. wind power. A high production from LSOWE plants often means that the primary utilities are forced down in the load area and as such away from the economic and technical optimum operating load.

Additionally, the ability to perform primary and secondary control may be expected to be a valuable product in a competitive market, as regulating power could be sold to the TSO for a price above the spot price. A large LSOWE production on European level would then require a higher amount of regulating power thus increasing the value/costs for this product.

Reactive Power

Even using advanced variable speed technology, wind farms can only generate reactive power to a limited extent. Unless the wind farms are grid connected through innovative HVDC-links with STATCOM-functionality, the development of LSOWE, partially replacing conventional power plants, will increase the reactive power generation requirements for the remaining conventional plants.

Primary control

Due to the short-term variability of wind power, the development of LSOWE will impose an increase of the primary regulation effort on all non-wind generators operating in the interconnected grid system, unless primary control requirements are equally imposed to the wind farms (i.e. unless wind farms are treated on an equal basis compared to conventional power plants).

At present, there are no studies showing quantitatively how much additional primary regulation will be required from conventional generators, if (offshore) wind energy develops according to national plans without primary control requirements.

Since some countries have already decided that wind farms should participate to primary control, there is manifest a need for the development of improved methods allowing offshore wind farms to participate to primary control. [Is this achievable?]

Secondary control
Due to the short-term variability of wind power, the development of LSOWE will impose increased secondary (frequency) control requirements to the generators in the national systems to which the wind farms are connected (due to operating practices and international rules), unless secondary control requirements are equally imposed to wind farms.

Unit Commitment and Spinning Reserve
Whether or not the development of LSOWE will create unit commitment problems will largely depend on the availability of reliable wind power forecasting tools.

Spinning reserve requirements will probably need to be adapted, taking into account the relative unpredictability of wind power generation, but also the possibility of losing an entire offshore wind farm due to grid faults, unless redundant grid connection is provided.

3.2.4 Design and operation of the transmission grid : C. Power system planning and grid access for LSOWE

3.2.4.1 Grid access requirements

The main operating requirement of an electrical power system is that voltage and frequency should be kept within permissible ranges. This determines both service quality and safety factors (ref. [1]):

- power system dependability directly determines the quality and continuity of service offered to consumers, especially since large-scale electricity storage is not yet a viable option for palliating the wide variations in consumer demand with season and time of day;
- protection of persons and property (under normal and incident conditions) is an increasingly critical issue given the growing dependence on electrical power in many aspects of everyday life.
- To ensure dependable power system operation, the operator must substantiate satisfactory performance of system components, both in the network (line protection efficacy, waveform quality, etc.) and in the generating plant (stability, supply capacity, impact on regulation, etc.). The term “performance” is used here, to refer indistinctly to functionality’s, technical characteristics and capacities.

Voltage regulation
To maintain contractual voltage quality and ensure system safety (i.e. avoiding voltage collapse), the system must be capable of keeping voltage within the permissible range.
As far as the power system is concerned, the crucial factors are voltage regulation and reactive power capabilities at the supply terminals, i.e. the busbar of the generating plant. Generating plant performance requirements are therefore specified at this location.
Again at the supply terminals, generating plants must be able to withstand voltage variation within “normal” and “exceptional” ranges, the former being specified with no duration or performance limitation.

Frequency regulation
The supply frequency reflects the power system’s generation/load balance, and should be maintained close to rated value. This requires a certain spinning reserve, to compensate against incidents, natural demand fluctuations, and generating plant tripping . The primary frequency regulation system is responsible for automatically adjusting generating plant output to accommodate changes in load.

UCPTE (Union for Co-ordination of Production and Transmission of Electricity) rules on primary frequency regulation[3] for member organisations state that above a power level determined by the connection voltage, generating plant operators must afford a constructive primary reserve capacity of at least 2.5% of the total plant power output.
Other recommendations specify the frequency ranges within which equipment is required to operate (normal frequency range of 49.5 to 50.5 Hz, plus exceptional frequency range).

Currently, in some countries voltage regulation and frequency regulation demands for LSOWE are identical to those of other power plants (ref. Denmark Eltra). In other countries no specific requirements are imposed. Nevertheless, when LSOWE forms a significant part of the total generating capacity, voltage and frequency regulation requirements can only be fulfilled if :

- the LSOWE take part in frequency and voltage regulation, which requires development of improved wind turbine control systems ;
- the burden of frequency and voltage regulation is put on the traditional non-renewable generating capacity, and the cost of frequency and voltage regulation is accounted for in the transmission fees.

The development of LSOWE may therefore require :

- to re-examine the UCPTE (supranational TSO) rules in respect with regulating capacity and margins at individual TSO level;
- to provide voltage and frequency regulation on wind turbines by using electronic power converters in combination with variable speed and pitch control;
- to implement non regulated RES-E with associated Static Var Compensator (SVC) for voltage control and/or energy storage (SMES, Pumped storage, Reversible Fuel Cells) for both frequency and voltage control.

Like the network itself, a generating plant (with its regulation system) should possess electromechanical characteristics capable of ensuring uninterrupted operation of the power system under incident conditions.

Very broadly, we distinguish between two types of incident situation: those which involve separation of the generating plant from the power system (to form an island or separate network), and those which do not.

Incident conditions without separation from power system
Because of the difference between protection plans for interconnection networks (400 and 225 kV) and distribution networks (less than 100 kV), we must specify the generating plant connection point. Specific incident conditions for examination could include the following :

- static stability or stability-related performance under minor incidents
- stability under heavy transients: response to single-phase/three-phase short-circuit or voltage dip
- behaviour under slow voltage collapse

On the opposite, voltage stability is a major issue. For instance, wind plants using induction generators are very sensitive to voltage drops which leads to loss of the wind turbine generation for the grid. As for the power electronic systems it is possible to operate, to a certain limit, at less than full voltage output capability, these wind turbines should not lose synchronism and thus stay stable after slight voltage drops. According to the French Technical Requirements for Power Plants Connection, it is required to IPPs plants to be stable and to stay connected to the grid after a defined voltage drop pattern. As a conclusion, it appears that requirements into generator manufacturer design for better stability to voltage variations, are still needed in order to avoid transfer limits on power from remote LSOWE plants.

[3] UCPTE recommendations on primary frequency regulation: UCPTE ground rules

An important design and operation requirement for safe utility and TSO operation is overall system stability on typical faults.
In a conventional system, this is essentially an electromechanical problem, whereby the behaviour of the (synchronous) production units is essentially represented by adequate models.
LSOWE plants with voltage sensitivity (inverters) or "induction generator" behaviour may well drop out for faults far earlier than the conventional generators in the grid.
In case of massive LSOWE injections, this may have unexpected adverse effects on the stability of the remaining system.
On the side of LSOWE technology, developments should be made to allow "reconnection in flight" of production units after a transient fault in the network. This supposes correct discrimination of the "external" fault by the wind turbine generator, safe disconnection without irreversible effects (blown fuses …) and smooth reconnection as soon as the normal grid conditions are re-established.
On the side of conventional network techniques one should consider network operation strategies, in which a substantial LSOWE production may disappear without resulting in system instability or voltage collapse.

Incident conditions with separation from power system
Following a serious incident, an isolation of generating plants from the power system may occur, in which case they may be isolated altogether or remain connected to an isolated sub-network. Generating plants must be able to withstand the resulting transient and sustain a satisfactory situation under these conditions (islanding or isolated sub-network) until restoration of normal conditions as part of the main network

Technical requirements
All grid operators apply technical requirements (e.g. Related to reactive power, flicker and harmonics), but these requirements vary greatly from country to country.
Some of the existing regulations are specifically adapted to wind power generation, but in most cases these special regulations are limited to connection at the MV-level. As such they may not be applicable to large offshore wind farms which will require connection at the HV-level.

Regulations specifically developed for large wind farms connected to the HV grid have already been developed in Denmark ???. If LSOWE develops significantly it may be expected that technical requirements for grid connection of offshore wind farms will become very similar to requirements imposed to other kind of power plant.

Non-technical requirements
Among the non-technical requirements imposed by most grid operators in a liberalised market is the requirement for a power purchase agreement (PPA) between the project developer (producer) and a client (consumer).

Grid support requirement
Regarding grid support requirements, two very different approaches are currently in use :

- In some countries (eg. DK) grid support requirements (primary and secondary control, reactive power production) are shared between all generators on a pro rata basis. In this case LSOWE plants must participate to grid support ;
- In other countries (eg. UK, B), grid support is provided by some generators only, in return for an economical incentive. In this case a free market for so-called ancillary services exists, alongside the free market for the physical electricity. This means that LSOWE plants have no obligation to participate to grid support, but they may choose to do so for economical reasons. It is important that the markets in ancillary services are fairly set up and regulated.

Impact
Requirements imposed by national grid codes are in general not considered to be a limiting factor for the development of LSOWE. From a technical point of view, even the most stringent current requirements can be fulfilled by using state-of-the technology. Nevertheless compliance with grid code requirements may cause a significant cost increase for some LSOWE projects.

Suitability
In general the requirements imposed by national grid codes are considered as being not particularly suitable for non-predictable, highly variable energy sources, with the exception of the Danish requirements which have been specifically developed for use in offshore wind energy.

In all cases, project developers may have to take additional measures to comply with the grid codes, such as : use of variable speed wind turbines, special purpose remote control systems (with individual power set points for the wind turbines)

In the long term, HVDC transmission and/or on-site storage facilities with controllable reactive power output, might present interesting opportunities allowing LSOWE plants to meet grid access requirements more easily.

Priority access
Priority access can be relatively easily accomplished for a small number of small-scale renewable energy projects (e.g. < 10MW). For large-scale offshore wind farms however, unrestricted priority access would create significant additional costs for the transmission system and/or the other generators. Then it has to be decided how these costs are calculated and distributed amongst the stake-holders. The question is: 'Who pays for priority access ? The project, the other generators, the customers, or the tax-payers ?'.

Ownership
In some countries (e.g. UK, B,) sea cables will be owned by the LSOWE project, and ownership limits will be decided on a project by project basis. In some other countries however (e.g. DK) the sea cables are owned by the national grid operator, who effectively extends his grid to the location of the LSOWE plant. This causes a significant cost reduction for the LSOWE project (as the grid connection cost is largely incurred by the grid operator who transfers this cost to all customers).

3.2.4.2 Ancillary services

According to [1], ancillary services are services needed to transmit the energy from generation plants to end users with guaranties concerning power system dependability. The main ancillary services concern active power and frequency regulation, reactive power and voltage regulation and system restoration after collapse.

Primary regulations : voltage and frequency
LSOWE plants using induction generators without any power electronic interface to the system can not ensure satisfactory performances, as far as primary regulations (voltage as well as frequency) are concerned, particularly when no wind, the basic power source, is blowing.

Concerning voltage control or VAR control (reactive power), the two other groups of generation systems can provide good performances and hold a unity power factor. This is a well established result for generation systems using conventional alternator. For generation systems using power electronic interfaces, it is possible to operate less than full voltage and thus to hold a various range of power factor.

According to the French Technical Requirements for Power Plants Connection[4], IPPs are required to maintain their output voltage to the nominal value plus/minus 5%, and thus to be able to regulate the voltage in one of the three different following options decided with the System Operator : at constant voltage, at constant reactive power output, or according to the linear relation $U = Uo + k.Q$ (Uo nominal voltage, Q constant reactive power output and k constant reactive droop).

Contribution of stochastic RES generation (e.g. wind turbines or PV) to frequency control is possible only if they use power electronic interface. But in such cases, an efficient frequency control would lead to decrease the energy output and consequently decrease their economical profitability.
Moreover in case of high penetration of stochastic RES generation in a network, power fluctuations from stochastic RES generation increase the need of spinning reserve[5] and frequency control includes an extra burden on the conventional power plants.
According to the French Technical Requirements for Power Plants Connection to, for example HTB, it is required to IPPs to provide spinning reserve equal to 2.5% of their nominal power. For the time being, nothing is specified for RES generation but should be in the future as far as RES penetration is expected to increase.
Technical solutions (blades and speed control, electronic devices, etc.) are possible for RES generation plants so that they can participate to frequency control. The funding of these technical solutions may be balanced in the new energy market by the ancillary services payment and less power fluctuation from stochastic RES may imply lower additional spinning reserve for the system.

Black start: Black start ancillary service is the ability for a plant to generate power after a complete collapse of the network (no more voltage and other generation).
Even if black start capability is not frequently required for traditional power plants, except for hydro units, it may be profitable for biopower and geothermal plants to propose this ancillary service particularly if they are well geographically located (e.g. close to a large power plant).

Reactive power
If required, LSOWE plants can contribute to reactive power generation. Controllable reactive power generation (i.e. with set points for reactive power determined by the grid operator) is however most easily accomplished by means of variable speed wind turbines and/or VSC HVDC transmission.

Primary control
If required, LSOWE plants can contribute to primary control (i.e. production/consumption balancing on a 10sec time scale), although this is associated with a significant energy penalty.

Secondary control
If required, LSOWE plants can contribute to secondary control (i.e. production/consumption balancing on a 10min. time scale), although as before this would be associated with a significant energy penalty.

Black-start capability
In general wind turbines require a pre-existing voltage source with stabilised frequency and can therefore not provide black-start capability. From a purely technical point of view, by means of advanced technology, black-start capability could be realised, but only at a very significant cost.

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4 French Technical Requirements for Power Plants Connection, for units under 120 MW and connected to HTB voltages (45 kV to 225 kV, 400 kV excluded) – Arrêté du 30 décembre 1999.

5 According to the UCPTE Ground Rules, the loss of 3000 MW of generation in the UCPTE grid must lead to a frequency collapse under 200 mHz. This point is the basic data to determine the spinning reserve needed for the grid.

Ancillary service opportunity
In principle, delivery of ancillary services, could be seen as an new economical opportunity for LSOWE plants. Nevertheless, wind farms can only provide ancillary services at a very significant cost. Therefore it is unlikely that LSOWE plants could become competitive to conventional plants on the ancillary services market, and it is equally unlikely that ancillary services would become a major source of revenue for LSOWE projects.

3.2.4.3 National Grid

Offshore grid extensions
Offshore extension of the transmission grid (i.e. the creation of offshore substations owned and operated by the TSO) may have an important cost reducing effect since this would allow to share grid connection resources between different wind energy projects in the same area. Shared grid connection has the additional benefit of reducing the environmental impact of the sea cable and its landfall. A single 100 MW cable is indeed expected to have lesser environmental impact than 5 separate 20 MW cables. Nevertheless, taking into account the current technological limits for 3-phase AC connection, large clusters of offshore wind farms (many times 100 MW) will still need several cables, unless HVDC links are used.

In principle it would also be feasible to interconnect several offshore substations by means of sea cables to create an interconnected offshore grid. This would increase the grid connection reliability of offshore wind farms. Nevertheless, it should be noted that onshore grid reinforcements are far less expensive and much easier to maintain than an offshore grid.

3.2.4.4 International Grid Aspects

ACE requirements
International Area Control Error (ACE) requirements force national TSOs to keep the imbalance between production and consumption on a 15min time-scale within pre-set limits, either by secondary control of production units, or by cross-border traffic. If these ACE requirements are not changed to reflect the increased production variability induced by large concentrations of LSOWE plants in some areas, this would severely penalise the countries having installed LSOWE. This would also effectively prevent achieving a truly international market for electricity from wind.

Cross-border transmission capacity
Both for long term transmission system planning as for daily operation of the European interconnected system a faithful representation is needed with sufficient (but not excessive) detail. These power system models, including data relating to production as well as equivalent network representations, should be developed and publicly made available or commercialised to all operators and players on the liberalised market at European scale.

An overview of exiting cross-border connections is presented in [1]. There is at present no comprehensive assessment the impact of cross-border transmission capacity on geographical smoothing of wind power variability , nor of the feasibility of long-distance energy storage.

3.2.4.5 Power System Planning

Long term planning has been carried out for long by utilities as they had to prepare generation and transmission investment plans to be submitted, amongst others, to national authorities and their management boards. Although it is expected that this practice will evolve in the near future according to the introduction of the market liberalisation, it is worthwhile examining how such planning practices were undertaken until now. Indeed, indicative planning will remain a necessity for national

authorities in order to monitor their electrical system and for the utilities, in order for them to comply with their own market share of the electrical power demand.
Long term planning covers time spans from one to 20 years. Each time-span can be divided in several sub-periods for analysis purposes. Several categories of analysis are currently undertaken in the framework of long term planning :

- investment planning, either by use of a pluri-annual optimising model or by simulating scenarios of investments on an annual basis using techniques of probabilistic costing;
- probabilistic generation costing, for the simulation of the generation system on an annual basis;
- reliability analysis in generation and transmission, usually by using Monte Carlo simulation techniques.

Currently available methods and tools for long term power system planning can already cope with centralised large-scale renewable energy sources, connected to the transmission grid. (ref. [1]) As such these methods should be suitable to deal with LSOWE.

3.3 RESEARCH NEEDS

3.3.1 Introduction

Some research needs which readily appear from the State-of-the-Art Summary are (but which are not necessarily critical research needs defined in Chapter 5) :

- Systematic evaluation of the results of test and demonstration projects
- Generic assessment of production-consumption unbalance based on : LSOWE plans in different countries, expected short-term and long-term variability (e.g. Based on reanalysis data), spatial correlation and cross-border transmission capacity with long-distance storage
- Analysis of the economical effect (cost) of increasing the flexibility of conventional power plants to compensate for the variability of wind power, taking into account LSOWE plans in different countries
- Evaluation of the feasibility and social acceptability of demand-side energy management measures to increase consumption when wind power is available
- All Research aiming to decrease the cost of energy storage
- Development of improved forecasting tools, adapted to large geographically concentrated production of wind power, and evaluation of the reliability of existing forecasting tools
- Development of methods to decrease currently required safety distances between sea cables
- Assessment of the reliability of VSC HVDC systems ; ‘marinization’ of VSC HVDC systems
- Harmonisation of electrical protection and reactive power requirements
- Study of the impact of grid limitations on offshore wind energy potential ; study of the relationship between technical-economical offshore wind energy potential and cost of required grid reinforcements
- Development of suitable wind turbine (generator) models for dynamic grid simulation codes (in particular for variable speed wind turbines)
- Development of methods to allow LSOWE plants to withstand transient external faults without disconnecting from the network
- Analysis of the economical effect (cost) of increased primary control and secondary control requirements imposed on conventional generator and/or Analysis of the economical effect (cost) of requiring LSOWE plants to contribute to primary and secondary control. Research in support of finding a socially acceptable way of allocating the system cost created by LSOWE (grid reinforcement, priority access, increase control requirements for conventional plants, …) to the different stake-holders (LSOWE project owners, all generators, all customers, all tax-payers)

3.3.2 Ranking

The table 3.1 (at the end of chapter 3) represents the results of the ranking of all issues of chapter 3 by the OWEE members. Rankings are weighted as follows

Weight	Rank	Description
3	‘CRITICAL’	An issue is considered critical, if all of the following conditions are fulfilled : (1) its solution will have a significant <u>impact</u> on the large-scale development of offshore wind energy (i.e. if no solution is found for this issue, the development of offshore wind energy will be limited or even prohibited), and (2) the issue is <u>not</u> easily <u>manageable</u> with existing technology, and (3) the issue will be important in the <u>short-term</u> (i.e. before 2010)
1	IMPORTANT	An issue is important if some, but not all, of the above mentioned conditions are fulfilled
0	LESS IMPORTANT	An issue is less important if none of the above mentioned conditions are fulfilled

The average ranking R_{avg} obtained by taking the arithmetic average of the individual ranking weights and by rounding to the nearest integer.

Critical issues are those issues which have an average ranking above 1. In table 3.1 these issues are shaded grey.
The solution of the critical issues will have a significant impact on the large-scale development of offshore wind energy (i.e. if no solution is found for this issue, the development of offshore wind energy will be limited or even prohibited). These issues are also not easily manageable with existing technology, and these issues will be important in the short-term (i.e. before 2010).

3.3.3 Critical Research Needs

Some of the research needs identified in §3.3.1 relate to 'critical' issues identified in §3.3.2. These 'critical' research needs are the following :

- Systematic, international evaluation of the results of test and demonstration projects
- Development of improved forecasting tools, adapted to large geographically concentrated production of wind power, and evaluation of the reliability of existing forecasting tools
- Development of suitable wind turbine (generator) models for dynamic grid simulation codes (in particular for variable speed wind turbines)
- Development of methods to allow LSOWE plants to withstand transient external faults without disconnecting from the network
- Analysis of the economical effect (cost) of increased primary control and secondary control requirements imposed on conventional generators and analysis of the economical effect (cost) of requiring LSOWE plants to contribute to primary and secondary control
- Generic evaluation of LSOWE investment costs taking into account cost influencing factors (distance from shore, water depth, wind and wave climate, soil conditions, …)

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Topic		**Avg. Rank**	**Participating countries**												
			BE	**DK**	**IR**	**IT**	**FI**	**FR**	**GE**	**GR**	**NL**	**PO**	**SP**	**SW**	**UK**
1	**Interaction between production and consumption – Energy Management Systems**														
1.1	Production and consumption patterns														
1.1.1	Consumption patterns	1										1			
	Diurnal and Seasonal Variation	0	0			1	0	0	0	0	0	1		1	0
1.1.2	LSOWE Production patterns														
	Diurnal and Seasonal Variation	0	1			1	0	0	0	0	0	1		1	0
	Variability (10min)	1	0			0	1	3	1	1	0	1		1	0
	Variability (24h)	1	1			0	1	1	1	1	0	1		3	1
	Power Gradients	1	0			1	3	1	1	1	0	3		3	1
1.1.3.	Production/Consumption Imbalance	1	3			1	0	0	0	0	0	1		1	0
1.1.4.	Spatial correlation	1	1				1	1	0		0	1			
1.2.	Energy Management														
1.2.1.	Demand side Management	1	0			0			1		0	1		1	1
1.2.2.	Increasing flexibility of conventional plants	1	1			1		0	1		1	0			1
1.2.3.	Compensation of power gradients via fast dispatching	1	0			1	0	1	1		1	1		3	1
1.3.	Energy Storage	1	3		3	1		3	0		0	1		0	0
1.3.1.	Pumped Hydropower	0	1			1	0	0	1		0	1		0	0
1.3.2.	Hydrogen	1	1			0	1	1	1		0	1		0	0
1.3.3.	Regenerative fuel cells	1	1			1	3	1	1		0	1		0	0
1.3.4.	Other solutions	0	1					1	0		0	1		0	0
1.3.5	Long distance storage	1	1				3	0	1		1	1		0	0
1.4.	Forecasting tools	2			3							1			
1.4.1.	Development of forecasting tools for wind energy production	2	3		3	0	3	1	3		1	1		1	3
1.4.2.	Suitability for balancing requirements	1	0			1	3	0	1		0	1		1	1
1.4.3.	Suitability for trading requirements	2	1		3	1	3	1	3		1	1		1	3
2	**Design and operation of the transmission Grid : A. Connection technology for LSOWE**														
2.1.	Feasibility limits	0										0			
2.1.1.	Cable length	1	1				3	1	1	1	3	0		0	1
2.1.2.	Operating conditions	1	1				0	0	1	1	3	1			
2.1.3	AC/DC conversion technology	1	1			1	1	1	1	1	1	1		1	
2.2.	Reliability / Maintainability	1	1								3	0			

2.2.1.	Component Reliability	1	1			1	3	0	0	0	3	0		3	1
2.2.2.	Component Maintainability	1	1			0	3	1	1	1	3	0		1	0
2.2.3	Grid connection lay-out	1	3			1	3	0	1	1	1	0		0	0
2.3	Innovative solutions	1	1				3	1	0		0	**0**		0	
3	**Design and operation of the transmission Grid : B. Impact of LSOWE on power system performance**														
3.1.	Power quality				3							1			
3.1.1.	Flicker	1	1			1	0	1	0	1	1	1		1	0
3.1.2.	Harmonics and interharmonics	1	0			1	0	1	0	1	1	1		1	0
3.1.4.	Impact of long-distance sea cable on power quality	1	1			1	0	1	0	0	0	1		1	0
3.1.5.	Power quality assessments	1	0			1	0	0	1		3	1			0
3.1.6.	Power quality measures	1	1				0	1	1		1	1		1	0
3.3.	Grid Infrastructure											1			
3.3.1.	Grid requirements	1	3				3	0	1		1	1		1	0
3.3.2.	Grid suitability	2	1			1	3	3	1	3		1		1	1
3.3.3.	Grid reinforcements	2	3				3	1	1	3	1	1		3	0
3.4.	Grid stability											1			
3.4.1.	(Static) stability	1	1			1	1	0	1		1	1			0
3.4.2.	Loadflow-analysis	1	1			1	0	1	1		0	1			0
3.4.3.	Dynamic Grid stability	2	3			0	0	3	1		3	1			3
3.4.4.	Dynamic Grid Analysis	1	3			1	1	1	0		1	1			3
3.5	Impact on national Grids														
3.5.1.	Reactive Power	1	1			1	1	0	1		1	3			1
3.5.2.	Primary control	2	1			0	3	0	3		1	3			1
3.5.3.	Secondary control	1	1				3	1	1		1	1			1
3.5.4.	Black-start capability and spinning reserve	2	0				3	1			3	1			1
4	**Design and operation of the transmission Grid : C. Power system planning and Grid access for LSOWE**														
4.1.	Grid access requirements	1										1			
4.1.1.	Technical requirements	1	3			0	3	1	1	1	3	1			0
4.1.2.	Non-technical requirements	1	0			1	0	0	1	1	3	1			0
4.1.3.	Grid support requirement	1	3			1	0	0	1	1	3	1			3
4.1.4.	Impact	2	3				3	3	1	1	3	1			3
4.1.5.	Suitability	1	1			0	3	1	1	1	1	1			3
4.1.6.	Priority access	1	0			3	0	1		1	1	1			3
4.1.7.	Ownership	1	1			1	3	0	1	1	1	0			0
4.2	Ancillary services	1										1			

4.2.1.	Reactive power	1	1			1	0	1	0	1	0	1			0
4.2.2.	Primary control	1	1				1	0	1	1	0	1			0
4.2.3.	Secondary control	1	1				0	0	1	1	0	1			0
4.2.4.	Black-start capability	0	0				0	0	1	1	0	1			0
4.2.5.	Ancillary service opportunity	0	0				0	0	0	0	0	1			0
4.3.	National Grid	1										1			
4.3.1.	Grid strength	2				1	3	3	3	3	1	1		3	0
4.3.2.	Grid Reinforcement	1				1	1	1	1	3	1	1		3	0
4.3.3	Off-shore Grid Extension	1	1			0	3	0	1	3	0	1			0
4.4.	International Grid Aspects	1										1			
4.4.1.	ACE requirements	1	1									1			
4.4.2.	Cross-border transmission capacity	1	3			1	0	0	1			1			
5	**Financing of large offshore wind farms**														
5.1.	Investment budget	2	1		3	0	3	1	1		3	0		1	3
5.2.	Investment risk	1	1		3	0	1	1			3	0		1	3
5.3	Financing conditions	1	1		3	0	3	1			1	0		3	1
5.4.	Insurance conditions	1	1		3	0	3	1			3	0		1	1
5.5.	Support mechanisms	2	1		3	1	1	3			1	0		3	3

List of Acronyms

ACE	Area Control Error
AGC	Automatic Generator Control
ATC	Available Transfer Capacity (MWe)
CHP	Combined Heat and Power (Co-generation)
DSA	Dynamic Security Analysis
DSM	Demand Side Management
DTS	Dispatching Training Simulators
ELTRA	Management Agency of the Danish Grid
EMS	Energy Management System
ESI	Electrical Supply Industry
FACTS	Flexible AC transmission
GTO	Gate Turn-off
HTB	High Tension Bus
HV	High Voltage
HVDC	High Voltage Direct Current
IC	Interconnection Capacity (MWe)
IGBT	Insulated Gate bipolar Transistor
IPP	Independent Power Producer
LOEE	Loss of Energy Expectation
LOLE	Loss of Load Expectation
LOLP	Loss of Load Probability
LSOWE	Large Scale Offshore Wind Energy
LV	Low Voltage
MV	Medium Voltage
NFFO	Non Fossil Fuel Obligation
NORDEL	Nordic Electricity Grid
NTC	Net Transfer Capacity (MWe)
NTF	Notified Transmission Flow (MWe)
OWEE	Offshore Wind Energy Europe
OWEN	Offshore Wind Energy Network
PV	Photovoltaic
RES	Renewable Energy Sources (Primary)
RES-E	Renewable Energy Sources for Electricity Production
RFC	regenerative Fuel Cell
RTU	Remote Thermal Unit
SA	Steady State Security Analysis
SCADA	Supervisory Control Data Acquisition System
SMES	?
STATCOM	Static Commutation
SVC	Static Var Compensator
TRM	Transmission Reliability Margin (MWe)
TSA	Transient Stability Analysis
TSO	Transmission System Operator
TTC	Total Transfer Capacity (MWe)
UCPTE	Union for the Coordination of Production and Transmission of Electricity
UCTE	Union for the Coordination of Transmission of Electricity (Formerly UCPTE)
VSC	Voltage Source Commuted
WPPT	Wind Power Prediction Tool
WTG	Wind Turbine Generator

CHAPTER 4

OFFSHORE WIND POWER POTENTIAL

SUMMARY

The objective of chapter 4 is to review of offshore resource modelling techniques and to discuss estimates regarding the offshore wind potential in Europe.

Wind resource studies for EU offshore regions are based on monitoring data and modelling techniques. The issue of offshore wind resources is complicated by a number of factors. Low roughness gives low turbulence and wind shear but thermal effects are important, particularly in coastal regions: wind speed profiles deviate from logarithmic and thermal flows are generated, such as sea breezes and low level jets. The paper discusses both offshore wind monitoring and state of the art modelling techniques. A major conclusion is that while current modelling techniques can provide good representation of general resources, specific site resource estimation still requires on-site measurements.

The offshore wind potential is derived from the wind resource in combination with a number of local constraints, such as technology limits (such as water depth), economy, ecology and conflicts of interest with other users. The resulting wind potential is thus a function of constraints considered, the assumptions applied and the level of detail. In the paper, available studies of the offshore wind power potential in the EU are collected, analysed and discussed in the context of the above. Unfortunately, most studies have been performed on a national basis and a specific set of assumptions and can not easily be combined for the EU total. Notwithstanding this difficulty, the paper develops an overall estimate, which comes at 140 GW, which is well in excess of the EU White paper target of 10 GW in 2010.
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 chapter.

CONTENTS OF CHAPTER 4 : OFFSHORE WIND POWER POTENTIAL

4.1 OFFSHORE RESOURCE ASSESSMENT

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. 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 two data sources are used. The first is the OWEE country by country survey (given in Appendix 2) which has been summarised in the tables 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 4.1 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 4.1. Offshore wind resource: importance of various factors by country

country	Topic						
	Onsite Measure-ments	Available data	Model estimates	Physical limits	Planned activity	Electricity cons.	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 4.2 gives an overview of resource assessment by country and the major criteria used in its development [1].

[1] *Resource supplied converted if necessary assuming 1000 MW ~ 3.3 TWh/y. [6] give 3530 'net full load hours' for North Sea sites and 3000 -3300 at interior water sites at Danish sites.

Table 4.2: Offshore resources

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 .	www.electrabel.com
DK	8000	26	4000	2030	Additional 4000 MW water depth > 20 m Exploitable resource 83-287 TWh/y	[1, 2, 3]
FI	6000	20	0			
FR	13000	44	0		EED studies indicate potential in four areas of 9125 MW or 30.1 TWh.	[2]
D	13000	45	0			[2]
GR	1500	5	0			[2]
EI	3300	11	1250	2010?	Water depth< 20 m, Min distance 5km, 32% of nat. electricity	
I	3000	10	1000	2030		[2, 4]
NL	10000	33	1250	2020	~11% of national electricity consumption	[5, 6]
PL	600	2-3	0		Technical potential is 11 PJ offshore wind energy. Two projects have consents and two more are pending.	BAPE
PT	0	0	0			
ES	2000	7	0		Two projects in planning, monitoring at one	[6]
SE	7000	22.5	650	2005	Many projects at planning stage	[2, 7]
UK	70000	230-334	2600	2010	Planned 2% of UK supply by 2010	[7]
Total	138600*	-76*[1]	10950			

Most studies are built on the first predictions of offshore wind energy resources from [8] 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. [2] 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 [2]. Ref [3] 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. Ref [5] 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 [9, 10, 11] for [12, 13] and the UK [14, 15].

[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 [5] estimate taken from BTM Consult which is 327 TWh/ year or from estimates without constraints.

National exploitation plans are highly variable by country and are described in Chapter 9.3. 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.

Wind energy developers and manufacturers are optimistic about the offshore market. A company report on Vestas [16] 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 [5], wind energy groups [3] and the Danish energy Agency and IEA CADDET Renewable energy Technologies Programme [2].

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 [17] and Japan [18]. Ref [19] 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 4.3 gives a summary review of the status of offshore resource assessment in the different European countries.

Table 4.3: 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, EI No target set, monitoring underway ES, FI 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 4. 2)

4.2 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: [20, 21, 22, 23]. 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: [13, 24, 25]. Interactions between the wind and the sea surface is also complex, particularly for extreme wind/wave studies e.g [26, 27]. Successful planning for operation and maintenance is crucial [2] 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).

4.3 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 [28]. Main recommendations (for resource assessment) 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. [29, 30]).
- 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.

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CHAPTER 5

MARKET DEVELOPMENTS

SUMMARY

The objective of this chapter is to describe market developments in the energy industry which are relevant for the development of offshore wind power.

In a number of EU countries (such as Belgium,, Denmark) minimum shares of renewable energy are required, either for utilities to sell, or consumers to buy. In other countries (Ireland, The Netherlands) green certificate markets have been established.

Both systems are expected to support the demand for renewable energy in general and experience has to show which system has the strongest impact on RES development.

CONTENTS OF CHAPTER 5 : MARKET DEVELOPMENT

5.1 DEMAND FOR ELECTRICAL POWER (ALL SOURCES)

Demand for electricity and generating capacity throughout Europe is variable and very much depends on the size of individual countries and the types of industry and commercial development, as tabulated in Table 5.1 below.

Table 5.1: electricity demand in European countries

Country	Demand TWh/year	Installed Capacity GW	Comments
Belgium	80	15	
Denmark			
Finland			
France			
Germany	477	109.2	
Greece			
Ireland	18.6	4.5	[1, 2, 3]
Italy			
Netherlands			
Poland		33	
Spain			
Sweden			
UK	379.5	75.305 [4]	28% is from coal, 24.5% from nuclear, 38.5% from gas, 1.5% from oil, 4% is imported, 2.5% is from ‘other fuels’ (biofuel 81.1%, hydro 15.9%, wind 2.6%).

Growth *trends* vary throughout Europe, for example, Ireland observed a 48% increase in demand between 1990-1998, whereas the UK only had an 8% increase between 1995-1999

Ireland *predicts* a 24% increase between 1999-2005 and Germany predicts demand to be 532 TWh/year in 2010, with capacity projected to be 115.4 GW in 2010.

5.2 DEMAND FOR POWER FROM RENEWABLES

Green energy products can include electricity from the following renewable sources (depending on the definition):

- Photovoltaics
- Onshore wind power
- Offshore wind power
- Wave power
- Large scale hydro
- Small scale hydro
- Geothermal
- Biofuels:
  - Landfill gas
  - Sewage sludge digestion
  - Industrial wood combustion
  - Coppice
  - Straw combustion
  - Waste combustion

Of the biofuels, waste combustion and use of landfill gas do not qualify under the UK Renewable Energy Obligation.

Poland
In Poland local municipalities must include a contribution from RES in energy plans. The theoretical potential output from renewable energy is given below:

Table 5.2: RES potentials for Poland

	Source	Energy [PJ]	Remarks
1.	Biomass		
	a. straw	160	
	b. wood	110	35 PJ- forest 15 PJ- afforestation 30 PJ-wood industry 30 PJ- recycling
	c. biogas+waste	236	36 PJ- animal manure 100 PJ- waste 100 PJ- waste water treatment plants
	d. biofuels	44	
2.	Hydropower	40	
3.	**Wind energy**	**47**	**36 onshore + 11 offshore**
4.	Solar energy	370	
5.	Geothermal	200	main sources
	Total:	**1 207**	

In Germany, due to liberalisation of the energy market, there are several green energy products available on the market.

Current Demand and Trends

Belgium
The Flemish region of Belgium issued a decree in July 2000 which requires 3 % of the total electricity sold to the distribution grid to be from renewable energy sources produced within the region by 2004. A penalty of 0.12 EURO per kWhr will be imposed for the missing green kWhr. It is likely that the Walloon region will follow suit. Over 50% should be from wind energy, of which 50% is likely to be offshore.

Denmark
In Denmark, the power market is fully liberalized. Regarding offshore wind energy, *Energy 21*, the current energy action plan, presupposes that up to year 2030 development of offshore wind turbines with a total of 4000 MW will take place. The production of electricity from wind power in 2030 is expected to contribute 40-50% to Danish electricity consumption.
Regarding renewable energy in general, it is expected from year 2003 that each consumer has to buy 20% of his electricity based on renewable energy sources. The ratio will be declared some years ahead and is expected to be increased in the coming years.
A green certificate market is expected to start up 2003 to cope with the demand for green electricity and by that establish a kind of liberalized green electricity market.

Finland
In Finland, the power market is fully liberalised, and there will only be commercial wind farms. The demand for green power is a prerequisite for wind energy installation. There is currently a small demand for green power, but several products are available

France
There is a national target of 5000MW of wind power by 2010 in France. The REFIT, Renewable Energy Feed-In Tariff, price is to be defined and a decree is to be published in March 2001.

Greece
In Greece since 1994 a number of laws and regulations (Laws 2244/94, 2601/98, 2647/98) have been instituted aiming at the exploitation of the vast RE resources in Greece, mainly sun, wind, large/small-scale hydro and biomass. Together with the broad use of natural gas, the penetration of “clean energy technologies” in the public, industrial, agricultural and commercial sectors has risen considerably in the past decade. The deregulation of the energy market in 2000 (Law 2773/99) followed vivid interest from private investors for installation & operation of RE plants. The central points of the present legislative and environment for RES-installations are summarised as follows:

- Production and trading of electrical power from RES by independent producers
- Buy-off commitment of “green” energy by the PPC
- Attractive tariff policy for “green” energy production
- Long-term purchase agreements for “green” energy
- Financial incentives for RES-installations (subventions, tax exemptions etc)

Fig. 5.1 shows the approved RE plant installations per technology, petitioned after the deregulation of the energy market was placed into effect. The plants are implemented with the “build-own-operate” (BOO) scheme. A large part of the plants is meanwhile in operation, while the rest is nearing completion.

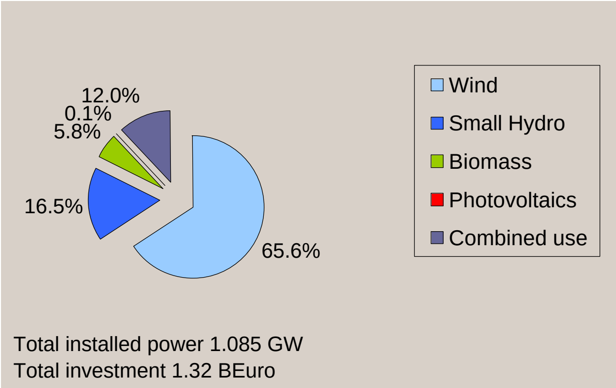

Fig. 5.1: Approved RES-plants after the deregulation of the energy market in Greece

Petitions are pending for farther plants, among which ~500 MW for offshore wind energy. The penetration of "green" technologies into the energy market is expected to reach the mark of 6% by 2008 (Fig. 5.2).

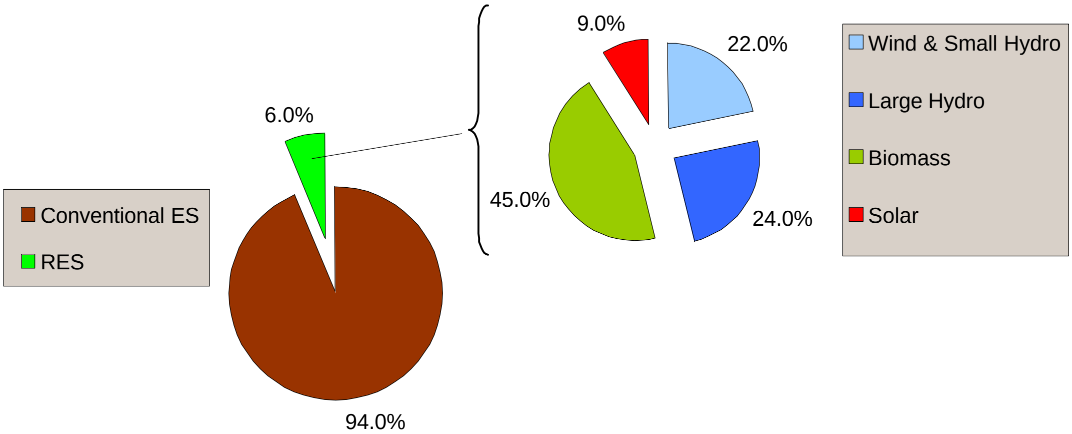

Fig. 5.2: Share of "green" power technologies in energy consumption by 2008

Ireland

In February 2000, the electricity market in Ireland was partially liberalised. All large electricity consumers (>4GWh per annum) may choose their suppliers. In addition all customers (of any size) who wish to buy green electricity may choose their supplier. Green electricity suppliers are now targeting commercial customers who pay the highest tariff and are offering green electricity at 10% below what these customers pay the Public Electricity Supplier for brown electricity. To date, two windfarms (13 MW) have been built to sell directly to green commercial customers and a further 25MW of wind energy is imported from Northern Ireland to meet demand. It is uncertain what will happen to this market when the commercial customers can choose from brown electricity suppliers also in 2005 (probably at more competitive rates). The Government target for renewable energy is an additional 500MW by 2005, most of which is anticipated to come from wind energy

Italy

The Italian Government attributes strategic importance to renewable energy sources because of the contribution they can give to the guaranteeing of greater security of the energy supply system, the reduction of the relative environmental impact and the opportunities for protecting the territory and fostering social development. One aim of the Government in this sector, as stated in the Italian White Paper for the exploitation of renewable energies in August 1999, is to achieve the goal of doubling the contribution of renewables by 2010.

In 1999, for the whole electricity sector, Italy's overall electricity demand was nearly 286 TWh (including transmission and distribution losses). Of this, about 42 TWh was imported from neighbouring countries. The net electric energy produced in Italy was 253 TWh.
Italy's net production from renewable sources in 1999 including large and small hydro, geothermal, wind and photovoltaic plants, was as much as 22 % of total net production.
Installed net capacity totalled about 73.8 GW (of which 20.4 GW were hydro and 52.5 GW were thermal plants) as of the end of 1999.

Total wind power capacity in Italy at the end of august 2001 was 610 MW, with an average turbine size of 552 kW, whereas the total number of wind turbines was 1110.
National targets have been fixed for wind power capacity for three periods: 2002 = 700 MW, 2006 = 1,500 MW and 2008-2012 = 2,500 MW.
Given the growing rate of new wind installations registered in the last year, it is very likely that the first goal, 700 MW by 2002, will be exceeded.
As regards the likelihood of reaching the other targets after 2002, this will depend on the effect of the new legislative framework including the new market stimulation instruments for renewable energy sources.

Since the end of 1996, the CIP (Interministerial Committee for Prices) Provision no. 6/92 has shown itself to be the most successful instrument for the commercial implementation of wind energy in Italy. This system was based on buy-back prices mechanism.
Now, a new Legislative Decree (no. 79/99), which provides for the liberalization of the electricity market on the basis of the European Union Directive no. 96/92/EU, will change the system of stimulation and exploitation of renewable energy sources. This Decree was followed by a specific Decree regarding renewable energy sources, which introduces the new support system based on green certificate mechanism.

According to Article 11 of Decree 79/99, the transmission system operator (GRTN) must assure priority in dispatching to plants fed by renewable energy sources. In addition, starting from 1st January 2002 onwards, there is an obligation to introduce into the public electricity network, or to acquire fully or partially, a given percentage of electric energy from renewable sources, for all the subjects producing or importing electric energy from conventional sources.
The above percentage is initially fixed at 2% of the conventional energy that exceeds a quantity of 100 GWh per year and must be exclusively assured through new or repowered plants entered in operation after 1st April 1999 (as to repowered plants, only the energy produced by the added capacity can be taken into account).

Electricity produced by renewable energy sources is labelled with green certificates issued by the transmission system operator (GRTN) and having a value equal to or multiple of 100 MWh. Green certificates are tradable.
Another important aspect of green certificates concerns their compatibility with other incentives. In other words, for a green energy producer it will be possible to combine green certificates with any kind of subsidy, except the premium energy buy-back prices of CIP 6/92.

Regarding the economics, in 2000 the wind plant cost was around ITL 1.9 million per installed kilowatt; therefore in the same year the total invested capital on wind energy plants in Italy was about ITL 280 billion.
In regard to the energy cost, the selling price of electricity (net prices without taxes) varies, for typical domestic consumers, from ITL 100 to ITL 300/kWh, whilst, for industrial consumers, from ITL 100 to ITL 230/kWh.
For wind energy, in 2001 the buy-back prices fixed by CIP 6/92 are: ITL 239.6/kWh for the first eight years of the plant operation; and ITL 133.9/kWh for the remaining lifetime.
As already said above, in the next future, because of the new legislative framework, the support system will change through the introduction of the green certificate mechanism.

Netherlands

In the Netherlands, a voluntary green energy system has been on the market for several years. The product has experienced growing popularity especially when it was exempted from the energy tax REB.

In the middle of 2001, an official scheme was introduced, together with liberalization of this “green market”. Consumers are free to choose their own supplier for green electricity. As a result competition between suppliers has been intense and in advertising, the “green image” of the supplying company plays since than an important role. This competition, in combination with the exemption from REB makes green electricity almost competitive with “dirty” electricity.

Spain

Policies for renewable energies in Spain are established in the “Plan de Fomento de las Energías Renovables” edited in December, 1999 by the Spanish Institute for the Energy Diversification and Saving (IDAE). This proposes a stable framework with direct price support for renewables, with a premium system similar to Germany’s.

Sweden

Sweden currently produces 145 TWh/year. As the market is deregulated there are very different market prices depending on many parameters; precipation, winter temperature, long or short contracts etc. The present average price is about 0.15 SEK, about 0.018 EURO, which is very low in comparison with countries outside Scandinavia. More detailed information can be found on the website for Nordpool-the common Scandinavian powermarket..

Hydropower provides approximately half Sweden’s electrical power, with the remainder mainly from nuclear. The Parliament has decided to close nuclear power stations and replace them with power from renewables. The process started with the closure of the first of twelve reactors, Barsebäck 1, in December 1999. Barsebäck 2 will be closed in 2003. There is currently no programme for closure of the remainder. Because of nuclear plant closures, more interconnection with grids in other European countries, and taxation on fossil fuels to incentives reduction of greenhouse gases, there will be a gradual increase of prices.

Sweden has many more electricity heated houses than in other European countries and has a very low dependency on oil and coal for electrical power production

A large number of utilities in the deregulated market offer “green electricity” and some offer “extra green” from wind power. The price for wind generated electricity is about 5 – 10 % more expensive than the standard product.

Most customers are companies looking to strengthen their green image and obtain favorable publicity or to be environmentally certified.

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CHAPTER 6

ECONOMICS AND FINANCING

SUMMARY

The objective of this chapter is to give a review of state of the art and trends regarding offshore wind farm economics and financing.

Economics: Offshore projects require initially higher investments than onshore due to turbine support structures and grid connection. The cost of grid connection to the shore is typically around 25% 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. Investment costs have been reduced from about 2200 € /kW for the first Danish offshore wind farms to an estimated cost of 1650 € /kW for Horns Rev (giving an estimated cost of 4.9 € cents /kWh). This compares with typical figures for onshore sites of investment 700-1000 € /kW and estimated energy cost of 3-8 € cents/kWh for a mean wind speed of 5-10 m/s.
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. Operation and maintenance charges are variable according to site but a rough estimate is 30 € /kW with 0.5 € cents/kWh variable.
A tentative conclusion is drawn that for good sites (not too deep water, benign wave climate, not too distant from shore, high enough resource) large offshore wind farms could in the near future generate electricity at costs, which allow for commercial exploitation. The paper gives an estimated range of production costs in €cents/kWh.
Whether offshore wind power could be commercially viable depends on whether sufficient project income can be generated. This depends on whether the energy produced can be sold on the (than) fully liberalised market at a reasonable rate and how the environmental benefit is valued. The paper discusses a number of factors (such as use of forecasting techniques), which are of influence on energy sales in a liberalised market. It is concluded that severe risks exist associated with market liberalisation where the environmental benefits are not adequately valued, which may jeopardise development at some sites. Despite the average cost of offshore wind energy being competitive with many traditional energy sources, projects may not be viable. 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.

Financing: From the current developments of demonstration offshore projects of various sizes, it would appear that sufficient equity capital is available for financing offshore wind farm projects. Some major oil & gas companies and utilities have announced projects, which could be financed by company equity. However it still remains to be determined under which conditions (due diligence, certification, insurance etc) bank loans will be granted for offshore wind farm projects. Only test and demonstration projects will provide information to allow an answer to this question. At least they will reduce the present uncertainties related to the cost of energy generated.
Important support comes from a variety of national incentive mechanisms, such as investment subsidies, tax exemptions, fixed tariffs and green certificate schemes.

CONTENTS OF CHAPTER 6 : ECONOMICS AND FINANCING

6.1 ECONOMICS

6.1.1 Cost Ranking

Chapter 2.2 presented an analysis of size, technology and resulting cost trends on the basis of currently available commercial offshore wind turbines.
In this chapter costs of actual projects are discussed.

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 {1, 2, 3, 4] 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. Ref [5] expect production costs of the order 0.05-0.055 €/kWh or equivalent to land sites. Ref [6] 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) [7]. The Opti-OWECs project illustrated that offshore wind energy should be economically viable in most Northern European coastal areas [8]. Energy costs in both studies and actual projects have steadily decreased over the last decade [9]. 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% [10]. However recent studies indicate that large offshore wind farms are competitive with other energy sources (e.g. [11]) 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 [12].

Table 6.1 (at end of chapter 6) shows details of current offshore wind farms. Production figures have been estimated if not available. See also: [30].
There is a major difficulty in comparing costs of energy produced due to:

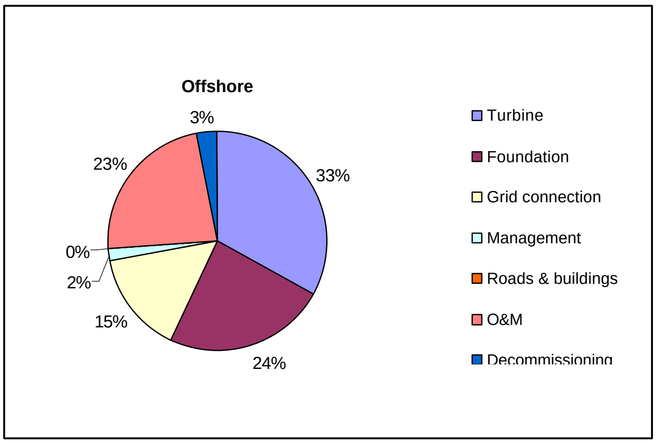
- the differences in project financing (lifetime, interest rates)
- costs of operation and maintenance
- commercial nature of projects means that this information is not in the public domain.

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. Ref [13] also show the average energy costs for offshore wind energy decreasing over the last ten years and give details of the sites.

Table 6.2 (at end of chapter 6) shows cost data for actual planned wind farms. It is difficult to distinguish “planned” from “tentatively explored” since some apparently promising projects stall or fall [14, 15] 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 [16] 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.

6.1.2 Cost distribution

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 [19]. The cost of grid connection to the shore is typically around 25% [10] 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 [10]. 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 [33] 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 [19]. 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 [8]. 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% [34]. For specific projects [10] 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 [10].
Figure 6.1 gives examples of planned offshore installation costs by component.



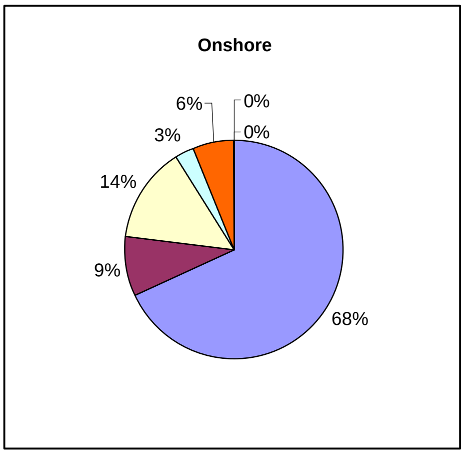


Figure 6.1 Examples of different component contributions to cost for on- and offshore wind farms

Other models exist e.g. [10] suggest 51% for turbines, 18% for grid connections, 16% for foundations, 7% for electrical, 4% for planning and 2% for operation and maintenance facilities.
Ref [13] gives cost breakdown for initial costs:

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

These vary slightly compared with those from [5] which are given in Table 6.3. Investment costs onshore are approximately €1.5 million/MW compared with onshore costs of approximately €1 million/MW.

Table 6.3 Investment costs by component, [5]

	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 [13] 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 [35, 36].

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.

6.2 FINANCING OF LARGE OFFSHORE WIND FARMS

6.2.1 Introduction

Investment budget
Contrary to onshore wind projects, the offshore technology is not in an advanced state to evaluate the total investment budget with enough precision. Indeed the foundation costs and the interconnection costs, which can easily exceed the cost of the wind turbines, contain some large unknowns and may vary considerably from site to site.

Investment risk
Large offshore wind farms contain considerable risk elements that can have a large impact on the production, and hence on the revenues. There is not enough experience with offshore wind parks to evaluate the technical availability, due to inaccessibility for repairs. Advances in technology (based on past experience) may possibly increase the technical availability and hence the production capacity which is a considerable risk factor to reckon with. Operation and maintenance costs are very difficult to predict. No guarantees can be given regarding lifetime of wind farm equipment in harsh offshore conditions.

Financing conditions and insurance
- Financing institutions are currently prepared to invest in offshore wind energy projects. Nevertheless, these projects are considered as high-risk investments. Financing conditions (e.g. minimum equity versus loan, rates) may therefore be higher than for conventional, and even onshore technologies.
- Important investments in large offshore wind farm will only be possible if the inherent investment risk can adequately be insured. Therefore, it should be examined to what extend and under what conditions insurance companies are ready to insure offshore wind farms.

Support mechanisms
Under the current liberalised market conditions, Renewable Energy technologies, face significant barriers to be widely used such as
- High capital cost
- Lack of network infrastructure
- Lack of confidence in these new technologies
- Technical problems associated with the geographical distribution of available potential, and the stochastic nature of the primary energy (Wind)
- Legislative barriers for obtaining construction and operating licenses.
- Electricity trading mechanisms which inequitably penalise unpredictability.

Support mechanisms are clearly needed to accelerate development of renewable energy in Europe.
The most critical policy issue towards the EU white paper targets concerns the support mechanisms to be established for Renewable energy. Across Europe, there exist a wide range of support mechanisms such as (see also Par 6.2.2.5):
- Fixed feed-in tariffs: (e.g. Germany) : not market based, but highly effective for promoting local industry
- Quota system (with or without penalties) : Competition based mechanisms ensure that the quota are obtained with the cheapest technologies.(e.g. Belgium)
- Public tender approach (cfr former NFFO in the UK) :
- Green certificates (Denmark, Netherlands) : A market based approach where the Wind park generates kWh and certificates which are both handled separately and traded. This requires however a large enough trading area (e.g. European) to be effective and stable. However, this presupposes harmonisation rules at the European level.

6.2.2 Summary of the state of the art

6.2.2.1 Investment budget

Generic information regarding investment budgets is available from many feasibility studies and to some extent from existing offshore wind energy projects. The available data however do not cover the entire range of cost influencing parameters (such as distance from shore, water depth, wind and wave climate, soil conditions) which may be encountered in case of a significant Europe-wide development of offshore wind power.

It should be noted that some of the above conditions, in particular soil conditions, may show significant variations even within a single country. For some projects, the differences may be large enough to require the use of different foundation solutions.

It should also be noted that investment costs related to the compensatory measures are difficult to evaluate by the lack of experience: example for the radar's or the UHF emissions, for protections anti-erosion, for the compensations of the fishermen. The costs of dismantling can be integrated in the initial invest (2% of the total budget as on the Danish projects, which appears weak) or in exploitation by constituting a reserve (as what is required in Belgium). Their evaluation is very difficult today. In addition, the regulation will be able to evolve (and will evolve): will it be possible in 20 years simply to explode the monopiles ?

6.2.2.2 Investment risk

Investment risk for onshore wind energy projects is well known and has been described to some extent in available literature. For offshore wind energy projects, additional risk arises due to :

- The possibility of major transport and installation delays due to bad weather,
- Large uncertainties on accessibility and availability
- Large uncertainties on O&M-costs (incl. Eg. Taxes and royalties)

In addition, even more far reaching risk may be caused by the application of relatively new technologies in environmental conditions that are badly defined. Questions remain related to eg. wake effects in large wind farms, lifetime of offshore wind turbines, etc.

Industry takes uncertainties into account by applying proper margins to budget estimates. However, for a better understanding and quantification of investment risk, it is required that operational feed-back from test and demonstration projects around Europe is analysed in a coherent way.

In the long term, a cost reduction could be possible by the introduction of a cost sharing system between different operators.. This requires cross holdings between operators limiting the risks and reducing the costs. This organisation is different from those of the terrestrial projects, and will be easier to realise with operators of big size that with smaller size wind turbine developers. Thus these operators could share a data base on the available resources and on the maintenance costs like it is done in offshore oil Companies. This would create a professional organisation gathering these data for the benefit of all. It is necessary to note that on sea the actors are naturally more "united" by the difficult conditions and of the significant costs. A mutation of wind energy seems necessary to this stage. We could then propose to provide the foundations of such exchange structure between operators (with various under-topics : technology, impacts, compensation, dismantlement).

6.2.2.3 Financing conditions

From the current developments of demonstration offshore wind farm projects of various sizes , it would appear that sufficient equity capital is available for financing large scale offshore wind farm projects. Some major oil & gas companies and utilities have announced offshore projects which could be financed by company equity.

Nevertheless, many other projects have apparently been announced well before financing was secured. It still remains to be determined under which conditions (due diligence, certification, insurance,…) bank loans will be granted for large scale offshore wind farm projects. Only test and demonstration projects will allow to establish an answer to this question.
Even in a country such as Germany where financing is easily achieved for onshore wind energy, it is not certain that off-shore wind energy projects could be financed in the same way. Obviously the financial risk involved in a large-scale off-shore wind energy investment is much larger than the risk involved in a series of smaller on-shore wind energy investments.

6.2.2.4 Insurance conditions

Whereas insurance conditions for onshore wind energy are well established (and typically amount to about 2.5% ot the annual 0&M costs), it remains to be determined at which costs machinery breakdown and/or production loss insurance will be available for large offshore wind farm projects. Only test and demonstration projects will allow to establish an answer to this question. The evolution of safety regulations may have an important impact on the evolution of insurance costs.

6.2.2.5 Support mechanisms en incentives

National experiences

In order to promote wind power (including offshore) most European countries have implemented support mechanisms, utilising a wide area of support mechanisms. The four main mechanisms applied are investment subsidies, tax exemptions, fixed tariffs and green certificates, often in some combination.

Table 6.3 (at the end of chapter 6) presents a comprehensive review of national incentives to promote offshore wind energy, based on questionnaires reported by OWEE members, see also Chapter 5 for a review of national market developements.
The responses to the questionnaires indicate that it is not only the amount of subsidies that determine the success of the schemes, but also the extent to which the income is safeguarded into the future. This is clearly indicated for e.g. the Swedish case, where the amount of subsidies obtainable appears promising, but where the schemes are modified too frequently for the schemes to make investors and creditors confident. Given the size of the investments and the relatively long payback times covering energy production facilities in general, risk evasive measures become of central importance.
To put it more directly: investors are generally willing to take risks, as long as the magnitude of risks is known. This requires that the support mechanisms are put into operation for periods long enough to cover at least the project planning period (so the initial feasibility study is also valid when it is put into operation). Two schemes that have obtained this are the former Danish and actual German feed-in tariff systems, which have secured significant investments in wind power, but other mechanisms might achieve the same goal if applied with care.

The ongoing liberalisation of the European energy sector has introduced significant uncertainties on subsidies, as the whole subsidy schemes have been revised, in order to comply with EU common market requirements. In some countries the procedure of exchanging old support mechanisms with new ones has been delayed, putting developers in a hard situation, not knowing which rules applied.

In general the liberalisation procedure seems to result in the subsidy schemes being harmonized towards the green certificate model, awarding wind power an extra bonus, determined by a certificate market. In the Netherlands such a scheme is already in operation. For other countries the schemes are not finally put in place, introducing significant uncertainties on future prices, see table 6.3.

March 2001, European Court of Justice made an important decision concerning the future of price support for the development of renewables, as it decided that The German Feed-in Law (the Stromeinspeisungsgesetz) was not state aid. The court also stated that the German rules were in compliance with internal market rules, as they were intended to help achieve environmental objectives, which are a priority for the European Community.

This decision makes it possible for member states to implement similar schemes without challenging European state aid rules, as these rules are not considered to act as barriers for countries that set an obligation to purchase electricity from renewable sources [41].

Since the time of this decision, the future of the green certificate market is becoming increasingly insecure, as the feed-in tariffs in Spain and Germany can now continue. Furthermore, a law on renewables resembling the EEG in Germany has boosted the very promising market in France.

A review of national incentives (2001), from [41] results in the table 6.4 relevant for offshore:

Table 6.4. The top 11 Offshore Markets

Country	Market support	Tariff, EUR/kWh
Denmark	Moving from fixed price to green certificates	min. 0.057 over 10 years ?
France	Guaranteed access, fixed feed-in tariff	app. 0.07 over 15 years
Germany	Feed-in tariff	0,091
Greece	Guaranteed access, fixed feed-in tariff on mainland and interconnected islands	0.06
Ireland	Fifth round of Ireland's Alternative Energy Requirement competitive bidding process has price cap of EUR 0.048/kWh over 15 years for projects larger than 3 MW.	0.048 for projects larger than 3 MW over 15 years (25% of which is linked to the Consumer Price Index)
Italy	Moving from relaxed fixed price system, with 2001 buy-back prices being EUR 0.124/kWh for the first eight years and EUR 0.069/kWh for the remaining lifetime, to green certificates market in 2002	0.124 for the first eight years, 0.069 for the remaining lifetime ?
Netherlands	Green certificates market introduced medio 2001	app. 0.077
Portugal	Interest-free loans, fixed tariff of EUR 0.06/kWh	0.06
Spain	Fixed payment EUR 0.0626/kWh or EUR 0.028/kWh on top of average market price	0.0626 +0.028
Sweden	Investment grants and payment of app. EUR 0,046 /kWh replaced by green certificate system in 2003	0.046 ?
UK	New system will link green certificates, worth app. EUR 0.047/kWh to obligation on power suppliers to buy renewables	0.047

conclusions

Regarding national incentives, history shows that feed-in tariffs have been used onshore in Denmark, Germany and Spain, Europe's top-three on-shore markets. After the feed-in-tariff in Denmark was announced to be replaced by a still not functioning green certificate market, the development of onshore projects has virtually stopped.

The conclusions, based on this example, is not necessarily that only feed-in-tariffs can secure future development of wind energy, including offshore, but it can be concluded that the countries within EU need to create *long-term* market support mechanisms that are sufficient and secure enough to attract investors and developers.

The EC Court of Justice decision regarding the feed-in-tariff system in Germany ("Stromeinspeisungs-gesetz") indicates that feed-in-tariffs are not in compliance with internal market rules, thereby securing this market support mechanism a future within the EU.

Support mechanisms applicable to large offshore wind farm projects vary from country to country. Some of the existing support mechanisms are not applicable to large scale projects (e.g. 100 MW) connected to the HV-grid. There is no consensus regarding the suitability of the different existing support mechanisms for offshore wind farm projects.

6.3 RESEARCH NEEDS

6.3.1 Economics

Research and development requirements for improving the cost-effectives\ness of offshore wind power are:

- 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 [37] 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 [13]. 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 chapter 2.
- Energy storage and transmission solutions to weak grid or loss in transmission problems (see e.g. [38,39]. See also chapter 3.

6.3.2 Financing

Table 3.1 form Chapter 3 also includes a ranking of research needs regarding financing of offshore wind farms. The ranking exercise within the CA-OWEE members results in the following critical research need regarding the financing issue:

- Generic evaluation of large offshore wind farm investment costs taking into account cost influencing factors (distance from shore, water depth, wind and wave climate, soil conditions)

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Table 6.1: Cost details of existing[1] wind farms

Name	#, size, make of turbines	MW	Year	€cnt /kWh	MWh/y	Investment [2] (€/kW)	Min fetch (km)	Water depth (m)	Comments	Refs
Nogersund SE	220 kW Wind World	0.22	1990		0		0.25	6		[17]
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.	[3, 5, 10, 18, 19]
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.	[5, 10, 19, 20, 21]
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 onshore farm. Mean wind speed 7.5 m/s.	[5, 9, 10, 19, 22, 23]
Irene Vorrink, NL	28 Nordtank 600 kW	16.8	1996		37000		0.02	5		[5, 19]
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	[4, 9, 10]
Blyth, UK	2 Vestas 2 MW	4	2000	7-8	12000		1	8.5	Coast approx. 5p/kWh	[24]
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.	[5, 25, 26, 27, 28]
Utgrunden,SE	7 Tacke 1.425 MW	10	2000		38000		8	7.2-10		[9]
Yttre Stengrund, SE	5 NEG MICON 2 MW	10	2001		30000					[29]
Total		~ 90			~170.000					

[1] see also par. 9.2.1 for other details of existing wind farms
[2] there is considerable variation in these costs from different sources

Table 6.2: Cost details for planned wind farms (Spring 2001)

Name	Turbines	Total MW	Year	Cost/ kWh	€cnt/ kWh	Production MWh/y	Comments	Refs
Horns Rev, DK	80 Vestas 2MW	160	2002	0.35 DKK	4.7			[5, 32]
Rødsand, DK	72 Bonus 2.1-2.2MW	151-158	2002	0.36 DKK	4.8			[5, 32, 33]
Breedt, FR		7.5	2002?		6.4			
Læsø Syd, DK		150	2003	0.35 DKK	4.8	396,000		[5, 10, 32]
Nearshore, NL		100	2003	0.16 NLG	7-8	300,000	receives subsidy of max NLG 60 m in connection with R&D programme	[10]
Omø Stålgrunde, DK		150	2004	0.37 DKK	5.0	434,000		[5, 10, 32]
Gedser, DK		150	2006	0.38 DKK	5.1			[5, 32, 33]
Arklow Bank, EI		500					10 km to coast, licence granted for monitoring Sep. 2000. ~ 27% more investment than onshore	

Note: a number of planned projects are not included because no cost details are known, such as the 13 sites in the UK, 17 in Germany and at least 4 in Poland. See chapter 9.2 for a full review.

Table 6.3 Description and evaluation of National incentives to promote offshore wind energy

	Description	Evaluation
BE	Currently existing incentives are limited to Independent Power Producers and to projects smaller than 10 MW. A new system based on green certificate trading and a renewable energy quota with penalties for the 2 main Belgian regions (Flanders and Wallonia) is expected soon.	N/A
DK	1. Utilities have until now been obligated to buy the energy produced by wind turbines. 2. The feed-in tariff is currently DKK 0.33/kWh (EUR 0.044/kWh) plus green certificates varying from DKK 0,1/kWh to DKK 0,27/kWh (EUR 0.013-0.036/kWh) running for the first 42,000 hours of an offshore project with the rated power in typical places, app. 10 years. For the Horns Rev and Rødsand projects, a tariff of DKK 0,453/kWh (EUR 0,06/kWh) has been set. After 42,000 hours with the rated power the price will be based on the day-to-day market electricity prices plus green certificates. The green certificate system has been progressively delayed and following the outcome of a public hearing on the subject (September 2001), its introduction is postponed for minimum two more years starting up from 2005. 3. Public support for feasibility studies for cooperatives	The uncertainty not knowing the prices (due to the introduction of green certificates) makes people reluctant. As a consequence, no onshore turbines have been planned since the green certificates were introduced. The fixed feed-in tariff was securing continuous investments in wind energy, but had to be given up because of political resistance and liberalization requirements.
FI	Investment subsidy of 25-30 % given by the Ministry of Trade and Industry. A part of the energy tax is refunded (0.04 FIM/kWh).	N/A
FR	No specific incentive for offshore.	N/A
GE	There is no firm governmental planning to develop offshore wind energy in Germany; Germany's Renewable Energy Sources Act (EEG – Erneuerbare Energien Gesetz) continues the reimbursement at a fixed feed-in tariff. In the reformed EEG a specially raised tariff is foreseen during the first nine years of operation of an offshore wind farm. This regulation is limited to projects coming online before the end of 2006.	The Development of wind energy in Germany under the umbrella of a fixed feed-in tariff system is seen as a major success and as an appropriate tool to develop a strong market. No evaluation as of yet – indication for attractiveness is the large number of projects applying for permissions in the German Bight.
GR	i) Subvention of up to 50% of the capital investment, ii) subsidization of loan interest, iii) tax-exemptions	N/A
IR	No specific incentive for offshore wind farms. The Alternative Energy Requirement (AER) competitive bidding process is open to offshore wind energy. The target in AER V for wind energy is 240 MW, 40 MW of which is reserved for small-scale (= 3 MW) wind farms. There are also plans for a Grid Upgrade Development Programme to accommodate additional renewable energy based generating capacity.	While AER V is open to offshore wind energy projects, planning permission must be evidenced in order to participate in the competition, which will effectively exclude offshore wind farms.

	Description	Evaluation
IT	Green certificates, region structural funds	N/A
NL	* System of Green Certificates. Spot market mechanism combined with a “Balancing Market” in the Amsterdam Power Exchange. * Fiscal incentives: Subsidies, REB (eco-tax), Vamil, Fiscal incentives do not yet apply outside the 12 nm zone.	Green certificates introduce more stability in the renewable energy market, which is a main requirement for potential investors. Spot market mechanism combined with the “Balancing Market” in the Amsterdam Power Exchange will positively affect the wind energy market. (Ref. Funtionele eisen van offshore winden, Kema, dec. 1998, pg. 15)
PL	None.	N/A
SE	There are currently no earmarked incentives focused on offshore wind power. The general support for introducing wind power in the power system is: 1. Investment aid, 15% of the total investment in a wind power plant is paid as a state subsidy. 2. Environmental bonus which is connected to the tax system for electric power , from 1 Jan 2001, 0,181 SEK (0,02 EUR) 3. Special support in order to make relief the consequences of fast decreasing power prices after deregulation 0,09 SEK (0,01 EUR) 4. Right to connect a small scale power station to the electric grid (small scale < 1,5 MW) 5. Special pay for decreasing losses in the electric grid up to 0,02 SEK (0,002 EUR).	The support system has been working the way it was intended – to develop an annual production of 0,5 TWh electric power from wind- but it has not given the long time security, which is needed, to interest investors and creditors. For example, today’s support system finishes 31 December 2002 with only promises of a new one, which nobody knows how it will be designed. A recent study initiated by government shall investigate how the support system can be replaced of a green certificate system 1 Jan 2003.
SP	No differences with onshore farms: The strategy of the Spanish government is summarized in the new "Program for Promotion of Renewable Energies" (Reference 1, see appendix) approved by the Parliament to maintain the situation of the Royal Law 2818/1998-23 December 1998, about the Electrical Special Regime for Renewable Energy Plants connected to the grid. That law fixed the price and the bonus of the electricity produced by renewable energy plants, price that will be up-dated every year by the Spanish Ministry of Energy and Industry according to the annual variation of the market price. All owners of installations using renewable energies as primary source, with an installed power equal to or lower than 50 MW, have two options, one is a fixed priced for the kWh generated, and a second option is a variable price, calculated from the average price of the market-pool, plus a bonus per kWh produced. In 2000 the bonus added to the base price was 0,0288 Euro/kWh and the fixed price was 0,0626 Euro/kWh.	N/A

Description		Evaluation
UK	Primary market is likely to be Licensed UK Electricity Suppliers to fulfil their Renewable Energy Obligation commitments. Revenue will consist of: • Energy sale to supplier on a "negative demand" contract or through amalgamation mechanism on NETA power exchanges. • Sale of Renewables Obligation Certificates (ROCs). • Sale of Climate Change Levy Exemption Certificates • Use of system charge or benefit Net value of the above expected to be around GBP 0.05/kWh (EUR 0.08/kWh). Internationally traded Green Certificates may also play a role. Capital grant budget recently announced of £39m from DTI plus £50m from National Lottery for offshore wind power (mainly) and biomass. Distribution method under discussion.	N/A

CHAPTER 7

ENVIRONMENT, CONFLICTS OF INTEREST AND PLANNING

SUMMARY

The objective of this chapter is to analyse the current state of the art concerning offshore wind farms in relation to the following subjects:

- environmental impacts
- social acceptance
- conflicts of interest
- national planning rules throughout the EU

The chapter reviews the knowledge regarding environmental impacts of offshore wind farms, especially in relation to birds and the visual impact. The main conclusion is that although there are no strong indications of severe environmental effects, there is yet very little real experience. This uncertainty and lack of actual experience threatens to develop into a limiting factor delaying licensing procedures for offshore wind farms.

Public attitudes are in general positive but may turn negative with actual projects. This is based on two different issues:

- the perceived potential of ecological damage, in particular in relation to birds
- the perceived visual and noise impact, in particular in relation to the recreational use and value of the adjacent coast.

Suitable strategies to manage this problem are discussed.

The main other conflicts of interest in developing offshore wind farms are with radar systems and marine traffic. Careful planning should resolve this conflict, as especially the potential effects on radar systems may become a barrier for future development of offshore wind energy projects. Regarding marine traffic, improved and suitable ship collision risk and damage consequence models should become available.

Since in most countries the political attitude towards offshore wind power is positive, national planning and regulation rules are being adapted for licensing offshore wind farms, both in and outside the 12 mi zones. Examples are given presenting legislation adaptation to promote offshore wind energy in different EU countries.

CONTENTS OF CHAPTER 7 : ENVIRONMENT, CONFLICTS OF INTEREST AND PLANNING

7.1 INTRODUCTION

The objective of this chapter has been to bring together existing knowledge concerning offshore wind farms in relation to the following subjects:
- environmental impacts
- conflicts of interest
- social acceptance
- policies

This draft report has been prepared based on answers to questionnaires received from 13 European Countries, evaluating the different topics, as seen from within each of these countries. The answers given to the individual questionnaires can be found in Appendix 3, arranged in order of subjects.

Where appropriate, each member of the concerted action has indicated the importance of specific subjects by giving them numbers from 1-3, "1" indicating high importance and "3" low importance.

On basis of this ranking and the responses from the members of the Concerted Action, and on the basis of interviews with key players within offshore wind energy, selected references have been reviewed in order to achieve the most up-to-date knowledge of the relevant issues of this cluster.

The focus, in particular for the section on environmental impact, has been to point to issues, which may become potential barriers for the large-scale development of offshore wind industry. Therefore the well-known environmental beneficial effects of wind turbine produced power are not specifically mentioned here.
The benefits to the environment from using wind power are mainly by reducing atmospheric pollution. As well as a significant reduction in CO_2, other pollutants are also reduced; SO_2, NO_x, CO, Methane and Particulates. The amount of CO_2 emitted by various types of power generation during all stages of a power generation plant's life cycle are listed below. The values given are subject to some local country by country variation, but wind power reduces emissions by orders of magnitude compared with conventional thermal power generation.

Technology	**CO_2 Emissions (Tonnes per GWh)**			
	Fuel Extraction	**Construction**	**Operation**	**Total**
Coal-fired [1]	1	1	962	964
Oil-fired	-	-	726	726
Gas-fired	-	-	484	484
Nuclear [2]	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood [3]	-1509	3	1346	-160

[1] Conventional plant [2] Boiling water reactor [3] Sustainable harvest

The actual saving in emissions depends to a large extent on the mix of types of power generation for an individual country or region and the type of plant replaced. It is apparent that any calculations on emissions savings must look realistically at the type of power generation likely to be replaced, and not just assume that the most polluting will be shut down.

As an example of this, it is interesting to note that the German energy mix including nuclear power is 0.6kg/kWh, whereas the mix excluding nuclear power is 0.89kg/kWh

Environmental benefits of wind power in comparison with fossil fuel powered generation is thus obvious.
It must however be noted that these benefits, the avoidance of pollutant gasses and the preservations of raw materials like gas and coal, should be clearly stated in the Environmental Impact Assessment and that the emphasizing of these *positive* environmental impacts is crucial in relation to the public and political acceptance of wind energy. A study on the positive impacts may be necessary as these may differ in detail from the onshore situation, e.g. different pollutant levels per kWh; job creation rate per kW different. Some work exists on this but may need final definition .

7.2 ENVIRONMENTAL IMPACT.

7.2.1 Environmental Impact Assessment

Within the EU, an Environmental Impact Assessment[1] (EIA) must be carried out before public approval for larger projects can be granted. The minimum requirements of the EIA are specified in the EC Council Directive 85/337/EEC [1] amended in Directive 97/11/EC [2].

The directives require that private and public projects, which are likely to have significant effects on the environment, must be subject to an assessment of their potential effects on the environment before they can be allowed to proceed.

An EIA shall identify, describe and assess the direct and indirect effects of a project on the following factors:

- human beings, fauna and flora
- soil, water, air, climate and the landscape
- material assets and the cultural heritage
- the interaction between these factors mentioned

The directives lay down rules for the EIA procedure, which includes a requirement for public participation: the results are to be made public, and the views of the public taken into consideration in the consenting procedure.

Wind energy projects are specifically mentioned in Annex 2 of the Directive 97/11/EC, indicating that the individual member states shall determine, either through a case-by-case examination or through thresholds or criterions set by the member state, whether wind power projects shall be made subject to an assessment.

In this way member states may exempt a specific project from the provisions in the directives, but it is unlikely that any offshore wind farm may be publicly approved without an EIA because of its size and the public attention regarding its environmental effects.

General conclusions:
Developers of offshore wind farms must carry out an EIA on the specific project, with the purpose of providing information about the possible impacts on the environment from the time of installation till the dismantling of the turbines and foundation.

The EIAs from individual offshore wind energy projects will contain much valuable information regarding the effects from wind energy on the environment, but due to the fact that the experiences with offshore wind power are still relatively limited, the literature on environmental impacts appears sparse. In some cases the first pilot studies are only now underway. Currently only Denmark, Sweden and UK have put a few relatively small offshore farms into operation, and in Holland a semi-offshore farm is in operation.

[1] The term “Environmental Impact Assessment” (EIA) covers the procedure that fulfils the assessment requirements of Directive 97/11/EC. In many countries, e.g. in the UK, the environmental information provided by the developer is presented in the form of an Environmental Impact Statement (EIS), which may then be described as the final product of an EIA. In this report only the term EIA will be used.

7.2.2 Biological impacts.

The lack of experience with offshore farms and the impacts from here is clearly reflected in the responses to the questionnaires.

Only a few case studies on the impact on fish, birds, sea mammals and flora have been carried out in connection with the offshore plans already established, either as part of the Environmental Impact Assessments or as individual studies. Nevertheless, the response on the questionnaires clearly indicates that this knowledge has not yet been compiled in any systematic manner, resulting in the fact that the biological impacts and mechanisms involved are still being covered by uncertainty.

Biological issues considered potentially problematic were indicated as:

- Collision of birds with turbines
- Ousting birds off their traditional feeding/roosting grounds
- Unknown effect of low frequency noise emissions on fish life and sea mammals
- Impacts on fish larvae
- Disturbances of seabed and fauna during construction and operation.

7.2.2.1 Birds

Terminology

In the EU, different terms for bird-protected areas exist, the most important regarding offshore conditions being: Important Bird Areas (IBAs), Special Protected Areas (SPAs), Special Areas of Conservation (SACs) and Ramsar areas.

- "IBA" – Important Bird Area - is a BirdLife term [3] and covers a conservable site identified on the basis of its international significance for the conservation of birds at the global, regional or sub-regional level for: threatened bird species, congregatory bird species, assemblages of restricted-range species and assemblages of biome-restricted bird species. IBAs are identified by the private organisation BirdLife using standardised, internationally agreed criteria, but the term IBA in itself does not imply any legal protection of the area. IBAs have borders described, but these borders may not all have been precisely defined. Furthermore, the selection of IBAs in Europe has not been finalised – national BirdLife partners may add more areas to the list, as indicated by e.g. the Swedish Ornithologist Organisation [4].
- "SPA" – Special Protection Area - is the official EU term regarding protection of birds, and SPAs are designated in the EU under the EC Birds Directive 79/409/EEC. The protections requirement regarding SPAs are given in Article 4(4) of the directive, where it is stated that for SPAs "…*Member States shall take appropriate steps to avoid pollution or deterioration of habitats or any disturbance affecting the birds, in so far as these would be significant having regard to the objectives of this Article…*Member states shall furthermore, according to the directive, "assess any plan or project that either by itself or in combination with other plans or projects is likely to have a significant effect on an SPA, and ensure that any such plan or project is not approved if it would adversely affect the integrity of the site, unless there are 'imperative reasons of overriding public interest'"[5]
  There are currently 1,375 SPAs in Europe
- "SAC" – Special Area of Conservation – is an EU term covering areas designated in relation to the EC Habitats Directive 92/43/EEC. The aim of the directive is to contribute to the maintenance of biological diversity through the conservation of natural habitats and of wild fauna and flora in the Europeans territory of the member states. According to the directive, member states are committed to protect wild species and the habitats of plants, mammals, reptiles, amphibians, fish and invertebrates and to conserve threatened types of habitats. The designation of a SAC is only possible after a site has been adopted as a Site of Community Importance (SCI). An aim of the directive has been to establish the "Natura 2000" network in

order to ensure that selected habitats and species are maintained at or restored to a favourable conservation status.

- Ramsar areas are designated on basis of the international Ramsar Convention on Conservation of Wetlands of International Importance, especially for birds. Sites included in the Ramsar List are subject to conservation measures, including the establishment of nature reserves. If a site is de-listed, states having ratified the convention are obliged to compensate for the loss by creating additional nature reserves or by protecting an adequate portion of the original habitat [5].

Other international conventions of relevance are the Bonn Convention on Conservation of Migratory Species of Wild Animals (“CMS”), aiming at conserving species of wild animals that migrate across or outside national boundaries, and the Berne Convention on the Conservation of Europeans Wildlife and Natural Habitats, aiming at the conservation of wild European flora and fauna in their natural habitats. The convention also covers non-European countries, e.g. in the case of migratory species moving to Asia and Africa.

Only the term IBA will be used in this report, for the following reasons:

- Ramsar areas, SACs and SPAs are in many cases the same
- the 1,357 SPAs overlap partly or wholly with 54% of all (3,619) European IBAs identified by the BirdLife European Partnership[2]
- the IBA approach is scientifically rigorous and BirdLife organisations advocates the importance of these sites
- according to the European Court of Justice[3] unclassified sites that deserve EU classification, should be treated as classified sites, in other words: IBAs, which have not been officially declared as SPAs, must be treated as an SPA until a decision has been made. BirdLife’s official goal is to have 75% of the IBAs declared as SPAs.

Impact on Birds

The answers to the questionnaires and the ranking of the subject show that the impacts on birds from offshore wind turbines are considered to be of very high importance in Europe – in Holland, for instance, the impact on birds is the most important environmental factor according to the government, and when ranking the different issues in the questionnaire, the importance is also reflected in the fact that the impact on birds (and the visual impact) received the highest importance score of all environmental subjects from the members of the Concerted Action.

It is difficult to pose any general conclusions about the possible impacts for the following reasons:

- the impacts are site dependent (e.g. distance to shore, presence of fish, migrations routes).
- the impacts are relative to various bird species.
- only a few studies have been carried out for offshore wind turbines: In Denmark, at Tunø Knob offshore wind farm, Before-After-Control-Impact and After-Impact studies were conducted from 1994-97, but the results – that no effect of the ten 500 kW wind turbines could be detected on the abundance and the distribution of Eider ducks – were only valid for wintering Eiders [6]
- In Sweden, two studies on migrating birds at Utgrunden and Yttre Stengrund are being carried out, but with no definite conclusions available yet.[4]
- the studies carried out for onshore wind farms in some cases present conclusions that contradict each other, some studies showing that birds avoid the vicinity of wind turbines (The Greenpeace Study [7]), other studies concluding that onshore wind turbines have only little or no impact at all on bird life (e.g.[8, [9]).

[2] Personal communication with Alison Stattersfield, BirdLife (June 2001).

[3] The Santoña Marshes case from 1993 (Case C-335/90, Commission v Spain ECR I-4221)

[4] Observations from Utgrunden indicate that Eider ducks have no problems avoiding collisions with the turbines, as the ducks discover the turbines already 3-4 km before they reach the farm, and then subsequently pass the farm at safe distance (1 km).

Expected impacts

Impacts on birds may be expected, such as:

- collisions of migrating or feeding birds with turbines (rotor)
- turbines acting as barriers between feeding and roosting grounds or in migrations routes
- ousting birds off their traditional feeding/roosting grounds due to physical changes of habitat

The expected impacts will depend on the following parameters (for a detailed discussion, also see [7]):

- construction work: the impacts on birds during the construction phase are only expected to be temporary and limited. However, the choice of foundation type may be of importance, as it is expected that the ramming of a monopile could cause noise levels up to 150 dB and potentially disturb both breeding and staging birds. If a caisson type of foundation is chosen, the noise level during the construction phase will be lower [10].
- bird species: different bird species react differently and individually to man-made obstacles such as wind turbines. The EIAs for each offshore wind farm must therefore address the avian issues in detail.
- flying heights and migratory paths, depending on the following parameters:
  - number of birds: migrating birds in larger amount often fly at higher altitude, thereby encountering less disadvantages of the wind farm. Migrating birds offshore, however, tend to fly at lower altitude than over land.
  - weather conditions: during conditions of poor visibility, e.g. in foggy weather, the risk of collisions for birds increases. Furthermore, air pressure, temperature and wind directions influence flying height and direction.
  - time of day: birds usually migrate at higher altitudes at night than at daytime, resulting in a decreased collision risk if the flying height then becomes higher than the zone of risk (the rotor height). But in general, as the collision risk increases in situations of poor visibility, the risk of collision will be larger at nigh time than at daytime.
- distance to shore: migrating birds often have their flight path near the coastline, therefore the effects of a near shore wind farm might be larger. In general the number of birds declines with distance to shore, but there is insufficient information available on bird migration away from the coastline
- water depth: as birds prefer shallow water to deep water, due to better feeding possibilities, the risk of collision and ousting should diminish if the farm is placed in deep water.
- feeding conditions: as the foundations prove a good living environment for small fish, mussels etc, this tends to attract bird colonies, feeding from this new fauna. If fishery, as expected, is to be forbidden within the offshore farms, the farm area may serve as feeding ground for birds, thereby improving feeding conditions and minimizing the ousting of birds off their traditional feeding/roosting grounds, but at the same time increasing collision risks.
- dimensions of the wind farm: it is believed that larger turbines, being more visible, will reduce the risk of collision. The negative effects of large-scale offshore wind farms on migrating birds might also be reduced, if a sparse layout arrangement is used.[5]
- operating strategies: the possibility of stopping all turbines at low visibility conditions would reduce collision risks e.g. during times of heavy migrations.
- color/illumination of turbine: the risk of collision may diminish if the turbines are as visible as possible (which on the other hand may influence the public acceptance negatively, depending on the visibility, i.e. distance to shore). The towers can be painted in bright colors and illuminated appropriately, but concerning illumination this is to be handled with great cautiousness as lights

[5] Tulp et al., 1999[11] suggest that the negative effects of large scale offshore wind farms on migrating birds might be reduced, if certain aspects are considered: as birds tend to avoid flying between turbines, the farm should not be long and line-shaped like a long row, lying perpendicular to migration paths. A corridor, with a distance between turbines of several kilometers, may be recommendable in order to minimize the risk of huge wind farms acting as barriers. Finally it is suggested that a small distance between the individual turbines, minimizing the total surface area of the farm, may reduce impacts on migrating birds.

may also attract bird, thereby increasing the risk of collision. Especially the mounting of light on the turbines for ship navigation or repair works may attract nocturnal migrants during conditions of poor visibility, leading to an increased risk of collision[6] [12].

- noise/movements during operation: as it is expected that offshore wind turbines will produce more noise than onshore models, e.g. due to increased blade tip speed (see Capter 2), this may influence the impact on birds both negatively (ousting) and positively (fewer collisions).
- The noise from maintenance vessels – or helicopters - may cause more disturbances to birds than the noise from the turbines themselves – maintenance should therefore also due to environmental concerns be minimised, using low-noise vessels if the farm is in the vicinity of areas with birds (or other fauna).

Another unsolved question, beside the ones mentioned above, is how close a wind farm can be situated to a bird protection area. In Denmark, the Rødsand offshore wind farm will be situated 3 km away from a Special Protected Area, making this farm a very important object in relation to impact studies in relation to birds.

It is obvious that an IBA in general cannot be recommended as a suitable area for a wind farm, as collision and ousting risk will be unacceptably high. More information about these areas is therefore necessary, also because the borders of IBAs are not always well defined (unless they are already defined as official EU Special Protection Areas). These investigations may result in more SPAs or altered borders of existing SPAs areas, thereby making the planning process of offshore wind farms more difficult.

General conclusions:
As studies regarding the impact of offshore wind farms on birds and general studies on migration patterns are sparse, and as the effects depend on many different parameters, more knowledge is needed, both as general studies concerning bird migration and as site-specific studies: Ecological monitoring programmes/ Before-After-Impact-Studies are highly desirable in order to judge the effect on birds. The public dissemination of such studies is vital to promote good practice through the industry.

Furthermore it will be very important to collect information from different studies in order to cover the whole area, as different “narrow” site specific studies are carried out at the different projects.

It is important not to cause public concern regarding the effect of offshore wind farms on bird life: careful siting of turbines, away from important migratory paths (where these are clearly defined) and bird habitats, on the basis of serious investigations of populations and behavioural patterns in the specific area, as part of the specific EIA, is necessary to minimize the effect of offshore wind turbines on birds.

If an offshore farm is placed in the vicinity of bird areas, effects on birds should be minimized by considering e.g. type of vessel (low-noise) and time of day and year for construction, maintenance and dismantling work: the collision risk will be lower when carrying out work at daytime and at a time of the year when the number of birds is low, and at a non-sensitive period: when birds are moulting or breeding, planned operations at the farm should be avoided.

[6] A case from the Oresund Bridge between Denmark and Sweden demonstrates how difficult this issue is to investigate. Despite of several studies being performed prior to the construction, concluding that the risk of bird collision was minimal, some 600 birds were killed at day one in October. Apparently the birds were attracted by the illumination lights on a very foggy day, and collided with the bridge in great numbers, falling to the road below. This situation had not been accounted for in any of the studies performed, and the situation may be expected to occur relatively infrequent. The story generated quite some debate in local media and illustrates the point that the “law of great numbers” apply. Even though the total impact is very small, isolated events as the one described, may cause significant decrease in public acceptance.

7.2.2.2 Sea mammals

The effect from offshore wind farms on sea mammals is generally not considered to be very important, as can be seen from the responses to the questionnaires (App. 2).

An assessment of the local mammal population, e.g. seals, whales and dolphins, is however needed in the EIA, and if the specific site is situated in the vicinity of e.g. grey-seal colonies this question may become crucial in relation to the approval of the project This was the case for the Swedish Bockstigen project, where a Before-After-Impact-Study was carried out before construction, during construction and two years after start of operation, showing that wind turbines did not affect the seals in any respect. [13]

The same experience can be drawn from the Tunø Knob Wind Farm, where the seals seem unaffected by the turbines.

At the moment a Danish project is underway by SEAS, where the movements of radio-tagged seals are followed as part of a larger seal surveillance program in relation to the construction of the Rødsand wind farm where the population of seals is significant.

Although the impact on mammals seems marginal, further investigation is needed in relation to the following subjects, as emphasized by the CA members:

Expected impacts:

- loss of habitat due to disturbance through noise emission from turbines and from construction and maintenance vessels (or helicopters) and equipment. The disturbance during the construction phase is expected to be only temporary, whereas disturbance from turbines and maintenance vessels might have permanent effects.
    - With regard to noise emission, for the Rødsand Offshore Wind Farm it has been estimated based on measurements from the Vindeby and Bockstigen offshore farms that the submarine noise will at most be audible to marine mammals at a distance of up to 20 metres from the foundations. [14]
- vibrations in the infra sound area could affect the animals' sonar system, making it more difficult to retrieve food[7].
- potential influence from low frequency sound emission and electric and magnetic fields in cables. However, calculations of magnetic fields from submarine cables dug down one metre under the seabed show that the magnetic field on the seabed above the cable will be smaller than the geomagnetic field.[8] Therefore no impacts are expected if the cables are properly buried. [14]
- effect on mammals may increase due to visual impact from large-scale offshore wind farms (moving blades, especially).

[7] On the other hand, when fishery (with trawling equipment) is prohibited in the vicinity of the wind farm, feeding possibilities might improve

[8] The geomagnetic field is the constant magnetic field surrounding the earth

General conclusions:

- More studies are needed to evaluate the effect from noise and magnetic fields, and the visual impact on mammals.
- Before-After-Impact-Studies, including seismic surveys and monitoring of underwater noise levels, and studies on noise reception of sea mammals must be carried out.
- When planning offshore wind farms, specific protections areas for sea mammals should be avoided, and duration and quantity of noise minimised during construction (especially at sensitive time periods) and operation. Submarine cables should be properly buried or shielded.

7.2.2.3 Fish

Only a few studies deal with the subject of the impact from offshore wind farms on fish, as the existing wind farms are erected in areas with no or very few fish.

A Swedish study of the first offshore wind power project in the world outside Nogersund, Blekinge (Sweden), showed that there was no negative impact on fish from the 220 kW turbine [15] – the fish population within 400 m from the turbine increased, however the fishermen caught less fish when the turbine was in operation (leading to a conflict of interest).

Expected impacts:

- Preliminary observations seem to indicate that the foundations tend to resemble a natural reef, giving good living conditions for fish, benthic communities[9] and fauna [16]. Also the fact that fishing with trawling equipment will not be allowed within and in the vicinity of farms, will affect the fish population in a positive way by improving habitat as breeding and resting grounds for fishery species. The exclusion of fishery will in many cases lead to conflicts with the fishing industry, see Section 7.3.3.
- Potentially negative effects are
  - effects of noise emission and vibrations on fish life both in the construction phase and after installation, which may lead to loss of habitat. Maintenance vessel may also have a negative impact, but compared to the “usual” impact from fishing boats this must be considered as a minor impact
  - especially during construction, sedimentation and turbidity[10] of water may impact on fish larvae, however this is regarded as a temporary impact. Construction during sensible periods should be avoided, as this may lead to a high fish mortality rate.
  - the fact that foundations will serve as natural reefs, but consist of hard material compared to the sea bed, may lead to changed biotope,[11] and thereby to a change in fish population. If the sea bed is rocky, as for instance at many Swedish offshore locations, the potential alteration of biotope will be limited
  - electric and magnetic fields around the cables may influence fish and fish breeding, but no research results have yet been found published on these issues

General conclusions

As the effect of noise, vibrations and magnetic fields on fish is relatively unknown, studies and surveys are needed before, during and after construction. Projects should seek to minimise the effect of structures and cabling on existing stocks, their food sources and spawning activity, e.g. by shielding and burying cables appropriately in order to minimise electromagnetic impacts on fish. Construction works should be avoided during sensible periods.

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[9] benthic communities: communities living on the sea bed, also known as “Benthos”. (“Benthos” originally means “seabed” in Greek)

[10] Turbidity is the degree of cloudiness or opacity of the seawater due to disturbed sediment.

[11] Biotope is a small area with its own environmental conditions that is home to a particular ecological community of plant and animal life

7.2.2.4 Seabed and benthos

In general the disturbance of seabed, and thereby of benthic communities, will primarily take place during the construction (and dismantling) phase. During operation the effects from gravity foundations will be higher than the effects of e.g. monopile foundations, both due to the simple fact that gravity foundations will cover an area of the seabed larger than is the case for monopile foundations and due to the risk of scouring of the seabed.
Even though a gravity foundation is chosen, the total seabed area covered by foundations will still be very small compared to the total area of the wind farm.

Expected impacts:

- loss of habitat and individuals due to construction activities. However, the disturbance of the seabed from sedimentation during the construction phase so far only seems to be temporary, as experience from the Swedish Bockstigen project shows
- changes in sediment structure may in some cases rise from changed water flow around the foundations
- footprint of turbine foundations and cables, maintenance vessels, electromagnetic radiation and noise may reduce abundance and diversity of seabed life
- the foundations act as natural reef and introduce fauna, however these artificial hard substrates may cause changes to the biotope structure with unknown consequences regarding benthos and subsequently food chain
- the absence of fishery and shipping (except for maintenance vessels) will have a positive local effect on fauna and seabed

General conclusions:

The quality and quantity of possible impacts on seabed and benthos are not well known, calling for surveys of specific project sites, both as part of the EIA and as generic studies. When designing wind farms, maintaining or improving habitat for local species of importance should be considered.
In general the subject of cables need to be further investigated in relation to impacts due to physical size and electromagnetism; the area around the cables may be included in the fishery exclusion zone.

7.2.2.5 Hydrography, sea currents and water quality

Expected impacts:

- These topics are only considered important at a very few special locations, due to the typical low ratio between foundation diameter to inter turbine spacing.
- However, detailed modelling may be necessary depending on size of project, proximity to shore, shallowness of water and general sensitivity of local hydrography or sea currents.

General conclusions:

In order to avoid impacts on hydrography, sea currents and water quality, foundations should be designed to minimise scouring, erosions, sediment redistribution and alteration to current flow. Projects must minimise risk of contamination during construction, operation and decommissioning and avoid use of pollutant chemicals when foundation, tower and turbines are protected against marine environment.

7.2.3 Effects from accidents

The effects on the environment due to accidents are to be taken seriously, as for instance a collision with an oil tanker may in worst-case cause severe damage regarding fauna and flora, water quality, coastline etc. It should however also be noted that especially the first generations of offshore farms may prevent accidents from happening, as the turbines will often be placed in shallow water, where the collision risk may already be high. Properly marked turbines will more clearly warn ships against the risk of collision, than was the case before the turbines were installed.

Collision risk analyses are carried out as part of the EIA, but so far it seems to be quite difficult to develop reliable risk models – as can be expected, taking the lack of experience with collisions of this kind into consideration.[12] Moreover, the effects of potential oil pollution for e.g. birds have not been estimated in e.g. the Danish EIAs.

Expected impacts
Accidental impacts on the environment may origin from collision between ship (e.g. maintenance vessel) or aircraft (e.g. helicopter) and turbine/foundation or substation, or from damage to submarine cable caused by anchoring, colliding or sinking ship, by trawling equipment or during construction.[13]

The effect of such accidents may be a pollution of the environment caused by substances from the offshore farm (turbine/substation/cable) or substances from the colliding ship or aircraft. The exact consequences of a collision are dependent on many parameters, such as type of ship/helicopter, collision angle, speed of colliding vehicle.
If larger ships, such as oil tankers, collide with a turbine, in many cases it is to be expected that only the turbine and foundation will be seriously damaged. In other words, a ship collision does not necessarily mean leakage of huge amounts of harmful substances.
Moreover, if a leakage of polluting substance is actually the result of the collision, the degree of impact on the environment will vary in relation to weather (temperature, wind speed) and of course the nature of the polluting substances.

The most possible polluting substance in these cases is regarded to be oil:

- oil spillage deriving from the turbine is not an issue of major concern, as the turbines contain only small amounts of oil.
- the diesel oil inside the substation is neither regarded as being a major source of risk, as the oil amount is limited and the diesel oil will relatively easy evaporate. However, to minimise risks of leakage, substations should be constructed with double walls.
- damage on submarine cables may cause release of mineral oil isolating the cable, is this type of cable is chosen. In a worst-case-scenario at Horns Rev [17], the maximum oil leakage amount would be 4,200 l. Although this is a relatively small amount, and although the risk of such accidents has been calculated to be very low (one every 32,000 years), mitigation measures such as protection of the cable (by trenching if possible) and prohibition against fishing within the area of the farm and around the cable are therefore highly recommendable. Moreover, the pressure inside the cable is to be monitored continuously in order to take immediate action in case of leakage.
- the most critical impact on environment regarding oil pollution would be caused by oil from ships. Diesel oil from fishing boats and maintenance vessels is not regarded as seriously as oil from larger ships, because diesel oil will evaporate to a relatively high degree compared to

[12] For instance, the risk analyses regarding the Rødsand and Horns Rev projects were not immediately accepted by the developers, as the figures were based on the assumption that a ship entering the farm area would unavoidably cause a collision. A revised risk analysis has therefore been carried out for the Horns Rev project, and a similar revised analysis is currently being carried out for the Rødsand project.

[13] During the construction of the Middelgrunden Offshore Wind Farm, the submarine cables were damaged three times, however without environmental impacts, as the cables did not contain oil as isolating material.

bunker oil. According to [17] the most critical event would be the pollution resulting from a collision with an oil tanker, as this collision would result in the leakage of considerable amounts of jet fuel (2,500 t), and bunker oil, (500 t). The bunker oil is the more destructive due to its low evaporation rate. The consequences of such a collision calls for development of special emergency procedures with a short reaction time for each large offshore farm.

General conclusions:
As the consequences of collisions may be very serious, mitigating measures are called for in order to minimise collision risks, such as: proper marking of farm/turbines and protection of cables. However it should be noted that the collision frequency is relatively low and that a collision would not necessarily result in severe environmental damage.[14]
For further discussions, please refer to Section 7.3.1; for a detailed discussion, see for instance [18]

7.2.4 Visual effect

The environmental impact, which is considered the most important along with the impact on birds, is the visual impact. This reflects the growing public concern in Europe on the visual effects of wind power on the landscape in general. The public concern is illustrated by e.g. the Danish case, where the future development of wind power politically has been bound to offshore locations. However, offshore farms raise new concerns regarding visual effects as wind turbines here represent man-made development in an otherwise structureless landscape.

Obviously the visual impact diminishes with the distance to shore, and in general it is assumed that the visual impact to viewers at sea level is negligible when the farms are located more than 8 km from shore. With distances larger than 45 km, the visibility will be almost zero due to the curvature of the earth's surface. These distances will be greater where there are elevated viewpoints, but may also be severely reduced depending on the atmospheric clarity.

The visibility from shore will also depend on the requirements regarding marking lights and painting – as the development within wind energy results in turbines continuously increasing in size, marking lights will be mandatory in order to avoid collision with low flying aircrafts. As the marking requirements may depend on turbine size, and as the choice of turbine often has not been made at the time of carrying out the EIA, additional marking requirements can actually change the visual impacts of an entire farm, when the turbine type has finally been chosen. These alterations in visual impact will require additional investigations and visualisations, after the time of public hearings, and may result in increased public resistance. Therefore marking requirements and their effects regarding visual impacts should be known as early as possible in the planning phase (see Section 7.3.1.3).

For the offshore farms already established at near shore locations, concerns on the visual impacts have played a major role in the public hearings. Also the visual impact is a determining factor for public acceptance at locations renown for their scenery or close to recreational areas.

A public opinion survey in the Netherlands concluded that visual intrusion was the most important impact factor, but would not necessarily result in fewer visit to the affected location – the wind farm may also have positive effects on the visiting public, becoming a tourist attraction with visitor centres onshore and boat trips to the farm.[15] The same results were found in Germany where it was concluded that offshore wind farms would have no negative impacts on tourism as long as the farms were not

[14] For Horns Rev, the revised calculations resulted in a ship collision risk of 1 collision every 641 years.

[15] The fact that offshore farms may become tourist attractions is probably one on the reasons why the mayor of Nysted (the municipality closest to the Rødsand Offshore Wind Farm) has insisted on renaming the planned wind farm. As a consequence, the official name of the Rødsand project is now "Nysted Offshore Wind Farm" (in this report, however, the term "Rødsand" will still be used).

placed in near-shore waters. If the farms were placed 15 km from shore, it would not be regarded as a problem at all [19].[16]

As the visual impact is a matter of the viewer's taste, it must be expected that there will always be public resistance, especially for near-coast projects, but even the visual impact from offshore projects invisible from the shore may experience resistance when being seen from ships, boats and ferry lines.
Experience from Denmark (Middelgrunden Wind Farm) indicates that local involvement in the ownership of the wind farm may have an important role for the acceptance of the visual impact close to a city, see Section 7.3.

Furthermore, an open and careful planning process with detailed visualizations may result in less public resistance. In the case of the Middelgrunden project, as a result of visualizations and public hearings, the farm layout was changed from 3 rows with 9 turbines to the existing curved profile with 20 turbines. This change of farm layout and thereby of the visual impact gave rise to increased public acceptance.

Swedish investigations indicate that visualizations can cause problems with acceptance because pictures do not present the true visual impact of wind turbines on a landscape. Neither do they present their functional contribution. People construe the depicted wind turbines not as a source of renewable energy but as a new element in the landscape that will diminish its scenic value. On the other hand visualizations of turbines undeniably have some value in accelerating social adjustment by providing an idea of what planned developments will look like. Inevitably, however, these pictures never truly depict the experience of an active wind turbine, although they are a great aid.

The benefits of using visualizations are connected to a person's professional training and their previous experience with wind turbines. If people can understand the rationale behind certain designs or if they can recognize some benefits in relation to other wind power locations, visualizations can work well to create a positive dialogue. In this context it is important to understand that a 'picture' can both suppress the benefits of wind turbines and camouflage some of the visual effects. Hence, visualizations must always be accompanied by detailed explanations. Furthermore, turbines are not only experienced by seeing them, but also through hearing and feeling their presence, and the use of "virtual reality" should be useful in this regard.

It is not possible to take everything into consideration when professionally designing a wind power site. It is, however, necessary to consider people's feelings and learn about the social network behind the sterile map when their backyard or beach idyll is entered. If a project has the confidence of the public there will be more space for artistic freedom and new solutions. The challenge is to use this trust in order to bring new meaning into a landscape. In the long run the choice of location and design cannot be explained and defended by saying that people's social and aesthetic preferences were merely anticipated, if the people affected most directly are not consulted with. Different individuals view wind turbines in accordance with their personal relation to a specific landscape, and the amount of time they spend in a particular place. Similar differences between occasional and permanent observers can be drawn from wind developments elsewhere, such as Palm Springs, California. Accordingly, the chances for constructive dialogue about landscape development can be improved if it can be clarified why some people view wind power as a practical solution to sustainable development while others see it as a threat to landscape preservation.
Time is an additional factor when it comes to recognizing the effects of different developments. People tend to react to immediate visual change in the landscape more vociferously than to widespread but long-term environmental effects of development. Hence, when summarizing some important factors concerning the concept of landscape and how the changes are perceived, it is found that time

[16]The tourists' answers were based on visualizations where wind farms with different layout were presented from different angles and distances.

and space are the common denominators. People tend to view change according to custom of use, the pace of change and the visual evidence.[20]

Most people cannot relate to the fundamental thought behind aesthetic solutions. In 1997 and 1998 Karin Hammarlund [21] tested several visualizations made by six different landscape architects based on their professional analysis of a particular landscape in relation to wind turbines. She asked representatives of the general public living in the areas concerned to grade the visualizations as good, acceptable or bad in relation to how they found them to harmonize with the surrounding landscape features. All at least made the grade of 'acceptable'. This result has to do with the relationship between form and function. Design that does not have an understanding of the function of the landscape to the people living in it, will not connect to the functional pattern of the landscape. It will show no concern of important recreational patterns or important viewpoints. It will not connect to the travel pattern of people, which is the way most people on a daily basis experience the landscape. Landscapes possess meaning for people and this meaning connects with how people make use of a place. This function strongly affects the conception of the landscape. So, what a particular landscape means to an individual depends on what this person is doing in that landscape. For this reason the function of each particular landscape must be specifically integrated with the aesthetics and design of a wind power site. Form that connects with function will mean something to the affected population, and not just to the designer, planner or landscape architect.

General conclusions

The general conclusion is that visual impact of wind power has a very high profile in the public awareness. This is a barrier for future development of wind power throughout Europe, and although moving wind power offshore might prove a partial solution to this if the distance to shore is above 5-10 km, the visual impact will still act as a barrier to some extent. The experience with offshore wind power clearly indicates that there is strong public concern for this issue, even concerning offshore wind power farms, which are, from the shore, barely visible to the naked eye.

Experience from existing farms indicates that the following recommendations can lead to reduced public resistance related to the visual impact of offshore wind farms:

- the offshore wind farms should in general be placed as far away from the coast as possible, and in particular proximity to recreational areas and/or coastal settlements should be avoided
- the planning process must be very open and careful, and if the farm is visible from land, the effect on the environment and economy (e.g. tourism) of the coastal area must be assessed
- farm formation, number and size of turbines and cumulative effects should be thoroughly and openly analysed and discussed before decision is taken
- early local involvement in the planning phase is essential and community involvement in ownership of the wind farm will be beneficial

7.2.5 Noise and vibration effects

Noise from wind turbines arises from the movement of the blades through the air (aerodynamic noise) and the consequent transmission of power and momentum in the nacelle (mechanical noise). Furthermore, noise may arise from the control equipment within the tower (power electronics).

The degree of noise effects is primarily dependent upon the level and character of the noise emitted, the distance from the turbines to potential sensitive receivers, wind directions and background noise levels.

7.2.5.1 Airborne noise

It is expected that airborne noise may have the following impacts:

- ousting of birds
- loss of habitat for marine mammals

- decrease in public acceptance if turbine noise is audible to humans from the shore

Several participants have indicated that noise is an issue of public concern, although the noise from offshore wind farms will not generally be audible on shore. Nevertheless, it appears that wind power has received a reputation for being noisy, which, together with the fact that noise propagates much easier over the sea than over land, is reflected in the public attitude towards wind power, including offshore wind.

One participant stated worries that the turbine manufacturers and project owners may be tempted to place less emphasis on noise control, because the noise impact from offshore wind farms is not perceived as a significant problem with the turbines being placed far enough from shore to give what is believed to be inaudible levels of noise. Such an attitude, combined with increases in turbine size and the blade tip speed might, however, lead to the problem arising anew.

During construction of offshore farms, airborne noise from construction work (vessels, ramming etc.) is expected to effect birds and marine mammals (ousting), but as the effects are of limited duration, the effects are expected only to be temporary. However, sensitive time periods like breeding or nursery periods should be avoided if the construction site is placed near important biological areas – which may be in conflict with the intentions of the developers to establish offshore wind farms when stormy weather is least probable.

7.2.5.2 Underwater noise and vibrations

During construction, underwater noise from construction vessels and drilling or piling equipment may have a detrimental effect on marine mammals, fish and benthos. These effects are especially evident, when hammering down monopiles – experience from Sweden indicates that this construction method results in a chock reaction from fish, actually loosing conscience and drifting in the water surface as were they dead. However, the effect is temporary, but sensitive time periods should absolutely be avoided – in the case of fish larvae, construction work at sensitive periods may result in a very high fish mortality rate.

During operation, noise from offshore turbines can be transmitted into the water in two ways: the noise either enters the water via the air as airborne sound, or the noise is transmitted into the water from tower and foundation as structural noise. The frequency and level of underwater noise is thereby to a certain degree determined by the way the tower is constructed and by the choice of foundation type and material (monopile/steel - or caisson type/concrete - foundation).

Underwater noise from offshore wind turbines must of course exceed the level of underwater background noise (ambient noise, especially from ships) in order to have any impacts on marine fauna.

The following frequency areas were used for measurements during the EIA process at Horns Rev [17]:

Porpoises:	
Produce pulsed sounds:	2 kHz (perhaps communication)
Echo localization sounds:	13-130 kHz
Fair hearing:	1-150 kHz
Good hearing:	8-30 kHz
Speckled Seals:	
Produce sound:	0,1-40 kHz
Fair hearing:	0,1-60 kHz
Good hearing:	1-50 kHz
Fish:	0-130 kHz

Generally speaking, porpoises and seals are sensitive to high frequency noises, seals in the range from 100 Hz to 40 kHz, porpoises at 100kHz and higher. Fish are sensitive to low frequency noises, below 20 kHz. [22]

The effects on marine life from vibrations of the turbines are rather unknown, but as the developers seek to avoid resonance in the tower, the effects on especially fish and benthos may be limited.

Measurements from Vindeby (caisson foundation type) and Bockstigen (monopile) offshore farms indicate that underwater noise is primarily a result of the structural noise from tower and foundation [22]. When the results were scaled up, based on measurements from a 2MW onshore wind turbine, it was concluded that the underwater noise might be audible to marine mammals within a radius of 20 metres from the foundation. Generally it is believed that for frequencies above 1 kHz, the underwater noise from offshore turbines will not exceed the ambient noise, whereas it is expected that for frequencies below 1kHz, noise from turbines will have a higher level than the background noise.

Only measurements and impact studies after the construction will reveal if underwater noise will really affect marine mammals.

The impact on fish from low frequency sounds (infrasound, below 20 Hz) was not estimated, and in general this area is covered with much uncertainty. A planned study at Vindeby, carried out by SEAS, investigating the effects from noise and electromagnetic fields on fish communities living at the seabed, may yield valuable information regarding this subject.

General conclusions

The general conclusion is that airborne noise impact has a high profile in the public awareness, but that this is related to previous generations of wind turbines and not to the technical realities of today. It therefore appears that a serious task for improving the public attitude towards offshore wind lies in demonstrating that noise from offshore wind power farms is not a significant problem. However, it is important to stress that noise impact may increase if the subject is neglected by the manufacturers - it must be remembered that noise may travel large distances over open water surfaces.

Regarding underwater noise and vibrations, the effects on marine animals, fish and benthos need assessment in generic studies and in a site-specific manner, because these effects are relatively unknown.

7.3 CONFLICTS OF INTEREST

As most European countries have procedures for hearings of interest groups, potential conflicts of interest are well known. Apart from various lobbying organisations, primary conflicts of interest concern: ship traffic, air traffic, defence and fishing interests.

Some areas may definitively be excluded from consideration for use for offshore wind power at the pre-planning phase. These are major ship lanes, areas close to airports, oil & gas pipelines, cable routes, raw material deposits, military restricted areas and areas of importance in relation to fauna, e.g. IBAs. However, most other suitable sites will confront a number of potential conflicts of interests with other uses and users of the locations.

7.3.1 Traffic

7.3.1.1 Ships

The subject of ships is, according to the CA members[17], the most important subject in relation to conflicts of interest. The reasons for this seem to be the following:

- ship lanes represent a siting limitation factor, as certain areas will be prohibited for use as offshore wind farms where established shipping lanes demand it. Furthermore, locations where ships may lay anchor to enter harbours, must be avoided.
- even where careful planning is carried out, and the farm is not placed near major navigation routes, or routes have been altered in order to minimise collision risk, there will still exist a risk of severe environmental damage in case of ship collisions with wind turbines, e.g. an oil carrier collision, as previously described in Section 7.2.3. On the other hand, when wind farms are to be located on reefs, banks and other shallow waters, which in themselves constitute a risk for ship collisions, well-planned offshore wind farms can contribute to maritime safety. In Danish EIA risk analyses (Middelgrunden and Rødsand), a calculated risk in the order of 1 collision every 10 years has been accepted by the authorities, as the risk frequency was not higher than at baseline conditions.
- offshore wind farms must be marked properly and effectively, in accordance with national or international guidelines (IALA 1984, IALA 2000 [23]), however painting and illumination /signal lights may have negative visual impact, which could lead to increased public resistance (see Section 7.3.1.3).

As collision risk analyses for all offshore wind projects is a mandatory part of the EIA, valuable information is and will be available from these studies, see for instance background reports to [14] and [17].[18]

Currently a large study and collision risk analysis is being carried out for the German Bight, and in general such risk studies and additional information on damage mechanisms are called for in order to investigate the issue of marine traffic safety and offshore wind farms more closely.

7.3.1.2 Air traffic

The main problem does not appear to be the civic air traffic, although certain areas will be prohibited by Civil Aviation Authorities, either national (CAA in the UK) or international (ICAO), for use as offshore wind farm sites where protection of air navigation demands this. Military issues incl. radar are dealt with in Section 7.3.2, below.

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[17] CA members: members of the Concerted Action on Offshore Wind Energy in Europe

[18] EIAs from the Dutch Near Shore (NSW) and the Q7 Wind Farm projects also include such risk analyses

The requirements posed by helicopter teams seem to be the most important concern, e.g. rescue helicopter teams, who might have to access the offshore wind farms in heavy weather. As the sites are covered by quite heavy turbulence, helicopter manoeuvres within the area are difficult, making marking lights and ability to switching off all turbines immediately a serious safety issue.

7.3.1.3 Painting and illumination/marking lights

In order to minimise the risk of collision with naval or air traffic, authorities put different requirements on blade painting and marking lights for the different countries involved. In most cases some kind of nacelle lights are required as a minimum, following the standards for onshore turbines and other high buildings.
In Germany, for instance, buildings larger than 100 m must have marking lights, and colours on the blades are mandatory for wind turbines larger than this size.

The use of good navigation equipment like radar and GPS[19] should make it less important to paint turbines in bright and shining colours. This issue has been a subject of negotiation for some sites, and is standard in other European countries.

In Denmark research is going on in order to find the most appropriate colour for towers, seen from a visual point of view – the goal is to make the turbines appear as neutral as possible in relation to the surrounding nature.

The general conclusion is that turbines must be marked properly and effectively in accordance with national and/or international guidelines in order to minimise risk of collision with ships, low flying aircraft or helicopters. However, painting and illumination/marking lights may have negative consequences for the visual impact and increase the risk of collision with birds, both subjects resulting in the fact that the public acceptance of the farm may decrease.[20]

Therefore the safety issue should be well balanced with the environmental impacts, and the consequences of marking lights etc. on visual aspects and bird interests should be thoroughly investigated in the EIA.

7.3.2 Defence

Military area restrictions disqualify a number of feasible sites from being developed. Especially for Sweden and Finland this is considered problematic, as areas owned by the military cover a significant amount of the areas potentially used for offshore wind power. In both cases practical solutions for co-existence between military and wind power are called for, but a solution must come through the political system.

As an example of the importance of and need for political solutions, the British Ministry of Defence has objected to chosen sites on land and offshore as it is believed they would interfere with low flying aircraft, even though these sites were not in close vicinity to military airports or equipment, but apparently just due to the fact that the height of the turbines represents a danger in itself [24].

[19] GPS: Global Positioning System – a satellite navigation system

[20] The subject of marking lights and visual impacts is illustrated in an example from Denmark, where the Danish Forest and Nature Agency has recommended that the turbines chosen for the Rødsand Offshore Wind Farm should not exceed 100 m. (from sea level to upper blade tip), in order to avoid marking light requirements set by the Danish Civil Aviation Administration. The recommendation of the Agency was purely motivated by visual impact concerns.

7.3.3 Radar and radio signals

Also the issue of disturbance of radio and radar signals has been a subject of negotiation in some countries, and in general the issue of radar is approached with much concern, as the disturbance of radar signal from offshore wind farms may become a serious obstacle to future development.

Based on result from preliminary Swedish studies [25] the following conclusions can be drawn, as an illustration of the potential problems and mitigations:

- The effect of wind turbines vary with different radar systems – the radar defence systems of NATO countries are less affected by disturbance from wind turbines than for instance the Swedish radar system, because NATO's radar system is primarily based on satellites and airborne radar equipment, whereas some parts of the Swedish radar defence system consists of older units and hence less advanced equipment. With modern radar equipment, disturbances should be minimal.
- The disturbance of (Swedish) radar equipment from turbines is only related to moving blades:
    - the movements of the blades are registered by the radar as false echoes, giving rise to several dots on the operator's screen, which may be confused with the echoes from an aircraft.
    - For experienced radar operators this disturbance should be easily handled when the radar installation is not situated within the wind farm, and if the exact coordinates of the wind turbines are known, the radar system/operator should be able to compensate from the false signals.
    - If the turbines are stopped, there will be no disturbance of the radar system.
- The disturbance of *radio signals* is primarily caused by reflections from the tower and is depending of the frequency band of the radio links – influence from wind turbines may impair the performance for radio relay links for frequencies between 2 and 10 GHz.
- The potential disturbance effect of radar and radio signals increases with the number of turbines

As an example of measures to mitigate wind turbines' effect on radar systems and decrease the collision risk, it can be mentioned that in the UK, whenever relevant, wind farms will be equipped with radar reflectors/intensifiers and fog signalling devices, as specified by the Department of Environment, Transport and the Regions [16].

However, the subject of radar a radio signal disturbance is still a key area of concern, e.g. in the UK where a BWEA working group has recently been convened to address the concerns of defence and aviation authorities collectively.

General conclusions

It can be concluded that although solutions seem to be available, it will be important for the development of large-scale offshore wind farms that the subject of interference with radar and radio systems is more closely investigated, as the potential effects are system- or country-specific.

The conclusions from the following studies may contribute with valuable information:

- A UK study carried out by Ministry of Defence, undertaking a number of trials to determine the extent of interference with radars from wind turbines, but these data have not been published yet. A BWEA working group has been convened to address this issue.
- The Swedish study concerning impacts on radar and radio systems will be finalised this year (2001).

7.3.4 Fishing industry

Restrictions to fishing rights from offshore wind power are bound to be an area of conflicting interests as the fishermen will lose trawling ground and possibly areas for pot fisheries. Up to now this conflict has not excluded any projects from being carried through, but financial compensation must be given to the fishermen, often without much evidence that fishing is actually reduced. This conflict appears to be especially problematic for France, where the fishing lobby is very strong and do not hesitate to block harbours, if they feel their interests threatened, but such problems may also occur elsewhere since the fishermen are generally well organised all over Europe.
In order to minimise impacts on fish, and thereby reducing the risk of conflicts with fishermen, it is recommended to

- avoid construction of wind farm in sensitive spawning areas, areas with species of commercial or conservation importance and areas with a very high value for fisheries
- avoid construction during important breeding, nursery or feeding periods
- carry out site-specific and species-specific monitoring studies in order to investigate the effect of offshore wind farms on fish, e.g. investigate if foundations may indeed serve as natural reefs, as indicated from previous studies (Vindeby), thereby increasing fish life, and investigate the consequences on fish population/fishing possibilities when fishing is restricted within and in the vicinity of the wind farm.

7.3.5 Birds

Ornithological associations are also a very strong lobby in most European countries, and negotiations are often carried out to define whether or not an area can be used for wind power.

In order to minimise potential impacts on birds and the resulting conflicts with ornithologists, the general conclusions about avoiding designated areas (including IBAs) and major migration paths should be followed. The layout of the farm and of the individual turbines (painting, illumination, size etc.) should also focus on minimising impacts on birds. Case studies/monitoring programmes should be carried out with the aim to investigate the effects of offshore wind farms on birds and bird populations, and furthermore generic studies concerning mitigating measures should be carried out.

The fact that not all Important Bird Areas have yet been officially designated, makes large-scale planning more difficult, and it should be in the interests of both the offshore wind turbine industry, ornithologists and EU/national nature protection societies and institutions that the borders of such areas are well-defined and well-known. Furthermore, guidelines for the proximity of an offshore wind farm to an IBA would be useful.

7.3.6 Other conflicts of interest

Raw material deposits
The siting of offshore wind farms may interfere with existing raw material deposits. As these deposits are well known already, this should however not lead to any significant conflict of interests. It is furthermore believed that offshore farms do not exclude extraction of, for instance, oil in the same area – one CA member mentions that there may be possible synergies from simultaneous energy production in offshore wind farms and raw material extraction.

Marine archaeology
Seismic site surveys and historical records investigation during the planning phase prior to the decision of the exact location of the turbines should avoid possible conflicts of interest. Specific areas of archaeological interest should be avoided. If, however, for instance a wreck is found during installation, this may lead to a serious delay of the whole project. Measures must therefore be taken to avoid such incidents by carrying out the investigations necessary in the EIA.

7.3.7 Conflicts of interest - general conclusions

The general conclusion is that conflicts of interest are restricted to areas already known in the planning phase, thus severe conflicts of interest which could stop a project can theoretically be avoided through careful, open planning. However, regarding radar no final conclusions can be drawn yet, calling for additional national investigations, as the disturbance effect may vary from country to country.

7.4 SOCIAL ACCEPTANCE.

In general, opinion polls in countries like the Netherlands, Germany, Denmark and the UK show that more than 70 percent of the population is in favour of using more wind energy ([26, 27, 28 ,29]). In the UK, a summary of opinion surveys indicates that 8 out of 10 support local wind projects [30], but no specific opinion surveys concerning offshore wind energy seem to be available.

In Germany, as mentioned in Section 7.2.4, a study on effects from on- and offshore wind farms on tourism (i.e. not the local population as such) indicated that offshore wind farms would generally be accepted by tourists as long as the farms were not situated too near the coastline.

The responses from the CA members received on social acceptance of offshore wind power at first sight indicate that there is no absolute clear conclusion as to the social acceptance of offshore wind power compared to onshore. Nevertheless, some hypotheses can be drawn from the responses received, and an analysis of the acceptance dilemma of onshore wind power applicable to offshore locations shows that:

- public acceptance in general is high but falls when it comes to our own living surroundings,
- coastal areas are more sensitive to change because of great recreational values,
- local acceptance seems to increase after the installation of turbines, provided that no disturbances are experienced,
- public acceptance increases with the level of information and economic involvement.

Social acceptance of wind power has often been characterized by a NIMBY (not in my backyard) syndrome. The NIMBY-explanation is however a too simplistic way of explaining all variables involved when determining the general and local public acceptance of a specific wind power development. This means that the question of social acceptance really has many components: e.g. the general attitude towards offshore wind power in the population as a whole, the acceptance in the population who will experience the local impacts, the conflict management strategies and economic involvement.

One possible way of overcoming the dilemmas is presented by the Danish case for onshore wind power. Here most wind turbines are owned by locally established private cooperatives. This appears to improve the social acceptance, as it is, generally speaking, the same people who experience the impacts that receive the financial benefits.
For the Middelgrunden Wind Farm outside Copenhagen, it is very probable that the project could not have been carried out without involvement of the local public in this way.

In Denmark, most of the offshore projects will be owned by the utilities, but it is still a political priority to encourage the formation of cooperatively owned offshore wind power farms as well. It is probable that the next generation of offshore farms (Horns Rev, Rødsand, Læsø, Omø Stålgrunde and Gedser) will be partly publicly owned, giving the possibility to test different ownership models [31]. The project will be managed by the Danish Association of Wind Turbine Owners, but has not been politically approved at the time of writing.

This "Danish model" is, however, rather unique, and for most other countries the offshore wind farms are either owned by utilities or private consortiums, thus only enabling indirect financial benefits and influence for the local citizens.

A broad-based participation in the implementation and decision process is used in a Swedish offshore project in Kalmarsund conducted by Vattenfall. This is a form of conflict management, which extends the group of actors involved in the decision process, increases transparency and promotes negotiations and discussions. An important factor is thus, who is involved in the decision process and in what form can different actors participate and represent their interest in the planning process. The result of this approach is so far that the project has conducted a management of dissent instead of putting trust in a fictitious consent. The importance of this type of conflict management seems to correlate with the amount of realised and planned projects in a demarcated and clearly defined geographical area suitable for offshore wind power.

One strategy concerning public involvement is to assume that the local public opposition can be overcome by rational decisions made by experts, and people will eventually get used to change. Another strategy is to directly involve the local public early in the planning phase, and incorporate the recommendations into the project at an early state. The purpose of this strategy is to give the local population a motivation to accept change by for example giving them a say in the planning of the project. The "risk" of this strategy is that the public debate generates so much awareness and thus delays the whole planning procedure. A delay, which on the other hand is unavoidable when permits are appealed against and projects face the threat of never being realised.

Presenting a wind power plan requires a sense of timing. In some cases, depending on the size of the project, it might be worthwhile to allow a certain period of adjustment. A large wind farm may in some cases be developed sequentially, which makes adjustments easier if people express misgivings. Such adjustments manifest the flexibility and reversible quality of wind power developments. Just because a wind farm can be erected quickly, does not necessarily mean it should be.[21]

Finally it should be mentioned that the social acceptance of offshore wind, as discussed in the introduction of this report, may expect to increase significantly, when people are aware of the positive impacts of offshore wind energy and when they realize the alternatives. The fact that oil and gas reserves are very limited, that other sources of energy are not only much more polluting but also more expensive when externalities are accounted for [32], should be stressed in the public dialogue.

General conclusions

According to experiences from the offshore farms already established it can be said that:

- the degree of involvement of the local population in the planning phase influences the public acceptance.
- the procedures on public involvement, hearings etc., vary considerably among countries and may even vary among regions within the same country.
- there is to day no clear overview on the results of different strategies for public involvement and conflict management.

The issue of public acceptance deserves to be studied in more details, e.g. through a monitoring programme focussing on public acceptance before and after the installation of an offshore wind farm in relation to the degree of public involvement and active conflict management.

[21] In Denmark, the pilot projects regarding five 150 MW offshore wind farms can be regarded as a sequential development of each wind farm – however, due to technical and environmental motives.

7.5 NATIONAL POLICIES

7.5.1 General attitude

On the political level the attitude towards offshore wind power seems to be very positive, which is reflected in the fact that several countries have established ambitious targets for the exploitation of offshore wind power , with corresponding support mechanisms, see chapters 5, 6 and 9.

In the most ambitious plans several 1000 MW offshore wind power plants are planed for within 10-25 years. In most countries, however the energy policy targets do not distinguish between onshore and offshore wind.

7.5.2 Planning rules

Planning rules and regulation only exist in some countries, but can be foreseen in the coming years.
The fact that the legal framework is still under construction and unclear in many countries is to be regarded as a major limiting factor to the development of offshore wind energy.
Moreover, national planning rules may vary significantly within the EU, and even on the national level, different and confusing legal frameworks exist within individual countries. Different regulations regarding the same subject exist in several countries, depending on whether a proposed farm is located inside the 12 nautical mile zone (often referred to as “territorial sea”) or outside (“exclusive economic zone”, extending from the 12 nm zone seawards to a maximum of 200 nm from the shoreline).
An example is Germany, where both federal and state law is applicable within territorial water, whereas only federal law is applicable further away from the cost.

For a detailed analysis of policies and regulations in Northern Europe (2000), please refer to the Dutch study carried out by Ecofys [33].

Table 7.1 (at the end of chapter 7) presenting national planning rules and regulations in the member states of the Concerted Action, has been based on responses from CA-OWEE members.

7.5.3 Conclusions

Regarding national planning rules and regulations it can be concluded that in many countries the legal framework has not been fully clarified yet, which is a barrier for future development of large-scale offshore wind energy. As suggested in [33], a one-desk policy for all necessary licenses would be beneficial in this regard.

7.6 ONGOING RESEARCH PROJECTS

Please refer to the appropriate sections in chapter 9.

It should however be noted that the five 150 MW offshore pilot projects in Denmark will all be subjects of environmental investigations, in fact the sites have in many cases been selected in order to thoroughly monitor and analyse environmental impacts. The project at Rødsand, as an example, is situated in close vicinity to an important Special Protected Area (birds) and an equally important Special Area of Conservation (seals) and in the middle of an important bird migration path.

The studies will be closely followed by a group of international experts, under the secretary of a representative from the Danish Forest and Nature Agency. Furthermore, the Danish Energy Agency has compiled an advisory panel consisting of representatives from (national) environment organisations, such as WWF and the Danish partner of BirdLife, The Association of Danish Ornithologist.

Results will be published both in Danish and English.

7.7 GENERAL CONCLUSIONS

The following conclusions and recommendations concerning future RTD-activities in most cases imply the construction of offshore farms, as monitoring programs and Before-After-Impact-Studies carried out at specific sites often represent the only possible way to achieve exact knowledge or at least an improved understanding of the impacts from offshore wind energy, particularly on the environment.

Furthermore, the offshore wind farms already constructed or planned may yield important information concerning issues like social acceptance and conflicts of interest if research projects dealing with these issues are carried out.

Therefore the recommendations below (Section 7.7.2) should not be regarded as barriers for the future development of offshore wind energy – on the contrary, it is necessary that offshore construction projects are carried out, and in many cases it is necessary that some large-scale projects are carried out in order to achieve more information and knowledge regarding especially environmental issues.

These projects must however be subjects of intensive national and EU-funded research in order to reach conclusions about the impacts from offshore wind energy in relation to environmental questions, social acceptance and conflicts of interest: It is highly recommended that the present uncertainties and knowledge gaps are replaced by knowledge and certainty before real large-scale development of offshore wind energy is initiated.

7.7.1 Identification of problem areas

Potential negative environmental impacts

Birds
- collisions with turbine
- turbines acting as barriers for migrating birds
- ousting of feeding/breeding areas due to
  - noise emission from turbines in operation and vessels during construction, maintenance and dismantling
  - movements of blades
  - serious changes in food chain, e.g. due to new sediment structure and “unnatural” reef effect
  - accidents (collisions with e.g. oil tanker not only causing ousting of birds due to oil spill, but also killing birds)

Mammals
- loss of habitat due to
  - noise emissions
  - movements of blades
  - food chain changes
  - electromagnetic fields and vibrations, e.g. affecting the sonar system
  - accidents

Fish
- impacts on fish and fish larvae from sedimentation/turbidity, underwater noise, vibrations and electromagnetic fields
- effects from unnatural reef
- effects of accidents

Fauna and Seabed

- changes in sediment structure
- direct loss from foundation and cable footprints
- impact on biotope from foundations/hard substrates and electromagnetic fields
- disturbance/destruction of benthos due to accidents with ships/aircrafts

Coastline

- impact on coastline due to current/sediment changes arising from cables
- impact on coastline due to accidents

Visual impact

- man-made obstacles in an otherwise structureless landscape

Noise impact

- increased blade tip speed and the ability of sound to propagate more efficiently on sea surface may lead to noise impacts
- impact on birds, sea mammals and fish from underwater noise

Conflicts of interest:

- collision risk with ships (including maintenance vessels), helicopters and low-flying aircrafts
- disturbance of radar and radio signals

Social Acceptance

- reduced acceptance due to unsolved environmental impact questions, lack of public influence on project (e.g. farm layout) and lack of public financial involvement in/ownership of offshore farms

Policies

- insecure/insufficient support mechanisms will block future large-scale development of offshore wind energy

7.7.2 Recommendations for RTD programmes

In general

- It will be very important to collect information from different studies in order to cover the whole area, as different "narrow" site specific studies are carried out at the different projects: Baseline and impact studies from individual projects are to be disseminated and jointly appraised (also suggested in [37]). Conclusions from local projects should be translated and all relevant existing material placed on a publicly accessible web site.
- The impacts from electromagnetic fields from cables on fish, marine mammals and benthos – and on pipelines (corrosion) and naval safety (disturbance of steering equipment) must be investigated – but this is not only to be regarded as the job for offshore wind developers, as it is a general issue of uncertainty.
- The impacts from above-sea and underwater noise emission and the impacts from vibrations during construction and operation must be investigated in relation to effects on birds and sea life
- Mitigation measures in general should be developed in order to reduce the environmental impact of offshore wind farms

Environmental impacts

Birds

- As studies regarding the impact of offshore wind farms on birds and general studies on migration patterns are sparse, and as the effects depend on many different parameters, more knowledge is needed, both as general studies concerning bird migration and as site-specific studies: Ecological monitoring programmes/ Before-After-Impact-Studies are highly desirable in order to judge the effect on birds

- Define IBA/SPA borders and proximity to offshore farms
- Define flight paths
- Investigate how to minimize impacts from different farm and turbine layout (incl. marking requirements)

Mammals

- More studies are needed to evaluate the effect from noise and magnetic fields, and the visual impact on mammals. Before-After-Impact-Studies, including seismic surveys and monitoring of underwater noise levels, and generic studies on noise reception of sea mammals are called for.

Fish

- As the effect of noise, vibrations (e.g. from placement of monopiles) and magnetic fields on fish is relatively unknown, studies and surveys must be carried out before, during and after construction: Site-specific and species-specific monitoring studies are necessary in order to investigate the effect of offshore wind farms on fish, e.g. investigate if foundations may indeed serve as natural reefs, as indicated from previous studies (e.g. Vindeby), the consequences hereof, and investigate the consequences on fish population/fishing possibilities when fishing (with net) is restricted within and in the vicinity of the wind farm

Seabed

- The quality and quantity of possible impacts on seabed and benthos is not well known, calling for surveys of specific project sites, both as part of the EIA and as generic studies. How will the foundations/hard substrates and cable footprints/electromagnetic fields influence base-line biotope? Investigations should seek to enhance habitat, e.g. by use of appropriate foundation design.

Visual impact

- Research of computer simulation possibilities to test different farm layout seen from different angels, levels and at different weather conditions in order to make visualisations comparable to real-life conditions.
- Clearer definitions of marking requirements.

Conflicts of interest:

- Risk collision studies and additional information on damage mechanisms are called for in order to investigate the issue of marine and air traffic safety and offshore wind farms more closely.
- Radar and radio disturbance: for the development of large scale offshore wind farms it will be important that this subject is more closely investigated – the conclusions from ongoing UK and Swedish studies may contribute with valuable information

Social Acceptance

- Studies of the effects of different ownership models and local ownership of offshore wind farms in relation to social acceptance

7.7.3 General recommendations for offshore wind projects

Fish, birds and other groups

Identification and avoidance of sensitive areas
Avoidance of site works during sensitive time periods

Birds

Layout design to accommodate flight paths, where these are defined.

Sea mammals

Minimisation of noise levels during construction, operation and dismantling

Fish

Minimise effect of structures and cabling on stocks

Seabed, Benthos

Minimize sedimentations and turbidity

Hydrography, currents and water quality

Use of appropriate foundation design

Avoid use of pollutant chemicals when foundation, tower and turbine are protected against marine environment

Visual

Early assessment taking account of distance from shore, marking lights and nature of viewpoints

Well-balanced marking lights taking into account safety issues (most important) and visual impact on man and animal

Noise

Ongoing PR work to counter poor publicity

Maintain good standards of noise emission despite increases in turbine size and tip speed

Social conflicts

Promotion of openness and local involvement

Risk management

Develop risk management methods and emergency procedures in order to reduce risks of ship collision and to minimize consequences of collisions

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Table 7.1 National Planning Rules and Regulations	
BE	Offshore wind energy legal framework is clearly defined, in: • Law on concessions for offshore wind and wave energy plants (as part of general electricity regulation law). • Law on (environmental) authorisations for all off-shore installations • Law on environmental impact reporting for all off-shore installations Some remaining uncertainties due to necessity of regional authorisations for grid connection.
DK	The Danish Energy Agency is authorising offshore wind farms inside as well as outside territorial waters. Planned 4000 MW before 2030. A national committee has pointed at specific potential areas of which 750 MW will be utility developed and serve as pilot projects to be established before 2008. There are ongoing negotiations to have 150 MW of these 750 MW owned and developed by cooperatives. After 2008, the offshore wind energy sector will be subject to the same rules as for offshore gas and oil exploitations, i.e. open bidding procedures.
FI	EIA requested from >50 MW power plants. Suggested for > 10 MW wind farms. Regional planning authorities. Local planning permission needed. (Depending on regional land use plan) National "Waters Act" "Environmental Protection Act"
FR	No specific rules. The work of the CA is taken as a guide for future rules (like for onshore wind farms in the 80's)
GE	Within 12 to 200 miles zone the National Authority for Sea Traffic and Hydrography is the entity for permissions, legal basis is the international bill of sea rights together with a national regulation for building and operation of plants in the 12 to 200 miles zone. For developments near shore and grid connection through coastal sea, the regional governments of the German countries bordering the North Sea are the permitting authorities. Regional planning procedures are required in which all relevant national laws and regulations are to be applied – may be rather time consuming
GR	Legislation for renewable energy sources applies also to large-scale offshore wind energy
IR	Procedures for applying for foreshore licenses (to investigate site suitability) and foreshore leases (to develop wind farms) published. Applications made to Department of the Marine and Natural Resources Offshore wind farms will not, as a general rule, be allowed within 5 km of shore. Certain areas are identified as prohibited to ensure safety at sea, protection of established shipping lanes, air navigation, telecommunication needs and defence requirements Planning permission required from relevant local authority for onshore infrastructure associated with offshore wind farms.

Table 7.1 National Planning Rules and Regulations	
IT	Planned 2500 MW on- and offshore within 2010 according to the National White Paper of 1999. Only a small fraction of this target expected to be offshore. Total offshore potential is about 3000 MW. The Italian Navigation Code (INC) and the Application Guide of INC (AGINC) are the reference legislation for offshore wind farms installation in the Italian national waters; specifically art.36 and following of INC and art.5 and following of AGINC (for the type and format of application documents). Special permits should be considered for offshore Wind Farms, because of the long time limitation related to their presence for the activity of navigation, fishing, marine sport, and others. Many other Administrations are involved in processing the installation permits: Ministry of Transport, of Defence, of Environment, of Industry, of Civil Works, of Sea and Terrestrial Resources (General Direction of Maritime Fishing) and others. The Environmental Impact Evaluation should be considered necessary, even though no clear policy is applied today. At the end of the procedure the Permits are issued by the Compartment of Maritime Transport and shown to public office of interested Municipality and Province for public information and possible opposition. The installation of Offshore Wind Farm and Permit applications is under the control of the local Harbour Authorities by their presence Coastal Guard. Safety features for navigation and aviation are requested in the Permit. Information on the offshore plants is due to Marigrafico office for its inclusion on the nautical charts.
NL	Within the 12-mile-zone, apart from a near shore wind farm pilot project (NSW), no wind farms will be allowed. There are practically no Dutch regulations and rules existing for large-scale offshore wind energy outside the 12-mile-zone. This could be positive or negative depending on political will. However, there are several laws and regulations that have to be considered when licenses in the Dutch Exclusive Economical Zone of the North Sea must be gained. These regulations are: • Sea Water Pollution Law (Wet Verontreiniging Zeewater) • Environmental Administration Law (Wet Milieubeheer) • Spatial Arrangement Law (Wet Ruimtelijke Ordening) • Environmental Protection Law (Natuurbeschermingswet) • Governmental Water Works Administration Law (Wet Beheer Rijkswaterstaatswerken) • Wreckage Law (Wrakkenwet) • Monuments Law (Monumentenwet) • Excavation Works Law (Ontgrondingenwet) • North Sea Installations Law (Wet Installaties Noordzee) • (Sea) Bottom Protection Law (Wet Bodembescherming) • Mining Laws 1810, 1903 & EEZ (Mijnwetten 1810, 1903 & NCP buiten 12 mijl – From recent studies, it seems that this law has no implications for offshore wind farms) • Route Law (Tracéwet – This law is important for the seaways to be chosen)
PL	Very broad planning rules of the Construction Law referring to constructions at sea, Energy Law pointing at the necessity of implementation of renewable resources.

Table 7.1 National Planning Rules and Regulations	
SE	Legal framework under construction. In a recently published study carried out by the Swedish Energy Agency 36, and initiated by the government with aims to make standards for the future offshore wind power, it is proposed that 3,300 MW of offshore wind power is to be developed within the next 10 to 15 years. Seven offshore areas have been suggested as locations of special interest, first of all in the Southern part of Sweden. For the moment a number of pilot projects are planned, and the intention is to follow these carefully during the whole planning and construction-process. It is expected that the current regulations (2001) are soon to be revised and simplified: • Building Permit required from local authorities' (municipality) building and planning committee, according to the Planning and Building Act. • Permit required from local County Administrative Board concerning environmental issues (according to the Environmental Code). For projects larger than 10 MW, permits are issued by the Environmental Court concerned. • Application for water operation permits shall be considered by the Environmental Court • The government shall assess the permissibility of wind farms inside territorial waters if they are consisting of clusters of three or more wind turbines with a total output of not less than 10 MW. • Construction of wind farms outside territorial waters requires permission from the government. • The Swedish Energy Agency issues permits regarding cabling
SP	Legislation for wind energy onshore applies also to offshore
UK	• Defined procedure for obtaining site lease from Crown Estates (who is the "landowner" of most areas within the 12 nautical mile limit). First round of site allocations was made April 2001, where the location of 13 potential offshore wind farm sites was announced. Each site will consist of 30, 60 or 90 turbines. Consents process still evolving but expected to include: • Dept of Trade and Industry (DTI) provide "one-stop" consenting assistance but Dept for Transport Local Government and the Regions (DTLR) and Dept for the Environment Food and Rural Affairs (DEFRA) also involved. • Undertake Environmental Assessment and consultation leading to EIS. • Apply to DTI under the Electricity Act 1989. • Apply to DEFRA under Food and Environmental Protection Act 1985. • Apply to DTLR under the Coastal Protection Act 1949, or Transport and Works Act 1992.

CHAPTER 8

SOCIAL ASPECTS

SUMMARY

Chapter 8 deals with employment prospects and industry benefits of the development of large scale offshore wind power.
The direct employment effects of offshore wind power are estimated as 4,5 ft jobs/MW. European industry could greatly benefit from taking the lead in offshore wind farm development and construction.

CONTENTS OF CHAPTER 8 : SOCIAL ASPECTS

8.1 EMPLOYMENT PROSPECTS FOR EUROPE

Estimates for employment prospects are predominantly available for onshore wind or the generic wind industry. DWTMA [1] gives estimates of employment generated by wind energy in Denmark, broken down by sectors defined in Danish input-output tables and applying economic multipliers. EWEA, Cambridge Econometrics and ECOTEC [2, 3, 4] use economic modelling techniques to estimate job creation for future energy mix scenarios. ESD for Friends of the Earth [5 surveys employment in the UK wind energy industry. [6]

Altener [7] provides estimates for both onshore and offshore broken down into construction & installation and operation & maintenance, for 1995 and scenarios up to 2020. ESD for Greenpeace [8] is dedicated to offshore estimates and uses input-output analysis to estimate job creation by industry sector as a result of installing some 10GW of offshore wind.

BorderWind for Greenpeace [9] is also dedicated to offshore wind and provides estimates of *direct* job creation by activity based on consultation with developers and operators. This estimate is reproduced in table 8.1 below.

Table 8.1 Estimate of direct employment to develop offshore wind farms.

		Full Time Jobs/MW
Project design and development	Marine/ground investigations	0.01
	Site development including permissions	0.1
	Design including structural, electrical and resource	0.02
	Finance	0.04
Component supply	Generators	0.15
	Gearboxes	0.9-0.4
	Rotor blades	0.5
	Brakes, hydraulics	0.04
	Electrical & control systems	0.04
	Towers	0.9
Assembly	Wind turbines	1
Installation	Foundation structure	0.3
	Electrical and connecting cables	0.05
	Wind turbines	0.3
	Project management & commissioning	0.11
Operation & maintenance	Management, routine and fault maintenance	0.06
TOTAL		4.52

Sweden has no wind power industry, however, even without turbine manufacturing in Sweden there will be an effect from the increasing wind industry upon the Swedish labour market. Steel manufacture and fabrication and electric equipment are standard Swedish export products.

Industry has started in Malmö and is planned in Kiruna and Luleå. The Swedish government has stated its intention to build wind power plants for 10 TWh annual production, of which more than half will be offshore.

It is predicted that in Germany, as a result of wind energy use, 25,000 to 30,000 jobs will be directly and indirectly created by the end of 2000 [10] & [11].

8.2 BENEFITS FOR EUROPEAN INDUSTRY

European industry at the forefront in providing consultancy services to wind energy, and this should continue for offshore. European offshore oil and gas sector experience of substructures, foundations and installation techniques is to some degree transferable to offshore wind. See Garrad Hassan and Partners: "Measures to Increase the UK-Manufactured Content of Wind Turbines", ETSU W/45/00479/REP/1 1996 and "Offshore Wind Industry Capabilities in the UK", ETSU W/35/00530/REP 1999.

The Netherlands has a large number of offshore engineering companies, who would be capable of manufacturing the offshore engineering components, however, the lack of a local market has handicapped the development of a flourishing wind turbine manufacturing industry.

Europe is a net exporter of services and equipment to the wind energy sector, thus securing more jobs and wider economic benefit in Europe than that supported by the domestic market alone. A mature European wind industry is in an excellent position to export to presently emerging or anticipated markets.
The technical advantage gained from European offshore wind farm development will be exportable to developing countries, which will provide new markets for wind energy industries & services. European developments will be a show-case for exports of consultancy services and equipment. See [12] & [13].

8.3 REFERENCES

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[13] Ernst and Young: "Renewable Energy Support Services as Exports" K/BD/00150/REP/1

CHAPTER 9

ACTIVITIES, PROJECTS AND PLANS

SUMMARY

The objective of this chapter is to give a comprehensive review of ongoing and planned activities in the European Union regarding RTD, projects and national plans on offshore wind energy.

It brings together current work from each of the EU member countries to help identify future strategies for adoption by the European Offshore Wind Industry.
The chapter addresses recent and current research activities in offshore wind energy. A very large number of national and international R&D projects on offshore wind energy have been undertaken over the last decades, the more recent and more relevant for today are each briefly described. These are divided into groups, approximately relating to:

- Resource assessment,
- Wind turbines (including support structures)
- Wind farm
- Installation
- O&M
- Integrated methodologies
- Environment and planning aspects

Conclusions are drawn regarding the main topics currently being studied.

The paper further summarises the various national plans that have been put forward by countries across Europe.

CONTENTS OF CHAPTER 9 : ACTIVITIES, PROJECTS AND PLANS

9.1 RECENT AND CURRENT RESEARCH ACTIVITIES

This section addresses recent and current research activities in offshore wind energy. A large number of national and international R&D projects on offshore wind energy have been undertaken over the last decades and the more recent and relevant are briefly described within this section. For convenience, they have been arranged in the following groups:

- Resource assessment,
- Windturbines (including support structures)
- Windfarm
- Installation
- O&M
- Integrated methodologies

Further information on European funded projects is available at the CORDIS and Agores databases and projects are generally reported at the appropriate European wind energy conferences:

- European Wind Energy Conferences [EWEC]
  - Copenhagen 2001,
  - Nice 1999,
  - Dublin 1997,
  - Gothenburg 1996.
- OWEMES Seminar (Offshore Wind Energy in Mediterranean and other European Seas):
  - Rome 1994,
  - La Maddalena 1997,
  - Siracusa 2000.

9.1.1 Resource assessment

This section briefly describes research projects that have focused on defining the resource, for purposes such as estimating energy production, predicting the loads on the wind-turbine, optimising the wind farm layout and evaluating the extent of the total offshore resource available.

Predicting offshore wind energy resources [POWER]
This European funded project was undertaken jointly by CLRC\RAL (lead contractor), University of East Anglia, KEMA, Ecofys and Risø under the Fourth Framework JOULE Programme, reference JOR3980286 and was completed in the middle of 2001.
The objectives of the project were to assess offshore wind power potential in EU waters. The work involves determining the geostrophic wind from long-term pressure fields, transforming the wind to sea level, taking account of nearshore topography using WAsP and correcting for stability effects using a Coastal Discontinuity Model.

Wind Energy Mapping using Synthetic Aperture Radar [WEMSAR]
This European funded project is being undertaken jointly by Nansen (lead Contractor), ENEA, Risø, NEG Micon and Terra Orbit under the Fifth Framework Programme, Reference ERK6-1999-00017, and is due to be completed and in 2003.
The objective is to investigate, validate and demonstrate the potential of satellite-based synthetic aperture radar (SAR) to map wind energy in offshore and near coastal regions for potential wind-turbines siting.

Wind resources in the Baltic Sea
This European funded project was undertaken jointly by Risø it, University of Karlsruhe, the Finnish Meteorological Institute, University of Keele under the Third Framework Programme, reference JOU20325 and was completed in 1996.

The objective was to describe and map the wind resources of the Baltic Sea and the Gulf of Finland and to create and test tools for siting of windturbines in coastal areas.

Study of Offshore Wind Energy in the European Community
This European funded project was undertaken jointly by Germanischer Lloyd and Garrad Hassan under the Second Framework Programme, reference JOUR0072 and was completed in 1993.
The focus of the project was to undertake an exploratory study covering the following four tasks: the potential for offshore wind energy in Europe, experience in offshore engineering relevant to offshore wind farms, design guidelines and consideration of combined wind and wave loading.

NTUA wave climate study
The National Technical University of Athens is carrying out research into wave resource modelling [1], specifically for wave energy schemes but of relevance to offshore wind projects for determining the wave climate.

New WAsP
The goal of the project is to develop the next generation of the WAsP computer program, which should be able to handle modelling in complex terrain as well as offshore in a better manner. Two tracks will be followed, one will try to take advantage of and implement the newest technologies within the flow-modelling field and the other will develop incremental improvements to the existing code. Once the new algorithms have been developed they will be implemented in the familiar WAsP GUI (Graphical User Interface) [7]-[11]

Zukunftsinvestitionsprogramm (FuE/ZIP)
This project (in English *Future Investment Programme)* is being undertaken jointly by BMWi [Ministry for Economic Affairs] and BMU [Ministry of Environment Protection], is due to in 2001 and will cover:

- measurement platforms in the North Sea and Baltic Sea for wind resource assessment and ecological monitoring research:
- bird migration
- marine acoustics with respect to impact on sea mammals
- investigation on sea bed life
- investigation on impact on fish

9.1.2 Wind turbine

This section briefly describes research projects that have focused on modelling the wind-turbine and the support structure. Regarding the current status of design tools, these include:

- the prediction of offshore wind regimes by analytical techniques and the monitoring of existing wind farms
- refinement and development of integrated dynamic structural models of the entire turbine and foundation system
- reliability/availability
- prediction of rotor dynamics

Recommendations for Design of Offshore Wind Turbines [RECOFF]
This European funded project is being undertaken jointly by Risø (lead contractor), CRES, ECN, Garrad Hassan and Germanischer Lloyd, under the Fifth Framework Programme, reference ENK5-2000-00322 and is due to be completed at the end of 2003.
The project aims at the provision of recommendations for a standard design of offshore wind turbines. Readily available information will be utilised to the extent possible and where a need is identified, research and development will be performed. The recommendations will be addressed directly to the two standardisation bodies: the International Electrotechnical Commission (IEC) and the European CENELEC.

Design Methods for Offshore Wind Turbines at Exposed Sites [OWTES]
This European funded project is currently being undertaken jointly by Garrad Hassan (lead contractor), AMEC Borderwind, Germanischer Lloyd, PowerGen Renewables, TUDelft and Vestas under the Fourth Framework Programme, reference JOR3980284 and is due to be completed in 2002.
The aim of this project is to improve the design methods for wind-turbines located at exposed offshore sites and to facilitate the gradual, cost effective exploitation of the huge offshore wind energy resource available in European Union waters. As part of this project, a measurement system has been installed on one of the wind-turbines to enable design and certification methods to be verified.

The Dynamic Response of Wind Turbine Structures in Waves
Research into 'The Dynamic Response of Wind Turbine Structures in Waves' is underway by Prof. J M R Graham (Imperial College) et al, funded by the UK DTI Renewable and New Energy Programme, Engineering and Physical Sciences Research Council – Renewable and New Energy Technologies; EPSRC - RNET, [5]

A report has been produced in Finland on the response of OWEC's to pack ice [6]

'BLADED for Windows' and 'TURBLOAD' have been and are under development by Garrad Hassan. Validation and further development of existing aero elastic models will be performed based on measurements at Blyth Harbour.

In the Netherlands, ECN have developed two wind-turbine models,

- the time-domain PHATAS-IV [14]
- the frequency-domain TURBU with the TURBU-OFFSHORE extension currently in preparation [13]

In Germany, wind turbine manufacturers, certifying bodies and universities are also cooperating in the development of their individual design tools [12]

In Belgium an integrated dynamic model of the complete system is currently under development using Finite Element (FE) analysis.

Proprietary computational fluid dynamics programs, for example by CFX, a division of AEA Technology, are used for the analysis of flow around and the behaviour of turbine blades.

Other Danish ongoing research focuses on:

- Aero-elasticity with special focus on offshore wind turbines.
- Design specifications for offshore wind farms

9.1.3 Wind farm

This section briefly describes research projects that have focused on the entire windfarm.

Cost Optimising of Large Scale Offshore Wind Farms
This European funded project was undertaken jointly by S K power (lead Contractor), National Wind Power, Risø, Nellemann, Nielsen & Rauschenberger, Rostock Stadwerk and the Polytechical University of Madrid, under the Fourth Framework Programme, reference JOR3950089 and was completed at the end of 1998.
This project investigated the technical and economic feasibility of a large scale offshore wind farm in the range of 200 to 500 MW in the Danish waters of the Baltic Sea and a Langeland Belt by examine the meteorological conditions and North

Efficient Development of Offshore Windfarms [ENDOW]

This European-funded project is being undertaken jointly by Risø (lead contractor), Garrad Hassan, Ecofys, Uppsala University, Robert Gordon University, NEG-Micon, SEAS, Oldenburg University, ECN and Elsamproject. under the Fifth Framework Programme , Reference ERK6-1999-00001, and is due to be completed in July 2003.

Using experience gained through the demonstration projects currently operating offshore, the major objectives are to evaluate wake models in offshore environments and to develop and enhance existing wake and boundary-layer models to produce a design tool to assist planners and developers in optimising offshore wind farms.

Measurement On and Modelling of Offshore Wind Farms

This European funded project was undertaken jointly by Risø, Bonus, Finnish Meteorological Institute and Madrid University under Third Framework Programme, reference JOU20350 and was completed in 1996. The main objectives of the project were to measure the nature of wind-turbine wakes at the Vindeby offshore wind farm, to investigate the structure of single and multiple wakes and to characterise the relationship between turbulence and wind-shear with wind-turbine separation.

Fyndfarm

Fyndfarm, a tool for optimisation of wind farm configurations, has been developed in the Netherlands.

9.1.4 O&M

Availability Model for Offshore Wind Farms.

This project is funded by the Danish Energy Agency (DEA) under the UVE Programme, reference ENS-51171-98.0033.

The project is managed by Riso, Department of System Analysis in co-operation with SEAS and is expected to be completed at the end of 2001. The aim of the project is the development of a general model for decision analysis for the optimisation of the availability of wind turbine farms offshore especially with respect to maintenance policy. A determination of the balance between reliability of the turbines, their interconnections and tower access conditions will be carried out. The model will be constructed as an influence diagram, and relevant variables including those mentioned above will be taken into account. The variables will describe the farms geographical site, the turbines, including their main component reliabilities, the site climatic conditions, transport infrastructure, electrical connections, local as well as remote surveillance and control.

9.1.5 Integrated methodologies

Structural and Economic Optimisation of Bottom-Mounted Offshore Wind Energy Converters [Opti-OWECS]

This European funded project was undertaken jointly by TUDelft (lead contractor), University of Sunderland, Kvaerner Oil and Gas and Kvaerner Turbin under the Fourth Framework Programme, reference JOR3950087 and was completed at the end of 1997.

The overall objective of the study was to identify designs leading to a reduction of the cost per generated kilowatt hour of offshore wind energy by using an integrated approach in the design process.

Site Specific Design of Wind Turbines Based on Numerical Cost-Optimization.

This Danish project involves the direct use of site characteristics in the design process, when optimising wind turbines. Design loads are determined by use of detailed wind climate information for mountainous complex terrain, large offshore wind farms and very low or high annual wind speed. Benefits will be determined from the design of site-specific wind turbines and multi-site wind turbines. Design guidelines will be established for the adaption of existing designs to a specific site with only small adjustments and for the design of entirely new wind turbines. Numerical optimisation will be used to optimise wind turbines for the specific site characteristics. Existing design tools will be improved by development a complete direct design method that combines state-of-the-art aero elastic calculations, wind modelling, cost modelling and numerical optimisation. Two three-bladed wind turbines based on different concepts will be modelled and the design load cases will be found for six wind climates. The benefits from site-specific design and the possibility for multi-site design will be evaluated covering both re-design of existing wind turbines and design of new wind turbines

9.1.6 Environmental impact and Miscellaneous Aspects

LCA

In Denmark, a tool for LCA (life cycle assessment) of wind turbines is being developed, which will enable the environmental impact of wind turbines to be predicted.

Umweltforschungsplan des BMU (UFOPLAN): “Weiterer Ausbau der Windenergie im Hinblick auf den Klimaschutz“

This investigation was undertaken by BMU [Ministry of Environment Protection] and focused on the further development of wind energy use in Germany with respect to climate protection. It is an ongoing project and examines:

- Further Development of Wind Energy Use on Land and Offshore
- Wind energy pricing (EEG Renewable energy Law)
- Repowering onshore
- Workshops on Offshore Wind energy Use in (April/June 2000)
- Integration of conflicting environmental interest
- Grid integration
- Feasibility of remote offshore wind energy
- Operational aspects of offshore wind energy use and cost of offshore wind

Umweltforschungsplan des BMU (UFOPLAN): “Untersuchungen zur Vermeidung und Verminderung von Belastungen der Meeresumwelt durch Offshore-Windparks im küstenfernen Bereich der Nord- und Ostsee“

This investigation was undertaken by BMU [Federal Office for Environmental Protection] and focused on the state of the art for avoidance and minimisation of environmental impact by offshore wind farms on marine environment. It is an ongoing project and examines:

- description of the state of the art with respect to environmental impacts on benthos, fish, birds, sea mammals
- development of IEA methodology
- risk analysis for ship collision
- formulation of measures to minimise impacts
- identification of knowledge deficits

Erfassung der Verbreitung, Häufigkeit und Wanderungen von See- und Wasservögeln in der deutschen Nordsee und Entwicklung eines Konzeptes zur Umsetzung internationaler Naturschutzziele (BOFFWATT)

This investigation was undertaken by BFN [Federal Office for Nature Preservation] and was completed in 1999; the report is available from BfN and covers:

- Investigation on sea bird populations in the German North Sea with respect to number of individuals and annual variations, feeding habits,
- development of a protection concept
- further need for research

<u>See- und Wasservögel in der deutschen Ostsee und ihr Schutz im Rahmen internationaler Vereinbarungen</u>
Additional ongoing study on sea bird populations, also undertaken by BfN for the German Baltic Sea.

<u>Erfassung und Bewertung ökologisch wertvoller Lebensräume in der Nordsee</u>
Identification, investigation and determination of potential areas for marine nature preservation (with respect to FFH-protected areas) in the German North Sea. An ongoing project also undertaken by BfN.

<u>Erfassung und Bewertung ökologisch wertvoller Lebensräume in der Ostsee</u>
Identification, investigation and determination of potential areas for marine nature preservation (with respect to Baltic Sea Protected Areas (BSPAs)) in the German Baltic Sea. Completed in 1999 and a report is available from the authors, BfN.

9.2 RECENT AND CURRENT PROJECTS

This section describes recent and current demonstration and full-scale commercial offshore wind farm projects. Many of the earlier projects have been accompanied by extensive measurement and analysis programmes, which are also described here.

Most of the existing projects are demonstration projects, with the exception of Middelgrunden wind farm, a 40 MW development three kilometres off the coast of Copenhagen, Denmark. Most of the planned projects are fully commercial enterprises.

Par. 9.2.1 gives a description on a national basis while par. 9.2.2. gives an EU summary.
Tables 9.2 and 9.3 (at the end of chapter 9) give details on current projects under development and tentative site explorations respectively.

9.2.1 Review per country

Belgium
The following offshore windfarms are planned in Belgium:
- Vlakte van de Raan - 100 MW wind farm 12-15 km from the coast , developed by Electrabel and Ondernemingen Jan De Nul. This project includes a 20 MW pilot phase
- Wenduinebank - 100 MW (50x2MW) wind farm 5 – 8 km from the coast , developed by C-power (Interelectra, Dredging International, and Turbowinds)

Denmark
Three offshore wind farms are already in operation in Denmark:

Name	Number of Blades	Diameter	Turbine Capacity	Number of OWEC's	Type of Foundation	Installation Method	Marinisation	Maintenance Access
Vindeby 2-6m WD 1.5-3km from shore	3	35m	450 kW	11	RC Gravity	Modified transport ship (base) Jack-up (tower)	Offshore paint system, sealed, recycled cooling air, dehumidified. Standby heating, Nacelle-mounted hydraulic cranes	Special boat
Tuno Knob 3-5m WD 6km from shore	3	39m	500 kW	10	RC Box Caisson Ore Filled	Modified barges Floating crane	NA	Special boat
Middelgrund 5-10m WD 2km from shore	3	76m	2MW	20	RC Gravity	Modified transport ship (base) Jack-up (tower)	Offshore paint system, sealed, recycled cooling air, dehumidified, standby heating. nacelle-mounted hydraulic cranes	Special boat

In addition, there are several at various stages of planning:
- Horns Rev 160 MW (under construction)
- Roedsand 150MW (under construction)
- Gedser 150 MW
- Omoe 150 MW
- Laesoe 150 MW
- Samso 25 MW (EIA study issued)

Measurements are being taken at the Middelgrunden Wind Farm to assess wind spectra around the towers and power output in relation to the placement of individual turbines within the wind farm. Forces in the towers and foundations under environmental loading will also be measured.

Finland

In Finland, offshore wind farms are planned for:

- un-named on small nearshore rock islands
- un-named 10-30MW 5km offshore 6-10m water depth

France

Currently, there are no existing offshore wind farms in France, however several are planned or at various stages of development, including at:

- Breedt,
- Dunkerque

Germany

The largest number of planned offshore wind farms are in Germany. Locations where wind farm developers have stated their intention for developing offshore wind farms include:

- Butendiek 80 x 3MW
- Dan-Tysk 300 x 5MW
- Nordsee AWZ 100-200 x 5MW
- Helgoland I and II
- Borkum Riffgrund 200 x 3-5MW
- Borkum Riffgrund West 458 x 2.5MW
- Borkum III 12 x 4-5MW
- Pommersche Bucht 200 x 5MW
- Arkona-Becken 172 x 4-5MW
- Adlergrund 69 x 3-5MW
- Nordergrunde 76 x 2.5-5MW
- Offshore Helgoland 100 x 2MW
- Schleswig-Holsteinische Nordsee 100-200 x 5MW
- Wilhelmshaven 2 x 4.5MW
- Mecklengburg-Vorpommern 20 x 2MW
- Sky 2000 50 x 2MW

Greece

In Greece, following the deregulation of the energy market in 2000, petitions for 4 LSOWE-plants with total installed capacity of ~500 MW are currently under consideration at the Regulatory Authority for Energy of the Ministry of Development.

Ireland

A number of offshore wind farms are also planned for Ireland, at [19], [24] & [25]:

- Kish Bank: 10km from shore, 200-250MW
- Bray Bank
- Arklow Bank: <10 m water depth, 10km from shore, 500+MW
- Blackwater Bank
- Codling Bank
- Greater Codling Bank

Italy

In Italy, there has been a feasibility study for out offshore wind farm at Ragusa.

The Netherlands

In the Netherlands, there are two offshore wind farms located in the inland fresh water IJsselmeer:

Name	Number of Blades	Diameter	Turbine Capacity	Number of OWEC's	Type of Foundation	Installation Method	Marinisation	Maintenance Access
Lely 5-10m WD 0.8km from A shore	2	40.8m	500kW	4	3.7m monopile		No	
Dronten 20m from shore		43.0m	600kW	28	monopile		No	

In addition, two further windfarms of planned:

- Q7 Sector 120 MW
- Egmont aan Zee 10 MW , the Nearshore Wind Farm in combination with an extensive RTD monitoring programme

Poland

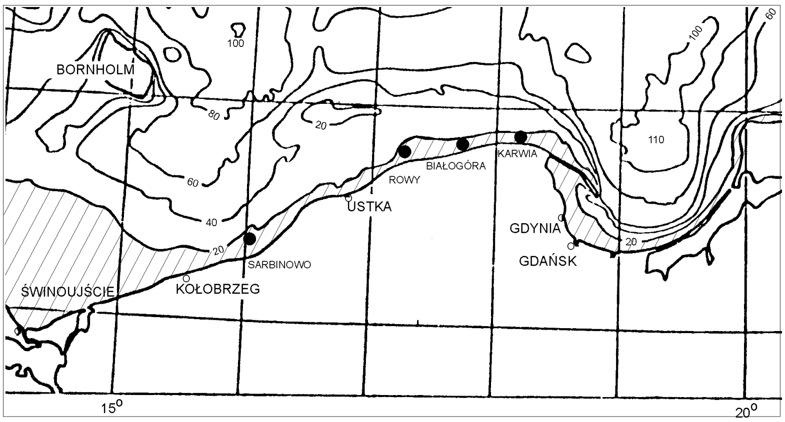
According to the Maritime Bureau, after exclusion of all restricted areas (birds, fishing, offshore exploitation), ca. 2 800 km^2 for development of offshore wind power is available in Poland, that is 8.5% of the Polish territorial waters. In the Gdansk Bay, the area where implementing wind turbines 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 costal banks at Wistula – and Szczecin Bays.

The Maritime Bureau in Gdynia has issued consents for two following offshore locations:

- 49-61 turbines of 2,0 MW near Białogóra. Project led by Nowa Energi
- 50 x 2 MW near Karwia (Dębki-Jastrzębia Góra). Project led by Wiatropol

At this moment there are two other pending applications at Słupsk Municipality, where Bałtyckie Elektrownie Wiatrowe S.A. (Baltic Windpower S.A.) request for permission near Sarbinowo, however no information has been cleared yet.

It can be assumed that all the locations referred to have at least pre-feasibility studies made, but nothing has been disclosed yet.



Source: Maritime Institute, 2000

Fig. 9.1: Locations for potential offshore wind power development on Polish territorial waters.

Sweden

Three offshore wind farms are currently operational in Sweden:

Name	Number of Blades	Diameter	Turbine Capacity	Number of OWEC's	Type of Foundation	Installation Method	Marinisation	Maintenance Access
Nogersund 5m WD 0.5km from shore	3	27m	220kW	1	Steel tripod	Submersible barge		Boat & ladder
Bockstigen-Valar 6-8m WD 4 km from shore	3	37m	500kW	5	2.15m drilled and grouted	Jack-up		
Utgrunden								

In addition, further offshore wind farms are planned at:

- Orestad
- Klasardenproject

A demonstration of the commercialisation potential (Valar 2, 5 MW)
This European funded demonstration projects was undertaken by Vindkompaniet under the Fourth Framework Programme, THERMIE project reference WE/00057/96 in 1996 and 1997.
Research will also be performed at the Klasardenproject; a 42MW development in Sweden planned for 2002 installation.

United Kingdom
There is one offshore wind farm in the United Kingdom off Blyth Harbour. Further information on this project can be obtained from www.blyth-offshore.co.uk: The Blyth offshore wind farm is a European- funded demonstration project undertaken by AMEC Border under the Fourth Framework Programme, THERMIE project reference WE/00208/95 between 1996 and 1999.

Name	Number of Blades	Diameter	Turbine Capacity	Number of OWEC's	Type of Foundation	Installation Method	Marinisation	Maintenance Access
Blythe Harbour, NE England5-11m WD 1km from shore	3	70m	2MW	2	3.7m drilled and grouted monopile	Jack-up		Boat & ladder

In addition, numerous offshore wind farms are planned (see figure 9.2) , including for:

- Barrow
- Burbo
- Cromer
- Gunfleet Sands
- Inner Dowsing
- Kentish Flats
- Lynn
- North Hoyle
- Rhyl Flats
- Scarweather Sands
- Scroby Sands
- Shell Flat
- Southport
- Teesside

Construction of the 37.5 MW Scroby Sands offshore wind farm, East Anglia, England
This European funded demonstration project is currently being undertaken by PowerGen Renewables under the Fourth Framework Programme, THERMIE project reference WE/00218/97 and is scheduled to be completed in 2003.

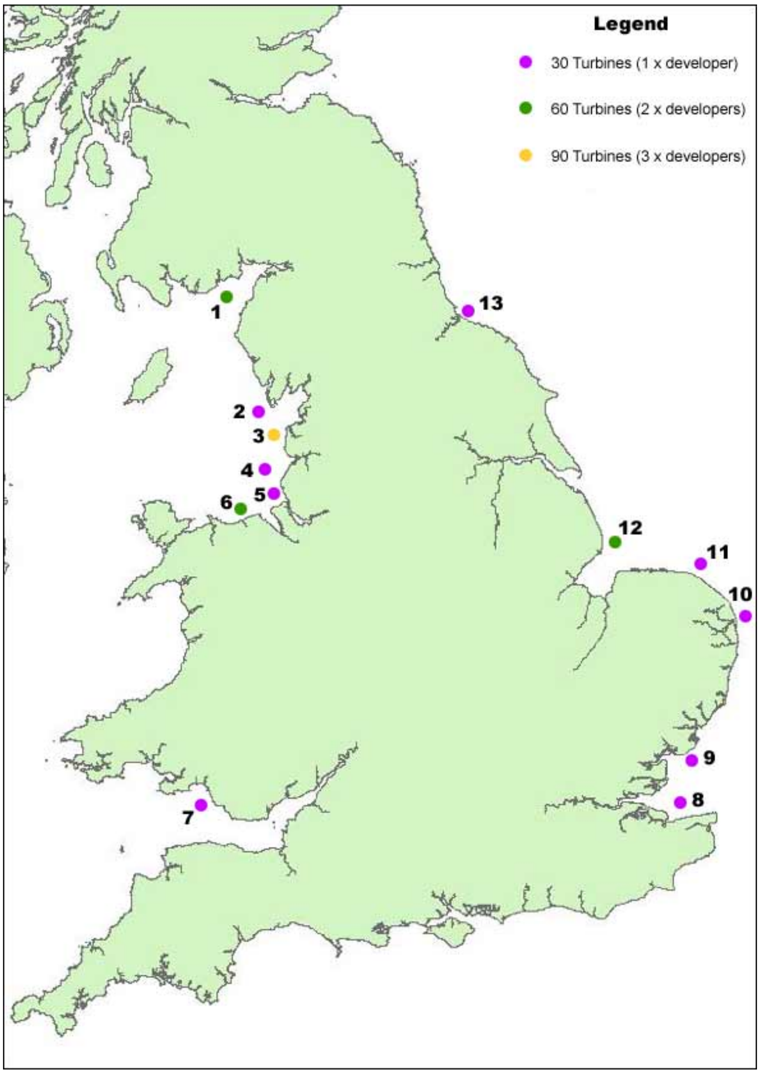


Figure 9.2 Potential offshore sites around the UK

As of April 5th 2001, according to a press release of the Crown Estate, 18 wind farm developers have successfully pre-qualified to obtain a lease of seabed in UK waters for the development of offshore wind farms. The net capacity of the sites in consideration is between 1000 and 1500 MW.

9.2.2 EU summary

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 [44], Opti-OWECS, [45], POWER [46], Cost-optimisation [47], Vindeby [48] and ENDOW [49].

Existing offshore wind farms which have been described in the previous section are summarised in figure 9.3.

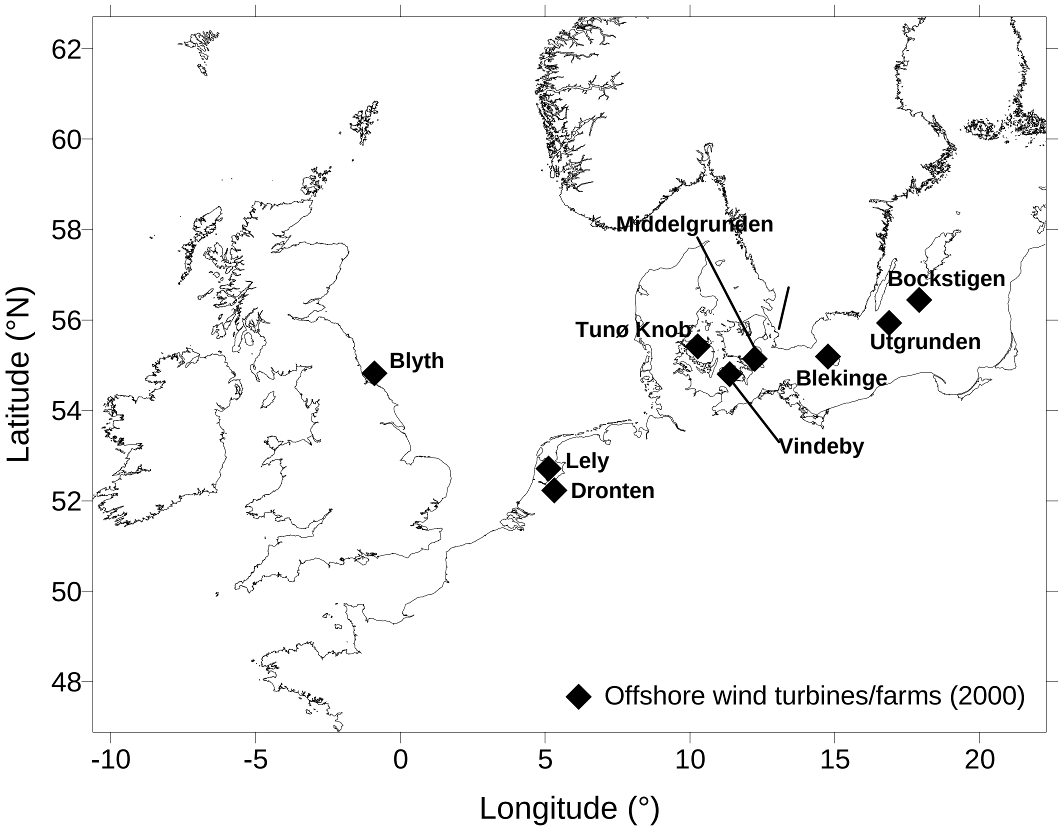


Figure 9.3: Current offshore wind farm developments in Europe (end of year 2000).

Figure 9.4 summarises current offshore wind farm projects under development, see also tables 9.2 and 9.3.
Note that detailed plans for Germany, the UK and Poland announced during spring/summer 2001 are not included

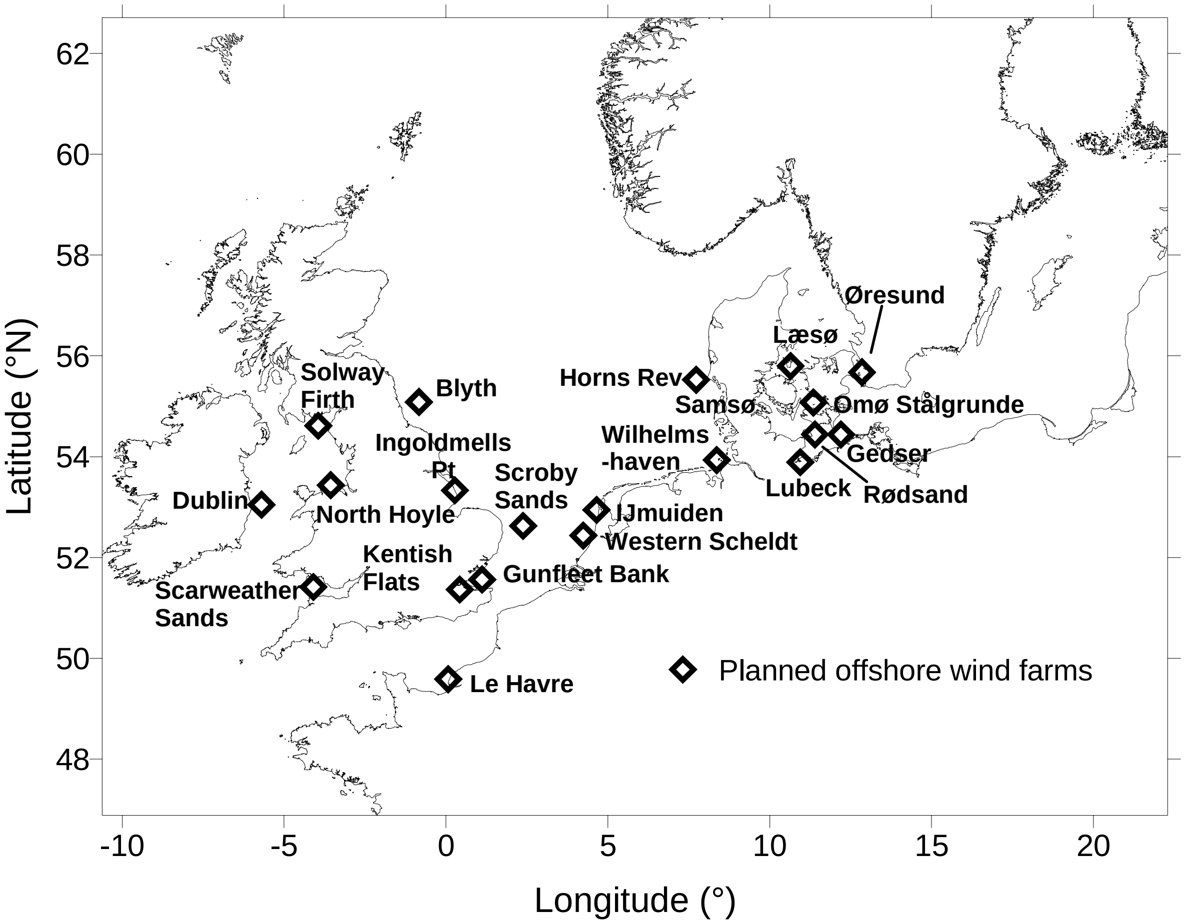


Figure 9.4. Planned offshore developments (2001 onwards)..

9.3 NATIONAL PLANS

This section summarises the various national plans that have been put forward by countries across Europe.

Belgium
Belgium's federal authorities have created a legal framework for granting concessions and authorisations for OWECS.

Denmark
Today, wind turbines produce 15% of Danish electricity consumption. Denmark has a 2030 target of 4,000 MW produced by offshore wind. This, together with other renewables, will cover 50% of the total electricity consumption. The first milestone is the establishment of 800 MW offshore wind farms by 2008. Of this 45 MW is already established (Middelgrunden, Vindeby and Tunoe Knob). The 160 MW Horns Rev and 150 MW Roedsand are under construction. [34]-[36]

Finland
The national energy strategy from 1997 mentions renewable energy to have significant role and wind energy to have a recognised role by 2025. The Action Plan for Renewable Energy Sources elaborated this, while recognising the Kyoto protocol on the reduction of emissions of greenhouse gases of 1997 and the EU White Paper endorsed by the Commission in 1997 and the Council in 1998, into a targets for renewable energy deployment.
The target is to increase the use of renewable energy sources at least by 50% (3 Mtoe/a) by the year 2010 from the level of the year 1995. 90% of this increase is expected to originate from of bioenergy, 3% from wind power, 3% from hydropower, 4% from heat pumps and less than 0.5% from solar power.

The share of renewable energy sources in power production would increase by 8.3 TWh (2010 MW) from the level in 1995. The major part, 75 %, would be generated from biofuels. Achieving the targets would reduce greenhouse gas emissions by about 7.7 million tonnes of CO_2 equivalent. The vision for 2025 is an addition of 100% (6 Mtoe) of renewable energy from the level in 1995, with biomass still dominating but already several per cents of the total electricity generated by wind.
The target for wind energy deployment is set to 500 MW in 2010 and a vision to 2000 MW in 2025. Thus wind energy production would reach 5 TWh/a in 2025, which is about 5% of the projected gross power consumption. http://www.vtt.fi/ene/results/renewable.htm

Action plan for Renewable energy resources in Finland, English translation, Ministry of Trade and Industry, Reports 1/2000. See also http://www.vtt.fi/ene/tuloksia/uusiutuvat/actionp.pdf

France
France has a target of 5,000MW to be generated by wind power in 2010.

Germany
In Germany there is no national plan in terms of installation figures, however the contribution of offshore wind energy use in the context of CO_2-reduction and sustainable energy supply policy are investigated in a national study on the "Further Use of Wind Energy with Respect to Climate Protection" [31]. Governmental objectives are set to cover 5-6% of the national net electricity consumption with wind generated electricity by 2010 and to reach a 50% renewable energy share of the national electricity demand by 2050 [17]. Germany's Renewable Energy Sources Act (EEG – Erneuerbare Energien Gesetz) [3] continues the reimbursement at a fixed feed-in tariff. In the reformed EEG a specially raised tariff is foreseen during the first nine years of operation of an offshore wind farm. This regulation is limited to projects coming online before the end of 2006.

Greece

The Greek government's policy is in line with EU energy policy regarding the penetration of RES in the energy market. [16] and [17]. The government is encouraging the large-scale installation of RES plants by means of subvention of capital investment, loan interest subsidies and tax-exemptions. The legislation also applies to offshore wind energy.

Ireland

Ireland has no specific targets or detailed national plans for offshore wind energy, but it is the main focus of policy targets for both maximising offshore resources and promoting renewable energy. 7 foreshore licenses have been awarded for site investigation and procedures for foreshore leases are in place. [18]-[24]

Italy

Italy has produced a 'White Paper for the valorisation of Renewable Energy Sources', which forecasts 2500MW of electricity produced from wind by 2008-12. However, it envisages that this would be mainly onshore. There is an initiative by the Ministry of Environment with Assomineraria to produce an agreement document for national waters. The Province of Ragusa, Sicily has issued a Call for Proposal and Assignment document. (in Italian)

Netherlands

Officially, the Netherlands target (Duurzame Energie in Opmars; Ministerie van Economische Zaken 1997) is 20% renewables by 2020, equivalent to 2759MW, of which 1250MW is from offshore wind, [25]. The government is expected to increase this targeted power quantity in the near future.

Poland

Poland has a strategy for Renewable Energy Development of 7.5% by 2010, [15]

Strategy aims to increase RES share in the total energy balance from the present 2,4% to 7,5% in the year 2010 and 14% by the year 2020. The document presents three scenarios of RES increase by the year 2010:

- 7,5% scenario,
- 9% scenario,
- 12,5% scenario.

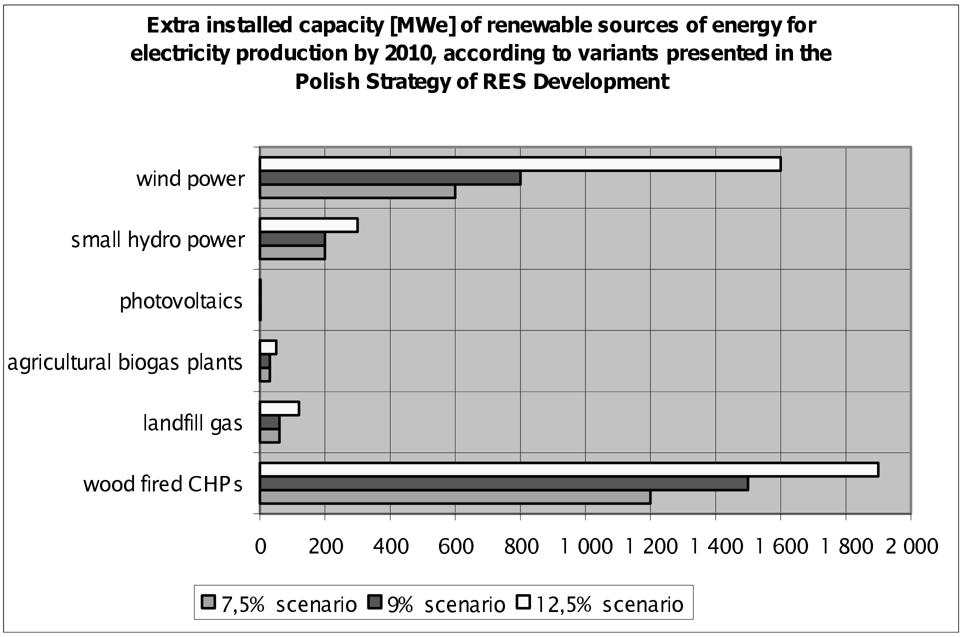


Figure 9.5: extra RES installed capacity according to the Polish RES Strategy

Spain
Spain has no national plans and has no specific incentives for OWECS.

Sweden
Sweden has no fixed target for offshore wind power, but it has been identified as a source of electricity generation that could replace nuclear, coal and oil. The state budget earmarks money for research and demonstrations in the field of offshore wind power. Many political and other groups are lobbying for offshore wind power and propose changing laws and regulations in favour of it. Some of the groups are developers and manufacturers with vested interests in promoting OWECS and some claims for future growth are considered unrealistic.

UK
The UK has now ended the Non-Fossil Fuel Obligation but is still providing support (between £60m - £80m this year) and has issued a consultation document on renewables [26]. The primary market is likely to be licensed UK electricity suppliers fulfilling their Renewable Energy Obligation commitments. Current estimates are for net revenue of around £0.05p per kWh. The national objective is to reduce greenhouse gas emissions by 12.5% from 1990 levels by 2010, to reduce CO_2 emissions by 20%, 5% of UK electricity from renewables by 2003 and 10% by 2010, with 2600MW offshore by 2010, [27] & [28]. The Crown Estate has pre-qualified and allocated Agreements for Lease for the first round of offshore sites to 18 developers for 13 sites [30].

European summary
Almost all Eropean countries with offshore wind resources have announced plans for development of the offshore resource. Key point can be summarised as in Table 9.... below.

Table 9.1 Offshore wind energy exploitation plans by country

country	Plans
BE	3% electricity from renewables. Offshore wind energy is not yet eligible for green certificates (under discussion).
DK	Government target set and plans for large scale developments in five areas mandated.
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.
GR	None publicly available
EI	Targets set. Measurements underway.
I	Discussion of 1000 MW target installation. Local feasibility studies.
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.
PL	Two wind farms of ~100 MW have consent near Bialogóra and near Karwia
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.

9.4 NATIONAL ACTIVITIES

9.4.1 National Organisations

Organisations that promote offshore wind energy are listed below by country.

Belgium
There are no national organisations that currently actively promote offshore wind energy in Belgium.

Denmark
- Dansk Vindmoelleforening (Association of Turbine owners in Denmark); www.dkvind.dk
- Vindmoelleindustrien (Danish Wind Turbine Manufactures Association); www.windpover.dk
- Energistyrelsen (Danish Energy Agency); http://www.ens.dk; Includes all official hearing papers like EIA Studies for new projects
- Energioplysningen (The National Danish Energy Information Centre); http://www.energioplysningen.dk
- Organisationen for Vedvarende Energi, OVE (Danish Organization for Renewable Energy); http://www.orgve.dk
- Forum for Energi- og Udvikling, FEU (Forum for Energy and Development, FED); www.energiudvikling.dk
- INFORCE (International Network for Sustainable Energy) ; http://www.inforse.dk

Finland
There is no specific organisation that support offshore wind energy but general information about wind energy is produced and distributed by
- Finnish Wind Energy Association; http://www.tuulivoimayhdistys.fi
- Vindkraftföreningen (Wind energy association of Swedish speakiong minority in Finland); http://www.vindkraftforeningen.fi
- Motiva, the Energy Information Centre for Energy Efficiency and Renewable Energy Sources. http://www.motiva.fi/english/index.html

France
- Syndicat des Energies Renouvalables
- L'Agence de l'Environnement et de la Maitrise de l'Energie, ADEME
- Conseil Regional Nord pas de Calais

Germany
- Greenpeace, Germany
- German Wind Energy Association, BWE
- German Association of Mechanical Engineering and Terotechnology (Manufacturer)

Greece
- CRES, Center for Renewable Energy Sources
- NTUA, National Technical University of Athens
- ΔΕΗ-ΔΕΜΕ; Division for RES of the Greek PPC.
- ELETAEN; Greek Association for the promotion of wind energy
- ELFORES; Greek association for the promotion of RES
- Greek Association of Investors in Wind Energy and RE

Ireland
- Irish Wind Energy Association recently set up a committee on offshore wind energy ('In the Wind')
- Irish Energy Centre has a Renewable Energy Information Office which provides info and advice on all forms of renewable energy. ('Energy Update Letter')

Italy
- Ministry of Environment
- Univ. of Bologna, Genova
- ATENA, ISES Italy, ANIV, A

Netherlands
- NEWIN,Nederlandsewindenergievereniging http://www.newin.tmfweb.nl/

Poland
- Wind Power Association
- Baltic Energy Conservation Agency (ewach@bape.ima.pl)
- EC BREC, (http://www.ibmer.waw.pl/ecbrec/)
- Elektrownie Wiatrowe S.A., (http://www.elektrownie-wiatrowe.org.pl)

Spain
There are no national organisations that currently actively promote offshore wind energy in Spain.

Sweden
- SVIF The Swedish Windpower association
- SERO The umbrella organisation for all small scale energy associations
- Fabrikantgruppen A new association for all OWEC manufacturers with a Swedish office.

UK
- EPSRC-OWEN
- BWEA (British Wind Energy Association)
- DTI/ETSU (Harwell)
- CADDETT/ETSU
- Greenpeace
- Parliamentary Renewable and Sustainable Energy Group
- CREA

Europe-wide
- EWEA (European Wind Energy Association)
- EREC (European Renewable Energy Council)

9.4.2 Media and Information

Sources of media and general information on offshore wind energy are listed below by country, followed by a section summarising the Europe-wide sources:

Belgium
There are no major sources of information on offshore wind energy in Belgium.

Denmark
Conferences
- Every year, a 2-day conference on the results of the Danish Wind RTD program (Danish Energy Agency). Proceedings only in Danish.

- *Wind Power in Denmark. Technology, Policies and Results* and can be found on the Internet at http://www.ens.dk/Publikationer/Wind_Power99.pdf
- The two leading journals in Danish are: *Naturlig Energi* www.naturlig-energi.dk and *Vindstyrke*: http://www.vindstyrke.dk/
- every year, the report: *The World Market Update* is published by BTM Consult www.btm.dk

Projects

- Middelgrunden Wind Farm; www.middelgrunden.dk
- Off shore Wind Farms in the Eastern part of Demark (SEAS, E2); www.seas.dk follow link to *vindkraft*
- Off shore Wind Farms in the Western part of Demark (Elsam); www.elsam.com follow link to *havmoeller*
- Proevestationen Risoe (Risoe national Laboratory, Wind department); http://www.risoe.dk/vea
- Energi- og Miljoedata (EMD); http://www.emd.dk

Finland

- Tuulensilmä, periodical published by Finish Wind Energy Association
- Vindögat, periodical published by Vindkraftföreningen

France

- French Wind Energy Conference (Narbonne December 2000)
- “Systemes Solaires”, a French magazine on renewables contains articles on wind power
- http://www.espace-eolien.fr/lille/Offshore/centrbreedt.htm

Germany

- DEWEK, German Wind Energy Conference 1998 & 2000
- Workshops on Offshore Windenergy Use within the national research project “Weiterer Ausbau der Windenergienutzung im Hinblick auf den Klimaschutz“, organised by Deutsches Windenergie-Institut, Wilhelmshaven,

Greece

- A number of national Conferences, symposia, seminars, exhibitions etc are organized each year by CRES and NTUA.

Ireland

- IWEA Autumn conference 2000 – Large scale wind development. Dealt with onshore and offshore wind energy. http://www.iwea.com/index.htm
- http://www.irish-energy.ie/reio.htm
- http://www.eirtricity.ie/eirtricity_ie/newsframeset.html
- http://www.powergenrenewables.com/harnessingoffshorewindpower.htm

Italy

- Ingegneria del Vento, SolarExpo -Verona
- ENEA reports, ISES Italy ,
- ENEA OWEMES conference proceedings

Netherlands

No national conferences but Dutch organisations tend to take full part in European conferences and activities.

- NEWIN organise regular seminars

Poland

- Annual meetings of Wind Power Association,
- International Seminar on Wind Power Onshore and Offshore, Sopot 15-17 December 2000

- National seminar on implementation of wind energy, Kołobrzeg , *March* 1999
- Wind Power; Energy, Power, Environment; Przegląd Komunalny, Rynek Instalacyjny bape@ima.pl

Spain
There are no major sources of information on offshore wind energy in Spain.

Sweden
A two days wind power conference supported by state money is held every second year. The last "Vind 2000" was very much focused on offshore wind power.
There are several commercial websites constructed by developers. Two uncommercial sites are:

- Vindkraft. Nu: a site with lots of general information about the national wind power development and
- Windpowerphotos.com: images from OWES and also onshore-based with focus on the beauty of wind power in nature.

UK
Conferences and seminars

- BWEA Annual Conference
- BWEA Offshore Briefing meetings for members
- Occasional ETSU workshops
- ESPRC Offshore Wind Energy Network (OWEN) special topic meetings

Internet sites

- www.blyth-offshore.co.uk
- www.bwea.com

Europe wide
Conferences / seminars / Trade Fairs

- World Renewable Energy Congress
- EWEA conferences
- Sustain trade- fair, held every two years at the RAI. Amsterdam, last one in 2001; promoted 'Campaign for Take Off', an initiative to promote all forms of renewable energy. One of its targets is 10000MW of electricity generated by wind power by 2003.

Journals and magazines

- WindDirections (monthly magazine of EWEA and BWEA)
- WindPower Monthly, www.wpm.co.nz
- WindStats Newsletter www.gridwise.com/windstats
- Renewable Energy World

9.4.3 Research and Education

Organisations active in research including offshore wind energy topics and opportunities for education in the subject are listed below by country.

Belgium
There is limited academic research and education about wind energy and none on off-shore wind energy specifically.

Denmark
The main research organisation is

- Proevestationen Risoe (Risoe National Laboratory, Wind Department); http://www.risoe.dk/vea;

Wind research activities are included in the overall research activities at the Technical Universities and Engineering Colleges.
No special offshore wind energy courses have been established until now but wind education courses are included in the different courses at:

- Technical Universities in Copenhagen
- Aalborg
- other Engineering Colleges.

M.Sc. and Ph.D. degrees can be obtained in accordance with the general Danish education system: You have to find a specific scientific subject, an RTD institution or Company who is working within or close to the specific subject and supporting your specific proposal. There after you have to ask for approval at the institution and apply for a grant if needed

Finland

- VTT Energy; R&D:
- Finnish Met. Inst.; R&D:
- Helsinki University of Technology; master's course – not offshore specific

France
There is a research group in Nord pas de Calais
University studies on the impact on the seabed, Institut Francais de Recherche pour l'Exploitation de la Mer, IFREMER

Germany
46 institutions are concerned with use of wind energy; details can be found in the "Directory of German Wind Energy 1998"
Short Courses are organised by:

- Deutsches Windenergie Institut GmbH
- BWE

And workshops, including by BfN**:**

- Workshop "Technische Eingriffe in marine Lebensräume
- Workshop "Technical Impacts in Marine Habitats", State of the art summary on environmental impacts of offshore wind energy use – held 1999 (report avaoilable from BfN)

Greece
Research conducted in Greek Universities and Research Institutes covers the entire field of RES (wind energy, solar energy, biomass, geothermal, wave energy etc). As regards wind energy-offshore wind energy research is mainly conducted at:

- CRES,
- NTUA
- University of Patras

Most Technical Universities, technical educational Institutions etc have integrated degree and postgraduate courses on RES in their programmes.
The Department for education of CRES is organizing annual educational courses and seminars on several fields of RES

Ireland

- University College Cork – wind energy forecasting, wind energy policy, market incentives, wind energy storage, energy trends. Recently developed renewable energy course materials with CREST (UK) and TUD (NL) in the context of an ALTENER funded project.
- University College Dublin – wind energy resource assessment

Italy

- University of Bologna,
- University of Genova ,

- University of Rome

Netherlands

- Technical University of Delft; wind energy research is spread across several faculties, and co-operate under the interfaculty group Duwind. A total of about 40 people work full or part time in wind energy . The members are:
    - Section Wind Energy
    - Offshore Technology
    - Wind Turbine Materials & Construction Group (all in Faculty of Civil Engineering and Geosciences)
    - Electrical Power Processing
    - Electrical Power Systems (both in the Faculty of Information Technology and Systems)
    - Production Engineering & Industrial Organisation
    - Systems & Control Group (both in the Faculty of Design, Engineering and Production)
    - Flight Mechanics and Propulsion (Faculty of Aerospace Engineering)
- Energieonderzoek Centrum Nederland (ECN); Wind energy research is undertaken in the section *Wind Energy Unit*, where about 45 people work full-time on wind energy research and commercial projects.

Students at TUDelft are able to take wind energy modules as part of their degree course. In addition, various external short-courses are offered by both TUDelft and ECN

Poland

- Akademia Górniczo-Hutnicza, Kraków

Spain

- Polytechnic University of Madrid, Departamento de Energética y Fluidomecánica

Sweden

- VKK
- Kortkurserna på Högskolan i Visby

UK

There are research groups active and educational opportunities in offshore wind energy at the following institutes:

- City University Wind Energy Research Group
- Oxford University Wind Energy Research Group
- CRES Loughborough University Wind Power Short Course; MSc Renewable Energy
- De Montfort University Wind Energy Training Course
- University of Reading Energy Group
- University of York
- Energy Studies Unit, Strathclyde

In addition, there are wind energy modules in many undergraduate courses

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Table 9.2 Planned wind farms (Spring 2001):

Name	Turbines	Total MW	Year	Comments
Klasården	21 NEG MICON 2 MW	42	2001?	Gotland
Horns Rev, DK	80 Vestas 2 MW	160	2002	
Rødsand, DK	72 Bonus 2.1-2.2MW	151-158	2002	
Q7-WP, NL	Vestas	120	2002	> 12 miles
Breedt, FR		7.5	2002?	
Læsø Syd, DK		150	2003	
Nearshore Wind Farm, Egmond aan Zee, NL		100	2003	Receives subsidy of max. NLG 60 m for RTD programme
Omø Stålgrunde, DK		150	2004	
Gedser, DK		150	2006	10 km to coast, licence granted for monitoring Sep. 2000. ~ 27% more investment than onshore
Arklow Bank, EI		500		
Kish Bank, EI		250		Öresund
Lillegrund, SE	48 Enercon 1.5 MW	72		Public hearing June 1999. Tenders issued November 2001.
Samsø	10 2MW	20		
Total		1513		

* 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 .

Table 9.3 Tentative site exploration (Spring 2001).

Name	Total MW	Year	Comments
Knokke, BE	100	2002 or later	12-15 km from coast
Wenduine	100	2002 or later	5-11 km from coast
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 8.5 km from shore. Preliminary consents for 60 turbines[1]
Barrow, UK			10 km from shore Off Walney Island, Cumbria. Preliminary consents for 30 turbines[1]
Shell Flat, Uk			Off Cleveleys, Lancashire, 7 km from shore. Preliminary consents for 90 turbines[1]
Southport, UK			Off Birkdale Merseyside, 10 km from shore. Preliminary consents for 30 turbines[1]
Burbo, UK			Off Crsoby, Merseyside 5.2 km from shore. Preliminary consents for 30 turbines[1]
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.
Scarweather Sands, UK		2004-2005	Off Porthcawl, South Wales, 9.5 km from shore.

			Preliminary consents for 30 turbines[1]. Developers are United Utilities .
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.
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.
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 2MW turbines.
Cromer, UK			Off Foulness, Norfolk, 6.5 km from shore. Preliminary consents for 30 turbines[1]
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.
Teeside, UK			Off NE Teesmouth, Middelsborough, 1.5 km from shore. Preliminary consents for 30 turbines[1]

[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).

CHAPTER 10

RTD RECOMMENDATIONS

SUMMARY

The objective of this chapter is to identify RTD requirements and to develop recommendations for an RTD strategy for development of offshore wind energy.
Based on the information collated as part of the Concerted Action, the project team has attempted to identify the key problem areas, which affect the future development of offshore wind energy

Particular issues, which have been addressed when drawing up the recommendations for an appropriate RTD strategy, include the following:

- Offshore technology with consideration of RTD requirements relating to wind turbine design, support structure and foundation design, installation and de-commissioning, O&M and reliability, electrical transmission and grid reliability;
- Grid integration and energy supply;
- Resource and economics;
- Recent and current activities and prospects;
- Social, political and environmental aspects.

Recommendations have been formulated for a programme of RTD, which is aimed at providing solutions to these problems.
The overall aim of the work has been to provide directives on the research requirements for offshore wind energy applications within the next five years. This chapter will present those directives and invite feedback from wind turbine manufacturers, project developers, financiers, government authorities, politicians and other interested parties.

CONTENTS OF CHAPTER 10 : RTD RECOMMENDATIONS

10.1 INTRODUCTION

The objective of the project Concerted Action on Offshore Wind Energy in Europe [CA-OWEE] has been to define the current state of the art of offshore wind energy in Europe. This has been achieved by the gathering and evaluation of information from across Europe, and the subsequent dissemination of the resulting knowledge to all interested parties.

Based on the information collated as part of the Concerted Action, the project team has attempted to identify the key problem areas which affect the future development of offshore wind energy. These problem areas include technology development, integration in the energy supply system, economics, public acceptance, environmental impact and the relation between onshore and offshore wind energy. Building on this work, recommendations have been formulated for a Research and Technological Development (RTD) strategy which is aimed at providing solutions to these problems.

The RTD strategy, which is presented below follows the same thematic format as the information-gathering exercise which preceded it. The offshore wind energy industry has been considered under the following categories and sub-categories:

1) Offshore technology
    - Design
    - Installation and decommissioning
    - Operation and maintenance / reliability
2) Grid integration and electrical transmission
3) Social, political and environmental issues
4) Recent and current activities
5) Resources and economics

Annexed to this chapter is a table with the key RTD actions identified by the project members. Also given in the table is a ranking in terms of the timescale on which progress must be made and the importance of that RTD action for the progression of the industry.

A summary of the table is presented in the following sections.

10.2 OFFSHORE TECHNOLOGY

Design

The highest RTD priority relating to offshore technology is to gain further improved understanding of the behaviour of dynamically active wind turbine support structures subject to combined wind and shallow water wave loading (including breaking waves). Through the development of appropriate predictive methodology, the effects on fatigue and extreme design loads of wind, waves and seabed geotechnical characteristics should be advanced. Research is therefore required in order to characterise offshore environmental conditions, define appropriate design criteria, and develop reliable computer models of offshore wind turbines. A review of safety factors employed for optimal structural design should also be made a RTD priority. There is an immediate requirement for dissemination of experience gained from a decade of European offshore wind farm operation, the execution of detailed measurement programmes, and best practice guidelines drawn up to assist future developments.

In the short term with highest priority, inherent design for improved reliability and installation expediency must be addressed. The logistical difficulties presented by locating turbines offshore imply a much improved reliability requirement be placed on offshore specific wind turbine variants, reliability levels which must exceed those currently displayed on onshore wind farms. Manufacturers involved in offshore wind are currently addressing a fuller understanding of the effects of a maritime climate on wind turbines, and results are awaited for recently introduced technological improvements.

The cost of installation is an inherent economic problem to the viability of an offshore wind farm mainly due to the weather constraints and type of equipment required. Traditionally, floating cranes and jack-up barges have and continue to be utilized by offshore wind farm developers, equipment which in general has been developed and coated for oil and gas exploitation. There must be concerted action to eliminate the need for expensive vessels to be employed at installation and major component change-out. Consideration must also be given to the loads experienced by large wind turbine components during transportation and erection at sea.

The best-practice approach to support structure design continues to be a medium term goal, with consideration of installation for increasingly arduous site conditions.

In the medium term with highest priority, component development particularly with the mandate to improved reliability and maintainability becomes a feature. Aero elastic and structural design of rotor blades must evolve with the continued preference for larger and higher performance wind turbine units.

Within this timescale with less urgency, the goals for optimal structural design and design for reliability and maintainability come to the fore. As the wind power industry evolves, the development of standards relating to wind turbine design is bound to mature in proportion. The standards currently being developed by bodies such as the IEC should be extended to include all aspects of offshore wind turbine design. The development and validation of such standards is important because the lack of reliable and commonly accepted design guidelines has the effect of reducing the level of confidence with which offshore wind projects can be financed and implemented.

Optimal structural design will focus on recurrent wind turbine aspects such as reduction of fatigue loading by introduction of inherent flexibility, and more sophisticated control as examples. More particularly, the features of offshore environment will drive closer attention to issues such as wave induced tower vibrations, ice loading, and positive aspects such as allowance of higher blade tip velocities.

Design for reliability and reduction of scheduled and unplanned maintenance will include obvious topics for improvement such as enhanced corrosion and lightening strike protection and reduction in overall number of components. More ambitious plans include the modular design of turbines to facilitate change-out and installation, and justification for the introduction of redundancy at component and turbine level.

Finally within this priority category, the conceptual design of large wind turbines and wind farms should be explored for technological and commercial viability.

Efforts over the next five year period with low urgency shall focus on innovative and evolutionary design of structures and alternative rotor blade numbers and hub configuration, namely the reduction in blade number to two coupled with the elimination of a teetering mechanism.

Long term goals for offshore technology will address siting structures in remoter/deeper water and may include support structure rationalisation methods such as multi-rotor. With the advancement in tidal stream turbine and wave technology, there may be scope for combined wind/wave structural innovation mounted on support structures which have life-ratings well above the energy capturing devices that mount them to facilitate re-use.

Research into the engineering and economic feasibility of floating wind turbine systems for deep water sites should also be considered as a long term objective.

Installation and Decommissioning

The highest priority in the short-term for installation and decommissioning is firstly to improve dissemination of knowledge from offshore and marine related construction procedures and techniques. The oil and gas industry has over thirty years of offshore experience in European waters, and inshore construction specialists have been in operation for many hundreds of years. Secondly, due to the cost of offshore operations, number and time of offshore operations must be reduced by improvements in installation techniques and more efficient planning. Finally, the rationalisation of offshore lifting operations must be addressed to reduce cost of hiring expensive lifting barges.

Also in the immediate term, occupational health and safety standards and procedures should be developed in line with the rapid development of offshore wind farms. While there is no need to constrain the wind power industry to the same levels of safety required for offshore oil and gas exploitation, the working practices applicable to offshore are far more life threatening than the equivalent onshore practices.

In the medium term, to allow offshore working a wider weather window, installation methodologies should be made less sensitive to wind/wave conditions. The development of erection techniques may be subject to review where more assembly operations are conducted onshore prior to transportation to site.

Within the next five years but with lesser priority is to consider decommissioning requirements at conceptual design and build-in features which will assist at the inevitable later stages.

Operation and Maintenance

The highest priority in the short-term for operation and maintenance is the safety of personnel who are required to visit offshore turbines throughout the year. The responsible party must provide safe access through procedure and adequate equipment. Another top priority task issue is to facilitate the remote control access of turbine control systems in order to investigate, rectify and re-set trips where possible.

A related priority is the development of mooring systems which provide safe access to personnel alighting from a vessel and disembarking from a turbine access platform. The development of operation and maintenance models should continue, particularly taking cognisance of operational data and experience, providing input data when choosing a suitable site specific maintenance strategy.

In the medium term, the development of inexpensive purpose-built vessels should be considered. Future offshore wind farms may be large enough to justify the purchase of a dedicated vessel for installation, O & M, and decommissioning activities. With recent advancements in SCADA technology, condition monitoring of components which are susceptible to wear and failure must be explored to reduce the cost and requirement for site visits. Innovative maintenance strategies should be explored in conjunction with the development of O&M models.

10.3 GRID INTEGRATION & ELECTRICAL TRANSMISSION

The highest priority attached to grid integration and electrical transmission is to develop wind turbine generator models for dynamic grid simulation. In particular the characteristics of variable speed machines coupled to mechanical dynamics should be modelled.

Of lesser urgency is the requirement to explore HVDC multiple (up to 35kV) and single grid (up to 200kV) link designs, the effect of LSOWE projects on grid operation.

In the medium term, there should be the development of HVDC converter stations, cabling and associated infrastructure. A fundamental stumbling block to further advances in offshore wind exploitation is the scarcity of suitable existing points of grid connection and grid fragility. A study of the relationship between technical-economical offshore wind energy potential and the cost of providing adequate grid reinforcement is required.

Of lesser priority in this timescale, is the requirement to eliminate offshore transformers by either generation at high voltage or offshore substation development. Wind turbines can be used to assist grid control in terms of power factor and voltage control, and the cost associated with the development of this ability should be explored. The availability statistics of a wind farm are affected by grid faults, and there is merit in developing turbines which can withstand transient external faults without consequential disconnection from the network.

Efforts over the next five years with lower priority should focus on socially acceptable methods for apportioning the grid integration cost of offshore wind farms from energy provider to energy user. A study is required to address whether the existing safety distances between subsea cables can be reduced.

Long term goals for grid integration and electrical transmission issues include wind farm control using centralised converters, and finding suitable methods for power storage.

10.4 SOCIAL, POLITICAL AND ENVIRONMENTAL ISSUES

Stated objections to wind farms widely vary depending on country, population, spheres of influence, demographic structure, etc, etc. A current priority is to look at air safety particularly with regards to alleged disturbance of radar caused by wind turbines.

The environmental impact particularly at the construction stage of an offshore wind farm requires careful assessment, and mitigating measures implemented to reduce the effects on natural surroundings, e.g. piling effects on marine life. There is a need for ongoing studies identifying sensitive and protected areas which are not suitable for development.

In the short term with less priority, validation of predicted visual assessment must be carried out to ascertain the accuracy of models in varying weather conditions.

In the medium term, environmental impact data from existing offshore wind farms should be disseminated and appraised for future developments. Clearer definition and standardisation of marking requirements may negate conflict from the shipping industry.

Within the next five years but of less priority is the need for improved public relations to counter the often ill-informed views of national populations. This task may be assisted by a willingness to share information through visitor centres for example, and involve local populations throughout the development process.

The biological impact of developments as affecting bird, mammal and marine life must be assessed, and every measure taken to protect and enhance where possible natural habitats. The effect of acoustic and electromagnetic noise emissions must be studied and mitigation measures incorporated in wind turbine and wind farm design.

10.5 RECENT AND CURRENT ACTIVITIES

There is an immediate need for a database of information on existing operational offshore projects and research work.

In the medium term the owners of early offshore wind farm projects should be actively encouraged to freely disseminate and evaluate them with a view to steering future projects.

The potential benefits to employment and benefits to European industrial development should continue to be assessed.

10.6 RESOURCES AND ECONOMICS

Immediate priority is to be given to enhancing weather forecasting methods in order to gain imminent wind energy production several days in advance. Evaluation and prediction of wave effects and turbulence on power output of large wind farms needs addressing. There is also an immediate requirement for development of risk assessment techniques and quantifying uncertainty in energy yield estimates.

In the medium term, development and validation of models assessing inshore joint wind/wave and wave induced current simulations is required. Wind data collection methodology should be improved to provide valuable reliable data at a reasonable cost. There is a need for concerted European and national wind monitoring programmes.

On a lesser priority rating, there may be a requirement for finding test sites which exhibit benign to extreme offshore wind conditions while providing easy access, e.g. small islands with a causeway.

table 10.1: CA-OWEE RTD Strategy Framework

CA-OWEE cluster	group	Topic	Timescale (years)	Importance		
				L	M	H
Offshore Technology	Design: Size and configuration:	Conceptual design of large wind turbines and wind farms (e.g. unit power rating greater than 5MW with rotors greater than 100m diameter, wind farm rating several hundred MW)	5			
		Alternative rotor blade numbers and hub configuration	5			
		Research into multi-rotor systems	10			
		Combined wind/wave/tidal energy devices	10			
	design: Power performance improvement:	Higher blade tip velocities	. 5			
		Work to establish whether the different conditions offshore (particularly turbulence) affect the pros and cons of variable speed.	2			
	Optimal structural design:	Better definition of design criteria and extreme wind/wave recurrence periods for inshore waters	2			
		Development and validation of models for reliable prediction of fatigue and extreme loads	2			
		Assess reliability of existing spectral wave models	2			
		Assess importance of wave-driven fatigue on offshore wind structures	5			
		Development of standards	5			
		Aeroelastic and structural design of large rotor blades	5			
		Measurement campaigns on early projects	2			
		Review of safety factors	2			
		Reduction of fatigue loading by introduction of inherent flexibility, e.g. flexible towers, compliant couplings, etc.	5			
		Reduction of fatigue loading through more sophisticated control. (Benefits of greater sophistication to be balanced against potential reliability problems.)	5			
	Design for reliability and maintainability:	Improve corrosion protection systems	5			
		Reduction of need for floating cranes by development of internal cranage capability for lifting all, including largest, components	2			

		Controlled nacelle environments	2			
		Enhanced lightning protection systems	5			
		Reduction in overall number of components (e.g. new drivetrain concepts - Windformer, Aerodyn Multiwind, permanent magnet generators)	5			
		Develop low maintenance/high reliability components	5			
		Building in redundancy	5			
		Modular design approach to facilitate changeouts	5			
	Design for installation:	Consideration of transport and installation loads	2			
		Sectional components to facilitate ease of transportation and lifting	5			
	Support structure and tower	Investigation of breaking waves, shallow water effects and resulting loads.	2			
		Development & validation of metocean prediction models	5			
		Further research on geotechnics of inshore waters - improve understanding of the interaction of seabed/soil characteristics with system dynamics - sensitivity of resonant frequencies, fatigue loading etc.	2			
		'Smart tower' which can alter natural frequencies	5			
		Better prediction of loading of various foundation configurations - validation through measurement programmes	2			
		Decision as to whether components (namely turbine and support structure) are treated in an integrated way during design, reducing conservatism.	2			
		Design for future re-use	10			
		Research into ice loading, support structure design to deal with ice	5			
		Optimal design of interface between tower and support	5			
		Innovative and evolutionary design of structures	5			
		Design for deeper waters including floating systems.	10			
	Installation and decommissioning	Improved dissemination of knowledge of offshore marine related construction procedures and techniques amongst designers/developers	2			
		Reduce sensitivity to wave / wind conditions	5			
		Reduce time for offshore working	2			
		Minimisation of offshore lifting operations	2			
		Control costs of overall installation process	2			
		Design for decommissioning	5			

		Occupational health & safety standards to be reviewed for offshore work 2 Medium	2			
		Optimise the cost-effectiveness of offshore wind structure installation operations by making use of novel construction sequences and scenarios 5 Medium	5			
	O&M/reliability	Development of mooring systems 2 Medium	2			
		Safety of personnel 2 High	2			
		Remote control facilities to allow manual over-ride of turbine control system from an onshore base 2 High	2			
		Development of O&M models 2 Medium	2			
		Development of purpose built jack-up barges, floating barges and landing craft 5 High	5			
		Develop condition monitoring via SCADA systems (enhanced capability, 2 from 3 decision-making, improved reliability) 5 High	5			
		Develop and analyse innovative maintenance strategies	5			
Grid integration and electrical transmission	Electrical transmission & grid connection	High voltage grid link designs, e.g.; multiple medium voltage links (up to 35 kV), single high-voltage link (100 to 200 kV), and HVDC	2			
		Offshore substation design development	5			
		Development of methods to allow LSOWE plants to withstand transient external faults without disconnecting from the network	5			
		Develop offshore converter designs (optimisation of power factor and voltage control)	5			
		Wind farm control (e.g. centralised converter)	10			
		Development of HVDC converter stations, cabling and insulation	5			
		Development of methods to decrease currently required safety distances between sea cables	5			
		Elimination of offshore transformers, generation at high voltage (AC or DC)	5			
		Power storage systems development and cost reduction	10			
	Grid Integration & Energy Supply	Evaluation of effect of early LSOWE projects on grid operation	2			
		System analysis based on future LSOWE plans, taking account of spatial correlation of supply, existing system characteristics, future plans for cross-border links, etc.	5			
		Analysis of the economical effect (cost) of requiring LSOWE plants to contribute to primary and secondary control	5			

		Evaluate feasibility of demand-side measures to accept high penetrations of LSOWE	5			
		Harmonization of electrical protection and reactive power requirements	5			
		Study of the impact of grid limitations on offshore wind energy potential ; study of the relationship between technical-economical off-shore wind energy potential and cost of required grid reinforcements	5			
		Development of suitable wind turbine (generator) models for dynamic grid simulation codes (in particular for variable speed wind turbines, and including mechanical dynamics)	2			
		Analysis of the effect on the transmission grid (at local, national, and international scale), including additional network costs and benefits, to accept offshore wind farms at high wind penetrations.	5			
		Research in support of finding a socially acceptable way of allocating the system cost created by LSOWE (grid reinforcement, priority access, increase control requirements for conventional plants, …) to the different stake-holders (LSOWE project owners, all generators, all customers, all tax-payers)	5			
Resources & Economics	Wind resource	Development of forecasting methods for wind energy production up to several days ahead	2			
		Improvements in methods for estimating wind resource in coastal areas, Mean wind speeds	2			
		Vertical wind speed and turbulence profile	2			
		Development & validation of inshore joint wind/wave simulations	5			
		Provide tests sites with suitable offshore conditions, e.g. small islands	5			
		Evaluation and prediction of wake effects and turbulence on power output of large wind farms	2			
		European and national wind monitoring programmes	5			
		Quantify uncertainty in energy yield estimates	2			
	Economics	Cost reduction and reliability improvement for methods for offshore wind data collection	5			
		Generic evaluation of LSOWE investment costs taking into account cost influencing factors (distance from shore, water depth, wind and wave climate, soil conditions, …)	5			
		Risk assessment (construction cost, delay risk, energy production, operating costs, availability)	2			
		Joint wind/wave loading on short time scales for weather forecasting, power output and improved maintenance scheduling	2			
Recent & Current Activities & Prospects	Experiences	Database of information on existing operational offshore projects and research work	2			
		Develop standards for offshore wind industry	5			
		Systematic evaluation of the results of test and demonstration projects	5			
	benefits	Benefits to employment	5			
		Benefits to European industrial development	5			
Social, Political	general	Baseline and impact studies from individual projects to be disseminated and jointly appraised	5			

& Environmental Aspects : Biological impacts:	Birds	Layout design to accommodate flight paths, where these are defined.	5			
	Sea mammals	Avoidance of sensitive habitats	5			
		Minimisation of atmospheric and subsea noise levels during construction and operation	5			
		Study effect of electromagnetic fields	5			
	Fish	Manage public awareness of "stunned" fish during construction (pile driving)	2			
		Minimise effect of structures and cabling on stocks	5			
	Seabed fauna:	Study effect of electromagnetic fields	5			
		Investigate value of local measures to enhance	5			
Social, Political & Environmental Aspects : Other Impacts	Hydrography, currents and water quality	Investigation of appropriate foundation design	5			
		Guidelines for site works	5			
	Visual:	Early assessment taking account of distance from shore and nature of viewpoints	2			
		Validation of visual assessment	2			
		Promotion of openness and local involvement	5			
	Noise:	Ongoing PR work to counter poor publicity	5			
		Maintain good standards of noise emission despite increases in turbine size and tip speed	5			
Social, Political & Environmental Aspects : Conflicts of interest:	Ship Traffic	Clearer definition of marking requirements	5			
		Collation of collision risk analyses	5			
	Air traffic:	Safety of civil air traffic	2			
		Safety of air traffic related to project	2			
	Defence:	Studies of disturbance to radar	2			
		Safety of air crew training	2			
	Fish, bird and other groups:	Identification and avoidance of sensitive areas	2			
		Avoidance of site works during sensitive time periods	2			

APPENDIX 1

CA-OWEE DETAILS

The CA-OWEE project

The project "Concerted Action on Offshore Wind Energy in Europe" is funded by the European Commission through contract NNE5-1999-00562 and as part of the FP5 Programme. This one-and-a-half year long project started at the end of June 2000 is being led by the Institute of Wind Energy at the Technology University of Delft. It includes partners from 13 different countries and from a wide range of fields of the offshore wind energy community, including developers, consultants, research institutes and universities. The partners are:

- Institute of Wind Energy, Technology University of Delft, The Netherlands
- Garrad Hassan & Partners, United Kingdom
- Kvaerner Oil & Gas, United Kingdom
- Energi & Miljoe Undersoegelser (EMU), Denmark
- Risø National Laboratory, Denmark
- Tractebel Energy Engineering, Belgium
- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spain
- Centre for Renewable Energy Sources (CRES), Greece
- Deutsches Windenergie-Institut (DEWI), Germany
- Germanischer Lloyd, Germany
- Netherlands Energy Research Foundation (ECN), The Netherlands
- Espace Eolien Developpement (EED), France
- Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA), Italy
- University College Cork, Ireland
- Vindkompaniet i Hemse AB, Sweden
- Technical Research Centre of Finland (VTT), Finland
- Baltic Energy Conservation Agency (BAPE), Poland

The project aims to gather and distribute knowledge on all aspects of offshore wind energy, divided into the five following broad working groups or "clusters":

1) offshore technology,
2) grid integration, energy supply & financing,
3) resources & economics,
4) activities & prospects,
5) social acceptance, environmental impact & politics.

For operational reasons and in order to keep the number of working groups limited, different subjects had to be combined in a single cluster. Each cluster was led by a task leader (Principal Contractor) which was assisted by a selection of the other partners. The table at the end of this Appendix gives the distribution of partners over the 5 clusters.
Overall management and co-ordination was performed by Andrew Henderson of Technical University of Delft.

Cluster task set-up and distribution

In most clusters, the work was organised by the task leader (principal contractor). Data on subjects was collected through literature search and through national questionnaires from all partners. Cluster members participated in drafting the reports.

For cluster 1 a different approach was followed than for the other clusters. Here it was decided that a trans-national approach rather than a country-by-country survey was more appropriate in view of the nature of the subject matter. Tasks were shared as follows:

- Garrad Hassan and Partners – work package co-ordinator and electrical transmission and grid connection
- ENEA – size and configuration of wind turbines
- Kvaerner Oil and Gas – support structure
- Germanischer Lloyd WindEnergie GmbH - standards
- VTT – installation and decommissioning
- Vindkompaniet – O&M

GH circulated a list of contents for the "state-of-the-art" summary in each of the above technical areas, with comments elaborating requirements, to form the basis of a draft report by the responsible party. The resultant reports have been collated and edited as input to the different paragraphs. The GH Contents List has been placed on the CA-OWEE website and some other members have also made contributions which have been used in assembling the text.

Chapter authorship

The chapters in this final report are based on the cluster reports, but subjects have been rearranged in a more logical order. Original cluster reports can be obtained from the cluster task leaders (see contact information below) or can be downloaded from the CA-OWEE website: www.offshorewindenergy.org.

The table below explains the link between chapter numbers and clusters and lists the main authors responsible for drafting the different chapters.

chapter		sources	main authors
2	Offshore Technology	cluster 1	C A Morgan, P Jamieson
3	Grid Integration	cluster 2	B. Boesmans, E. Stubbe
4	Offshore Wind Power Potential	cluster 3	Rebecca J. Barthelmie and Sten Frandsen
5	Market Development	cluster 4	B. Smith
6	Economics and Financing	clusters 2, 3 and 5	Rebecca J. Barthelmie, Sten Frandsen
7	Environment, Conflicts of Interest And Planning	cluster 5	Hans Christian Soerensen, Lars Kjeld Hansen
8	Social Aspects	cluster 4	B. Smith
9	Activities, Projects and Plans	cluster 4 plus clusters 1 and 3	B. Smith
10	RTD Recommendations	workpackage RTD	CA Morgan

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Other information sources

Website

All results of the CA-OWEE project are available for downloading at the projects dissemination website at: www.offshorewindenergy.org

Publications

A number of publications have been published which refer to, or are based on, the CA-OWEE project. Examples:

- A.R. Henderson, Offshore wind energy in Europe - an expert guide to the knowledge gained, EWEA 2001 Conference, Copenhagen
- A.R. Henderson, G. J. W. van Bussel, Offshore Wind Energy in Europe - the Current Status, MAREC 2001Conference
- A.R. Henderson, C. Morgan, B. Smith, Offshore Wind Energy in Europe, BWEA 2001 Conference

√ = Cluster member: L = leader,

				cluster number:	**1**	**2**	**3**	**4**	**5**
ID	**Organization**	**Country**	**Type**	**Short**	**Offshore Technology**	**Grid, Energy, Finance**	**Resources & Economics**	**Activities & Prospects**	**Social, Environmental & Political**
1	TU Delft	Netherlands	Uni	DUT	ö	ö	ö	ö	ö
2	Garrad Hassan & Partners	United Kingdom	Com	GH	L	ö	ö	ö	ö
3	Kvaerner Oil and Gas	United Kingdom	Com	KOGL	ö			L	
5	EMU Energi & Miljoe Undersoegelser	Denmark	Com	EMU		ö	ö	ö	L
6	Risø National Laboratory	Denmark	RI	RISOE	ö		L		
14	Tractebel (Energy Engineering)	Belgium	Com	TEE		L			
7	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Spain	RI	CIEMAT			ö		ö
8	Centre for Renewable Energy Sources	Greece	RI	CRES		ö	ö		
9	Deutsches Windenergie-Institut	Germany	RI	DEWI		ö			ö
10	Germanischer Lloyd	Germany	Com	GL	ö	ö			
11	Netherlands Energy Research Foundation	Netherlands	RI	ECN			ö		ö
12	Espace Eolien Developpement	France	Com	EED		ö		ö	
13	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente	Italy	RI	ENEA	ö			ö	
15	University College Cork	Eire	Uni	UCC			ö		ö
16	Vindkompaniet i Hemse AB	Sweden	Com	Vindkompaniet	ö			ö	
17	Technical research Centre of Finland	Finland	RI	VTT	ö	ö			
18	Baltycka Agencja Poszanowania Energii SA	Poland	Com	BAPE				ö	ö

APPENDIX 2A

QUESTIONNAIRES FROM CLUSTER 3
RESOURCE AND ECONOMICS

Importance of subjects is determined using the following score:

Score
1=low
2=medium
3=high

For each country, the questionnaire contains questions regarding:
- the offshore wind resource potential
- economics: experiences from current and planned offshore wind farms
- uncertainties in energy yield

The answers are arranged country by country, i.e. in the following order:

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

1. Offshore wind resource potential				
Topic	*Score*	Main Conclusions	**Refs**	**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

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	Score	Main Conclusions	Refs	Available (Y/N)
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.		

Country: Denmark **Forms filled out by: Rebecca Barthelmie, Riso**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Score*	Main Conclusions	Refs	Available (Y/N)
1.a Onsite Measurements	3	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	Typically use purpose built masts. Satellite data under investigation in WEMSAR project		
1.c Model estimates	3	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	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	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	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	See above		

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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		Horns Rev (1st phase)	https://www.elsam.com/default_ie.htm	Yes
2.a Size of wind farm		150 MW		
2.b Year of construction		2002		
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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		Læsø Syd (1st phase)	https://www.elsam.com/default_ie.htm	Yes
2.a Size of wind farm		150 MW		
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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		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. 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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		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. 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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		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 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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		Middelgrunden	www.middelgrunden.dk, www.middelgrunden.com,	Yes (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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		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.d Distance to coast		4 km		
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	Score	Main Conclusions	Refs	Available (Y/N)
3.a Mean wind speed	3	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	Most analysis focuses on access for maintenance. Studies ongoing.		

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	*Score*	Main Conclusions	Refs	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]	

<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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		Arklow Bank	[1], [8]	Y
2.a Size of wind farm		500 MW	[8]	Y
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.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	

<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	Score	Main Conclusions	Refs	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.d Distance to coast		10 km	[9]	Y
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		Codling Bank Wind Farm	[1]	Y
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	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	Score	Main Conclusions	Refs	Available (Y/N)
2a. Name of wind farm		Blackwater Bank Wind farm	[1]	Y
2.f. Other		Foreshore licence to allow wind measurement awarded September 2000	[1]	Y

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	Score	Main Conclusions	Refs	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]	

Refs:
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: Finland **Form filled out by: Jonas Wolff**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*Score*	Main Conclusions	**Refs**	**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**			
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	**Score**	Main Conclusions	**Refs**	**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**		

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	**Score**	Main Conclusions	**Refs**	**Available (Y/N)**
3.a Mean wind speed	**3**	**No experience yet**		
3.b Availability	**3**	**No experience yet**		

Country: FRANCE Form filled out by: P.BRUYERRE

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*score*	Main Conclusions	**Refs**	**Available (Y/N)**
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	**Score**	Main Conclusions	**Refs**	**Available (Y/N)**
2a. Name of wind farm		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	**Score**	Main Conclusions	**Refs**	**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.		

Refs :

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	*Score*	Main Conclusions	**Refs**	**Available (Y/N)**
1.a Onsite Measurements		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		

Refs

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 considerations concerning resource assessment

Topic	*Score*	Main Conclusions	**Refs**	**Available (Y/N)**
1.a Onsite Measurements		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	**Score**	Main Conclusions	**Refs**	**Available (Y/N)**
2a. Name of wind farm		***Planned Study Offshore Wind Farm***		
2.e Special considerations physical parameters e.g. icing, high waves please specify		High salinity		

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	**Score**	Main Conclusions	**Refs**	**Available (Y/N)**
3.a Mean wind speed		2European wind atlas	Risoe	y
3.b Availability	2			

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	*score*	Main Conclusions	Refs	Available (Y/N)
			Summary in 1 and 2	Yes (Eng)
1.a Onsite Measurements	3	"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	3	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	2	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	3	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	3	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	2	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	**Score**	Main Conclusions	**Refs**	**Available (Y/N)**
2a. Name of wind farm		Nearshore Windfarm NSW, 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]	
2a. Name of wind farm		Offshore Q7-WP (E-connection)		
2.a Size of wind farm		60 turbines (~120 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.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. 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	**Score**	Main Conclusions	**Refs**	**Available (Y/N)**
2.d Distance to coast		800 m		
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.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	**Score**	Main Conclusions	**Refs**	**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	

Refs:

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**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*score*	Main Conclusions	**Refs**	**Available (Y/N)**
1.a Onsite Measurements	1			
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		

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	**Score**	**Main Conclusions**	**Refs**	**Available (Y/N)**
3.a Mean wind speed	3	Experiences only in onshore measurements by meteorological stations (10 m heights)	2	Y(PL)
3.b Availability	1	Non applicable		

Refs:

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: Spain **Form filled out by: CIEMAT**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment						
	Topic	*Score*	Main Conclusions	**Refs**	**Availa. A/N**	**Langua ge**
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. 2.- Ships: Campaigns of Spanish Institute of Oceanography. 3.- Satellites: Images of the sea surface temperature	www.puertos.es/redes-eng.html contact to: andres@puertos.es; ignacio@puertos.es; www.ieo.es/ship.htm contact to: carlos.masso@md.ieo.es; 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 A	ES, EN ES 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			

Refs:
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: Sweden **Form filled out by: Vindkompaniet**

1. Offshore wind resource potential: Please specify national experiences and/or considerations concerning resource assessment				
Topic	*score*	**Main Conclusions**	**Refs**	**Available (Y/N)**
1.a Onsite Measurements		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.		

<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	**Score**	**Main Conclusions**	**Ref**	**Available (Y/N)**
2a. Name of wind farm Bockstigen,Valar Utgrunden Yttre Stengrund		1.Bockstigen/Valar 2.Utgrunden 3. Yttre Stengrund		
2.a Size of wind farm		5 x 0,5 MW; 7 x 1,425 MW; 5 x 2 MW		
2.b Year of construction		1997; 2000; 2000/2001-01-01		
2.c kWh per year		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		1. Installation cost 7 MSEK compared to 4 MSEK onshore. 2. Unknown. (Efforts to investigate can be made if wanted.) 3. 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.		

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	**score**	**Main Conclusions**	**Ref**	
3.a Mean wind speed		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 refs 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.		

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

<u>1. Offshore wind resource potential</u>: Please specify national experiences and/or considerations concerning resource assessment				
Topic	score	Main Conclusions	**Refs**	**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

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	**Score**	Main Conclusions	**Refs**	**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		

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	**Score**	Main Conclusions	**Refs**	**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.		

Refs:

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.

APPENDIX 2B

QUESTIONNAIRES FROM CLUSTER 5 SOCIAL ACCEPTANCE, ENVIRONMENTAL IMPACT AND POLITICS

CONTENTS

The following guidelines were given to the CA members before filling in the questionnaires:

Guidelines for questionnaires:

This questionnaire will be used in Cluster 2.5 of OWEE with the purpose of ranking the relevant issues and collecting the information available on topics concerning Social Acceptance, Environmental Impacts, Conflicts of Interest and Politics.

Information Collection

The tables below will serve to collect the information available on each issue, and will be used as a starting point for writing the state-of-the-art summaries.

Please provide a short statement regarding the available information or a short, conclusive answer to the questions in the column **Main Conclusions**.
Please also provide in column **Reference** a (bibliographic) reference to the source of your information. You could also here refer to a number in a list of references that you write at the end of the document.
Please indicate in column **A/N** whether the source document is available (A) in your organisation or not (N).
Please indicate the language of the document in column **Language**.

You should feel free to add to the list any other issue that you consider to be important.

Importance

Please indicate for the relevant topics your evaluation of its importance, by using numbers 1, 2, 3, according to the following:

1	HIGH IMPORTANCE	An issue is of high importance if it is expected to have a significant impact on the large-scale development of off-shore wind energy (i.e. if no solution is found for this issue, or if the problem is being ignored, the development of off-shore wind energy will be limited or blocked)
2	MEDIUM IMPORTANCE	An issue is of medium importance when it is considered not being of high or low importance...
3	LOW IMPORTANCE	An issue is of low importance if it is regarded as only having importance on the large scale development of offshore wind farms at some very specific local areas or is regarded as having no impact

The average ranking AVG has been found by taking the arithmetic average of the country specific ranking and rounding of to one decimal.

Ranking Table

		AVG	BE	DK	FI	FR	GE	GR	IR	IT	NL	PL	SE	SP	UK
1	Environmental Impacts														
1.a	Birds	1,5	1	1	1	1	1	2	2	2	2	2	2	1	2
1.b	Sea mammals	2,4	3	3	2	2	2	1	1	3	3	3	3	3	2
1.c	Fish	2,2	2	3	2	1	2	3	1	2	2	3	3	3	2
1.d	Marine biology	2,3	2	3	3	2	2	3	1	1	2	3	3	3	2
1.e	Hydrography	2,1	3	1	3	2	-	2	1	2	3	2	3	1	2
1.f	Seabed	2,5	2	3	3	1	3	3	1	3	3	3	3	3	2
1.g	Sea currents	2,4	2	2	3	2	3	3	1	2	3	3	3	2	2
1.h	Water quality	2,5	3	3	1	3	3	3	1	2	3	3	3	-	2
1.i	Visual effect	1,5	1	1	1	1	2	1	3	3	1	1	2	-	1
1.j	Noise Impact	2,0	3	3	1	3	2	1	1	1	3	1	2	-	3
1.k	Raw materials	2,6	3	2	3	-	3	3	-	1	3	2	3	-	3
1.l	Marine archaeology	2,4	3	2	3	3	3	1	1	2	3	2	3	-	3
1.m	Recreational areas	1,8	2	1	1	1	2	1	-	3	3	1	3	-	2

		AVG	BE	DK	FI	FR	GE	GR	IR	IT	NL	PL	SE	SP	UK
2	Conflicts of interest														
2.a	Ships	1,3	1	1	2	1	1	1	1	3	1	1	2	1	1
2.b	Air traffic	1,7	-	2	2	2	3	1	1	1	2	1	-	3	1
2.b.i	Marking lights	2,0	3	1	2	-	3	1	1	3	-	2	2	3	1
2.b.ii	Colors	2,2	3	1	3	-	3	2	1	2	-	2	3	3	1
2.c	Defence	1,6	-	3	1	-	2	1	1	3	-	1	-	1	1
2.c.i	Radio/Radar	1,9	1	2	1	1	2	2	-	3	3	2	1	3	2
2.c.ii	Training grounds	1,8	3	1	1	3	2	1	-	2	2	1	1	2	2
2.d	Fishing interests	1,4	1	1	1	1	2	1	2	2	1	2	2	-	1
2.e	Bird interests	1,5	2	1	1	3	1	2	1	2	1	1	2	-	-
2.f.i	Cables and pipelines										2				
2.f.ii	Dredging										3				
2.f.iv	Coastal amenity														1
2.f.v	Dump sites								1						
2.f.vi	Oil drilling							1							

Answers arranged in relation to specific subject

Table A.1. Environmental Impacts

1. Environmental Impacts: **Please specify national experiences and/or considerations concerning environmental impacts from *Offshore Wind Farms* during construction and after installation in relation to the topics listed below:**

Importance		Main Conclusions	References	A/N	Lang.
1.a Subject: Birds (migrating and resting)					
BE	1	Distance from shore is important parameter. Insufficient information available on bird migration behaviour away from coastline.			
DK	**1=H**	Site dependent. The impact also depends on the various bird types at each site.	Different reports for diff. locations – all in Danish, some with an English summary e.g. Ref. Nr. 10 (Sørensen et. al. (1999))	A	Danish (DK), English (UK) summar y
FI	1	Depending on site and species. Sea birds will rise as an important topic.	http://www.pvo.fi/merituuli/svenska/index.asp	Y	
FR	1	High dependance of the location (distance to the seashore) and of the presence of fish. Little existing knowledge on sea birds : requires specific methodology and equipment (boat)	Study for Breedt offshore wind farm, Greet Ing., 1999-2000 Identification of offshore sites in Languedoc, Meridionalis, 2000	N (authoriza tion needed) A	French French
GE	1	Impacts on birds are expected such as * collisions of migrating feeding birds with turbine * turbines as barriers between feeding and roosting grounds or in migration routes * ousting birds off their traditional feeding/roosting grounds [1,2,3] Detailled discussion on the above topics and many references available in [3].	[1], [2], [3] references in [3] [3] references in [3]	A A A NA	German German English English
GE cont		German Bight with its Wadden Sea is seen as an important area for migrating birds as roosting and feeding grounds. Birds are migrating across the German Bight with rather unknown pattern with respect to used migration paths, migration heights and influences of weather conditions on flight behaviour. Investigations on these issues are required in Before-After-Impact Studies (ecological monitoring programmes) [2,3, refernces in 3] Flight behaviour of stationary birds [2,3]: *spatial intensity: how far? *frequency: how often? *general flight behaviour (hight, paths, weather influence) Some knowledge available from Dutch and Danish investigations (see references in [3]) however behaviour best known during breeding time. Bird populations well known for summer time deficits for winter time [2] Boundaries of Important Bird Areas IBAs are not yet well defined. Legally, according to EU regulations, those areas that might qualify for IBA shall be treated as IBA until a decision has been met whether they become official IBA's or not [3]	[2],[3] references in [3] [2],[3] references in [3] [2], [3]	 A A	 Ger Ger
GR	2	Main considerations concern endangered species living onshore	15, 16, 17	N(*)	GR

IR	2	Through careful siting of turbines and investigations of populations and behavioural patterns, the effects of wind turbines on birds can be minimised. Do not site in main bird flight path. Impacts on migrating birds are of particular concern.	[1],[2] drawing on [3],[4],[5], [6],[7] & [8]	only [1] & [2] A	English
IT	2	Only considerations for semi-offshore farms after installation	No ne		
NL	2	Possible effects : *Low flying, foraging birds could collide with rotating blades, especially in foggy weather. Rotor turbulence could also a cause of accidents. *This effect is permanent. Birds could avoid the Windpark area after a while, getting accustomed to the new situation. *Migrating birds (larger amount) often fly at higher altitude and will encounter less disadvantages of the Windpark. *The negative effects on foraging birds is small on regional ecosystem scale. On migrating birds, having their flight path often near the coast line, the effect of a near shore windpark might be larger. *Study on combined effects of movement and sound of windturbines on birds is done earlier[i] This is the most important environmental factor according to the government[ii].	Reports with [ii iii iv]	Yes (all)	NL (all)
PL	2	Poland lies on some major routes for migrating birds from Scandinavian countries *and Baltic countries*	Seminar "Wind Power Onshore and Offshore"	A	PL
SE	2	Impacts on migrating birds is studied on two sites in Sweden. Utgrunden and Yttre Stengrund. Serious impacts are not assumed so permission is given on both sites. The bird study is a condition for getting permission. Both plants are located in a migration path , the southeast coast of the mainland and the Kalmarsund. The study has started but no report is finished. The level of knowledge about windpower-impacts upon birds migration and resting has to be increased. There is need for many studies, but the issue should not be overemphasized. It´s very clear that on-shore WECS located close to or within areas with migrating, nesting or grazing birds don´t make any impacts at all on birdlife. Visiting people and predators make impacts not the windturbines. When the WECS don´t impact birdlife on land why should they in the sea?			
SP	1	High importance in "Estrecho de Gibraltar" in Cádiz. As no windfarm is installed in Spain the information is not available. Huelva Harbour: Just beginning the environmental impact study.		N	
UK	2	Need to avoid migratory paths and habitats of national or international importance (RSPB – main authority). Environmental Impact Study (EIS) must address avian issues in detail, particularly if this is not the case.	1	Y	

1.b Sea mammals					
BE	3				
DK	3	In addition to larger projects, the authorities responsible for the environment ask for an assessment of the local mammal population.	Only a very few reports in Danish	A	DK
FI	2	Influence on seals important but conclusions can be drawn from Swedish projects. If building on small rocks and islands in the archipelago this question will be very important.			
FR	2	Potential influence of low frequency sound emission	Study for Breedt offshore wind farm, Greet Ing.1999-2000	N	French

1.b Sea mammals					
GE	2	[4] expects possible loss of habitat due to disturbance mainly through noise emmission from turbines and from construction- & maintainance vessels and equipment (piling); noise reception of the sea mammals not sufficiently quantifiable; According to [3] impact may rise from noise or visual impact, however, degree of impact unknown. In [3] a source is quoted that common and grey seals do not seem to be significantly disturbed; suggestion is to avoid sensible areas and to perform Before-After-Impact Studies (ecological monitoring programmes)	[1],[4] [3] references in [3]	A A N/A	German English
GR	1	Specific protection areas for sea mammals (e.g. monachus-monachus seal in West Aegean Sea, sea turtles in Ionian Sea)	14, 15, 16, 20	N(*)	GR
IR	1	Seismic surveys, construction and operating noise may disturb whales and dolphins. Assess use of proposed sites by mammals, review need for seismic surveys. Minimise duration and quantity of noise during construction. Quantify, minimise and monitor underwater noise levels during operation.			
IT	3	Only considerations for offshore farms after installation	No nex		
NL	3	The presence of vibrations could affect the sonar system to retrieve food. *This effect is permanent , but expected to be limited, both locally and regionally.			
PL	*3*	*There are only a few seals in the Polish part of the sea*		N	
SE	3	To avoid impacts on two grey-seal colonies was a key-factor in the struggle for permission at the Bockstigen/Valar site. Following conditions were given. Counting and observation of sealbehavior before starting construction, during construction and two years after start of operation. The report concludes: There is no evidence that windturbines affect or impact the seals in any respect.	Sundberg&Söderman ”Windpower and grey seals: An impact assessment of potential efects by sea-based windpower plants on a local seal population”. Department of Animal Ecology Uppsala University	y	English
SP	3	Not high importance in Cadiz. Begining studies in Huelva.		N	
UK	2	Study will be needed based on existing records of mammal populations necessary in EIS. Possibly also supplemented by surveys before, during and after construction.	1	Y	

1.c Fish					
BE	2	Effect may be positive or negative depending on complex food chain interactions.			
DK	3	Foundations act as natural reef and seem to increase fish life, but see “Conflicts of interest”	A few reports about specific sites, e.g. Ref. Nr. 4 and 5	A	DK, UK
FI	2	Conclusions can be drawn from Swedish projects			
FR	1	Impact on fisheries : the presence of offshore wind farms will limit the territory for fishermen			
GE	2	[1] expects possible loss of habitat due to disturbance mainly through noise emmission from turbines and from construction- & maintainance vessels and equipment (piling); noise reception of fish yet totally unknown - not uantifiable; negative impact on fish larvae through water turbidity and sedimentation; another impact may arise from electric and magnetic fields around cables. [5, 3] generally see final scientific evaluation of impact on fish disabled by lack of demonstration plants offshore that might serve as a study base; sedimantation and turbidity of water has only temporary impact; population of fish might change due to changed biotope by placing foundations (hard substrates) of wind turbines on the sea bed; hard substrates are considered uncommon in the North Sea; fishing will not be allowed in the wind farms leading to a resort for fish and it’s larvae	[1], [5], [3] references in [3]	A NA A NA	German German English

1.c Fish					
GR	3	The effects of LSOWE on fish fauna is considered limited. However there might arise conflicts with fishing industry (see 2.d)	5, 10	N(*)	GR
IR	1	Use artificial reefs to improve habitat for fishery species. Shield and bury electrical cables appropriately to minimise electro-magnetic impacts on fisheries. Projects should seek to minimise the effect of structures and cabling on existing stocks, their food sources and spawning activity.	[1],[2]	A	English
IT	2	considerations for offshore and semiøoffshore farms during construction and after installation	No nex		
NL	2	The negative effect of Vibrations will also encountered here. *The absence of fishery and shipping in and around the windpark will probably result in a safe area to rest and breed. This will affect the fish population in a positive way. Successively, foraging birds could also take advantage of this effect.			
PL	3	There is an opinion that wind turbines bases are good for fish		N	
SE	3	Very few studies. The existing windfarms are erected in areas with no or very little fish. A study is made about the impacts on fish in the first offshore windpowerproject in the world 1 x 220 kW WindWorld outside Nogersund, Blekinge.			
SP	3	No studies available. Information about fishing interesting areas in Secretaría General de Pesca Marítima (Agriculture, Fishing and Food Ministery) and autonomic comunities	Silvia Revenga Tfno: 34 914025000	A	Spanish and English
UK	2	Effect of vibration on fish less well understood than on mammals. Study based on existing records of fish stocks and experience on other offshore projects necessary in EIS. Possibly also supplemented by surveys before, during and after construction.	1	Y	

1.d Marine biology (sea bed vegetation and fauna)					
BE	2				
DK	3	Foundations act as natural reef and introduces fauna	See above	A	DK
FI	3	Important but depending on site. Offshore construction in general has not taken this into consideration.			
FR	2	Very site dependant (benthos)	Study for Breedt offshore wind farm, In Vivo, 1999-2000		
GE	2	[1, 5, 3] expect possible loss of habitat and individuals due construction activities i.e. piling foundations will cause sedimentation covering benthos; changes in sediment structure may rise from changed water flow around foundations; also artificial hard substrates(foundations) might cause changes to the biotope structure – different species might find better conditions as in areas without hard substrate and with fishing activities going on. Judgements on quality (good or bad) and quantity of the possible impacts are debatable and not well known yet	[1] [6] [3] references in [3]	A A A NA	German German English
GR	3		5	N(*)	GR
IR	1	Research is ongoing, information not fully collated on the underwater ecology of sand banks. Footprint of turbine foundations and cables, traffic, electromagnetic radiation, noise may reduce abundance and diversity of seabed life. Design windfarm to maintain or improve habitats for species of importance.	[1],[2]	A	English
IT	1	considerations for offshore and semiøoffshore farms during construction	No nex		
NL	2	*Seabed vegetation and fauna will suffer mostly during the construction phase. But this is not a permanent effect. Also here, the absence of fishery and shipping will have a local positive effect. The presence of the construction on the sea bottom could also have positive effect on some habitants.			
PL	3				

1.d Marine biology (sea bed vegetation and fauna)					
SE	3	No evidence of impact is found on marine biology in the Bockstigen/Valar project or the Utgrunden project. There were fears of of sedimentation of seabed before both projects because of lots of silt and mud from the monopile drilling. A little sedimentation could be seen around the monopiles the first days after drilling at the Bockstigen project. It disappeared and diluted completely after the first storm. The problem was totally avoided at Utgrunden as the monopiles were hammered down.			
SP	3	Not available studies			
UK	2	Vindeby (DK) study indicates positive impact on local populations due to artificial reef effect. EIS will have to address and surveys are likely to be necessary.	1	Y	

1.e Hydrography					
BE	3				
DK	1	Site dependent, but no observations indicating problems	No		
FI	3	Largely done by now. Only some parts not mapped.	http://www.fma.fi/english/index.html	Y	
FR	2				
GE	-				
GR	2				
IR	1	Design foundations to minimise scouring, erosion and sediment redistribution	[2]	A	English
IT	2				
NL	3				
PL	2				
SE	3	No studies. The risk of impacts on hydrography is minimal while using monopiles. The monopiles are only 3-4 m in diameter and the distance between them will be 3-600 m. Maybe it is a risk of impacts on current if much bigger concrete foundations are used, although it is not very probable.			
SP	1	Not available studies			
UK	2	Detailed modelling may be necessary depending on size of project, proximity to shore, shallowness of water and general sensitivity of local hydrography	1	Y	

1.f Sea bed					
BE	2	Seabed stability against drifting could be important			
DK	3	Covers existing fauna, but look 1.d	No		
FI	3				
FR	1	Risk of scouring on sand banks : difficulty to calculate maximum scour and/or guarantee the efficiency of protection	Laboratoire National d'Hydraulique (EDF), 2000	N (authorization needed)	French
GE	3	no major impact expected	[3] references in [3]	A	English
GR	3				
IR	1	Scouring of the seabed can be a serious issue with gravity caisson type foundations	[1]	A	English
IT	3	Some cases only during construction	MiddleGrunden Dk	y	
NL	3				
PL	3				
SE	3	Removal of WECS after finished operating period should be prepared			
SP	3	Not available studies			
UK	2	As above but must also consider construction and decommissioning phases as well as sub-sea cables	1	Y	

1.g Sea currents					
BE	2	Constitutes an extra forcing input for dynamic analysis			
DK	2	Only important at special locations	A few reports about specific sites	A	DK

1.g Sea currents					
FI	3				
FR	2	Induce loads on foundations	Laboratoire National d'Hydraulique (EDF), 2000	N (authorization needed)	French
GE	3	no major impact expected	[3] references in [3]	A	English
GR	3				
IR	1	Design foundations and footprint of area to minimise alteration to current flow. The typical low ration between turbine foundation diameter to inter turbine spacing means effects on overall tidal current flows should be low	[1],[2]	A	English
IT	2	Some cases only during construction	Bostigen SW	y	
NL	3	can cause changes, which can effect fish-spawning grounds and insect larvae development (fish food)	[iv]		
PL	3				
SE	3	See 1e			
SP	2	Not available studies			
UK	2	As in 1f	1	Y	

1.h Water quality					
BE	3				
DK	3	No information	No		
FI	1	The state of the Baltic Sea is alarming but wind power could hardly affect that.			
FR	3				
GE	3	as sedimantation processes and trubidity of water only arises during construction phase water quality is not seen as a problem	[3] references in [3]	A	English
GR	3				
IR	1	Concerns exist regarding waste generation and disposal during construction and maintenance	[2]	A	English
IT	2	Salt content-corrosion offshore structures	General	y	
NL	3				
PL	3				
SE	3	No risks			
SP	-	Not available studies			
UK	2	Project must minimise risk of contamination during construction operation and decommissioning. Must be addressed in detail in EIS.	1	Y	

1.i Visual effect both seen from land (specify distance) and offshore					
BE	1				
DK	1	Especially coast near In general in DK 8 km from land – then minor importance – see conflicts of interest, 2.5.2.	Different examples of visualizations, e.g. Ref. Nr. 8		DK/UK
FI	1	This is the most important question. (One opinion by a regional environment authority was that wind turbines must not be seen from ferry lines.!)		N	
FR	1	Dependant of the visibility (rough statistics available) : difficult to take in account in photomontages (blur effect ?)			

1.i Visual effect both seen from land (specify distance) and offshore					
GE	2	[1] sees intrusive impact to landscape due to the fact that wind turbines represent technical buildings in an otherwise structureless landscape "visual impact is a matter of the viewers taste" [3] visual impact must be considered when developments are to take place in the coastal zone [7,3] i.e. rather close to the shore line – recreational use might be impacted negatively and also general landscape conservation must be considered most developments are expected to take place in the 200-Miles zone (?Exclusive Economic Use Zone? – *German term translated*) i.e. beyond the 12 sea miles border and with large distances from shore visibility is very low – with distances larger than 45 km visibility is nill, hence no visual impact to shore based observer	[1] statement from Greenpeace Int. [7] [3]	A NA A	German German
GR	1	Visual intrusion of great importance near recreational areas and/or coastal settlements			
IR	3	Offshore generating stations will not as a general rule, be allowed within 5 km of the shore but applicants may make a case for such if they consider that the proposed construction will not interfere unduly with the visual amenity of the area in question (both seascape and landscape). Such applications will be subject to special consultation procedures.	[9]	A	English
IT	3				
NL	1 (tourism)	A comment which seems to reflect the general opinion is: 'the near-shore windfarm has a negative impact on the landscape and possible birds. This can be reduced by moving further offshore, using smaller turbines, building a smaller windfarm and switching off the turbines when birds are flying passed[iv] The windfarm's visual impact could also have positive impacts on the visiting public, though a visitor centre, trips to see the windfarm from the coast and on boat trips. A public opinion survey concluded that visual intrusion was the most important impact factor but wouldn't necessarily result in fewer visits to the affected location.[v]			
PL	1	Wind power plants - are <u>not included</u> to a list of severely damaging the environment and/or influencing it negatively. Society is rather democratic, and usually there are always parties which will compete with the public. Possible distance of 5 km from land.	The Decree of the Ministry of Environment, 14th July 1998,	A	PL
SE	2	Can not be avoided. The issue should be carefully considered during the planning period. Key-factors: 1. Distance from coast 2. Avoid coastal areas known for their magnificient sceneries! 3. Use efforts upon educating people in the necessity of off-shore windpower and how people can benefit from it. 4. The planning process must be very open and careful. 5. Start with smaller demonstration projects.			
SP	-	Because of spanish sea depth, wind farms should be built near shore, hight visual effect from land.			
UK	1	If at all visible from land, the effect on the environment and economy (e.g. tourism) of the coastal area must be assessed. Effect on offshore viewpoints is primarily related to safety (e.g. visibility, distraction effect)	1	Y	

1.j Noise impact (onshore and offshore)					
BE	3				
DK	3	The general opinion is that noise is a problem, but in practice this is not a problem	Measurement reports		
FI	1	There is some strange noise propagation experienced offshore.			
FR	3	Except for low frequency noise and its impact on marine life (unknown)			

1.j Noise impact (onshore and offshore)					
GE	2	noise impact on sea mammals and fish from turbine noise emitted into water is regarded as a "fashionable" area of interest; noise imissions into the North Sea are already large by now so it must be assumed that noise sensitive species have already left the area airborne noise might be of equal importance as onshore considering developments rather close to shore and considering the possibility that noise may travel large distances over open water surfaces	oral information author's opinion		
GR	1	Acoustic intrusion of great importance near recreational areas and/or coastal settlements			
IR	1	It is unlikely that airborne noise from offshore wind farms will be a major issue. The effects of underwater noise needs assessment in a site specific manner.	[1],[2]	A	English
IT	1				
NL	3				
PL	1	Public is convinced that wind power generates significant levels of noise.	Seminar "Wind Power Onshore and Offshore"	A	PL
SE	2	Noise onshore from offshore windplants can not be heard provided the distance from shore is at least 3 km and good low-noise turbines are used. There is a risk that noise-problem will be considered as non-existing by the turbine manufacturers. Long distances-no noise problem. There is a motorwaylike murmuring in distances up to 1,5 km around a big windpark with 5-600 kW turbines - even longer at special weather conditions. The turbines are expected to be 3- 5 MW size, offshore even more.. The murmuring can then be heard maybe 7-8 km if no steps are taken to make big turbines low-noise.			
SP	-	NA			
UK	3	Visibility effect will typically drive turbines far enough from shore to give inaudible levels of noise. Assessment similar to that for land-based farms will, however, be necessary.	1	Y	

1.k Raw materials					
BE	3				
DK	2	A few sites have been appointed to serve as raw material deposits, here no farms	Public sea maps		UK
FI	3				
FR		?			
GE	3	German coastal shelf is distributed into several areas with mining concessions for individual companies; these have the rights (company interest) and the obliagtion if considered necessary (public interest) to exploit possible fossil energy sources (s.a. oil and gas); companies have probed their areas and have partly found oil or gas; exploitation however is currently economically unattractive	oral information at hearing organised by planning authority		
GR	3		8	Y	GR
IR	-				
IT	1				
NL	3				
PL	2	Exploration of crude oil on *the Polish part of the sea*			
SE	3	A simple inquiry to the special state-authority gives the answer if the site holds any important raw materials. Extracting of raw-materials for instance oil or gravel can be possible to doin combination with offshore windpowerproduction. There are possible synergies.			
SP	-	NA			
UK	3	Case for good net energy balance and effective use of raw materials must be made in EIS.	1	Y	

1.l Marine archeology					
BE	3				
DK	2	Must be examined as all other constructon works – can result in delay of project	No		

1.l Marine archeology					
FI	3				
FR	3				
GE	3	could be a problem if wind farm site coincides with site of archaeological interest; prior scanning of the area of interest could avoid these problems	[3] references in [3]		
GR	1	Specific areas of archeological interest (e.g. Northern Crete, Central Aegean) where interventions on terrain are prohibited			
IR	1	The National Monuments Acts (1930-1994) make extensive provision for the protection and preservation of national monuments, historic monuments and archaeological areas. These acts operate in addition to the planning controls and are relevant as they apply to the sea bed, which is outside of the jurisdiction of the planning authority. Many shipwreck sites in the shallow underwater banks and shoals around the coast are under protection.	[1],[2]		
IT	2				
NL	3	possibility of damage to ship-wrecks, these are marked in [vi via ii and iv]			
PL	2	Many wrecks of ships			
SE	3	Sometimes a study is needed .			
SP	-	NA			
UK	3	Some listed wrecks (e.g. war graves) but typically in deeper water than is envisaged for wind farms			

1.m Recreational areas					
BE	2				
DK	1	8 km from sea shore, see 2.5.2.	Danish law about use of the coastal zone		DK
FI	1	The Finnish coastline is full of summer cottages and recreational areas. Boating is very popular in summertime, including picnics to the outer archipelago. Wind turbines will be both liked and disliked under theese circumstances, as always.			
FR	1	Very sensitive to locations : “wind wall” effect	Offshore in Normandy, 2000 Offshore in Brittany, 2000		
GE	2	see visual impact			
GR	1	Visual intrusion is of great importance near recreational areas and/or coastal settlements			
IR	-				
IT	3				
NL	3	only with respect to visual impact at beach (see 1.i); little impact at the location itself[ii]			
PL	1		Seminar “Wind Power Onshore and Offshore”	A	PL
SE	3	If the planning process has been good enough there will not be any problems.			
SP	-	Wind farms near shore, problems with beach and recreational areas in countries both with a tourism based economy or depressed.			
UK	2	As 1I			

1.n					
GR		Environmental Policy-Legislation	1-4, 6,7, 19	N(*)	GR
NL		From several studies in the past the local and regional effects are qualitatively clear. The magnitude of impact on the environment is often not determinable yet and differs from place to place.			

Table A.2. Conflicts of Interest

2. Conflicts of Interest: Please specify national experiences and/or considerations concerning conflicts of interest in relation to *Offshore Wind Farms* during construction and after installation in relation to the topics listed below:					
Importance		**Main Conclusions**	**References**	**A/N**	**Language**
2.a Effect on traffic: ships					
BE	1	Marine traffic safety issues should be investigated. Also possibility for severe environmental damage in case of oil carrier collisions with wind turbines. Insufficient information on damage mechanisms.			
DK	1	Avoid official ship routes	Afmærkning af Danske Farvande (Buoying Danish Waters, 6th revised version, 2000)	A	DK
FI	2	This is a technical siting limitation.			
FR	1	The offshore wind farm has to be away from maritime routes (presence of an other sand bank between the wind farm and the maritime route)	Breedt offshore, EED, 2000		
GE	1	as the German Bight has very dense ship traffic a study on collision risk is necessary and currently being carried out	[8]	N	
GR	1	Frequent traffic on the islands especially during spring-summer. LSOWE installations might require reconsideration of routes	Ministry for Shipping		
IR	1	Certain areas will be prohibited for use as offshore wind farm sites where protection of established shipping lanes demand it. These are listed in reference [9]. As offshore structures are a potential hazard to marine navigation, it is imperative that they be marked properly and effectively, in accordance with international guidelines. The commissioner of Irish Lights and local ports authority should be consulted, in this regard. There are some concerns regarding the need to alter existing sea traffic routes and the increased collision risk which may be mitigated by avoiding construction of wind farms near major navigation routes.	[9] [2]	A	English
IT	3				
NL	1	was reason why proposed location for Near-shore Windpark was moved from IJmuiden to Egmont.[iv] Windfarms must avoid traffic lanes, plus cable routes must avoid locations where ships may lay anchor while waiting to enter harbours. [iv] Lely windfarm (in the IJsselmeer) has coloured stripes plus warning lights for ships (located about 1 km of a harbour entrance) [vii]			
PL	1	Polish coast has several major routes connecting Scandinavian countries and Poland		N	
SE	2	There must be lots of discussions and cooperation during planning period with cost guards and the Sjöfartsverket (shipping board). Offshore windfarms will be located on reefs, banks and other shallow waters which must be avoided by at least big ships. Thus good planned offshore windparks can contribute to the maritime safety	The Swedish Shipping Board have produced guidelines for location and illumination of windturbines in Swedish waters.	A	Swedish
SP	1	No problems in Cadiz and Huelva. Traffic ship information at	www.mfom.es/documentacion/top_documentacion.html www.mfom.es/marinamercante/top_marina.html	A	Spanish and English
UK	1	Existing rights of navigation must be safeguarded – required as part of permitting	1,2	Y,N	

2.b Effect on traffic: air traffic					
BE					
DK	2	Turbines must be below 150 m for usual navigation	?		
FI	2	This is a technical siting limitation.			
FR	2	Beaconing day and night like onshore sites			
GE	3	no major effect expected with large developments at large distances to shore	oral information and authors perception of the discussion	--	

2.b Effect on traffic: air traffic					
GR	1				
IR	1	Certain areas will be prohibited for use as offshore wind farm sites where protection of air navigation demands it. The Irish Aviation Authority should be consulted.	[9]	A	English
IT	1				
NL	2	avoid landing strips and potential location for proposed offshore airport [iv]. The negative impacts are obstruction plus potentially additional turbulence, avionics and landing gear and pilot psychology, but none of these have been investigated scientifically [iv].			
PL	1	The Ministry of Transport for civil aviation The Ministry of Defense for air force		A	
SE	-				
SP	3	No information			
UK	1	Siting must be approved by Civil Aviation Authority. Helicopter routes may be major concern for some offshore areas.	1	Y	

2.b.i **Marking lights**					
BE	3	No specific requirements			
DK	1	Helicopter rescue service makes demands about very visible marking lights, which may reduce public acceptance if carried out	Two-year committee work just started		
FI	2	Needed on nacelle top but has negative impact on birds.			
FR	-				
GE	3	for buildings larger than 100m marking lights are mandatory	national regulation	N	
GR	1	The illumination should clearly demarcate the outer dimensions of each machine and the entire plant. Related standards for onshore wind farms available	Ministry of Traffic, Commercial Aviation Service		
IR	1	No prescriptive conditions - it is imperative that they be marked properly and effectively, in accordance with international guidelines	[9]	A	English
IT	3				
NL		not a requirement for aircraft currently			
PL	2	Lights are obligatory			
SE	2	Marking lights and the location of those marking lights are important issues. Rescuing with helicopters can be necessary in a windpark. Then turbulent wakes behind big windturbines makes a considerable risk for loosing control of the helicopter. The phenomenon has been observed at the Bockstigen site even with the small turbines on that site with 37 m rotor and 40 m hub height. The illumination must be studied in connection with the visual impact. Safety aspects are of course the first, but good illumination for safety is best if it is beautiful at the same time. Too much marking lights can make a risk for migrating birds. They cause orientation problems for the birds.			
SP	3	No information			
UK	1	May be required for vessels and aircraft	1	Y	

2.b ii. Colors					
BE	3	No specific requirements			
DK	1	see above	Ibid		
FI	3	In some cases red blade tips has been used but nowadays nacelle lights is accepted.			
FR	-				
GE	3	for wind turbines larger than 100m signal colours on the blades are mandatory	national regulation	N	
GR	2	Related standards for onshore wind farms available	“		
IR	1	No prescriptive conditions - it is imperative that they be marked properly and effectively, in accordance with international guidelines	[9]	A	English
IT	2				

2.b ii. Colors					
NL		not a requirement for aircraft currently			
PL	2	No regulations			
SE	3	The widespread use of good navigation equipments, radar,GPS etc can be mentioned here. It makes it less important to paint the turbines in bright and shining colours which is positive for the visual impact.			
SP	3	No information			
UK	1	May be required for vessels and aircraft	1	Y	

2.c Defense					
BE					
DK	3	Only problem at a few known sites	Official navigation maps. Most area restrictions are shown on navigation maps	A	UK
FI	1	The military owns large parts of the coast, the archipelago and the sea. There is a decision not to allow wind turbine installations on army areas. One conclusion is that this is a temporary decision that can be withdrawn when wind energy is more common. The army does not want their areas to be a demonstration site with huge public interest. Nor do they want the eventual discussion on pros and cons of WE to be related to their sites and activities.		N	
FR	-				
GE	2				
GR	1				
IR	1	Certain areas used by the Department of Defence as gunnery, bombing or firing ranges are prohibited, listed in [9]	[9]	A	English
IT	3				
NL	-				
PL	1				
SE	-				
SP	1	No information. Difficult access			
UK	1	Siting must be approved by MOD	1	Y	

2.c i. radio/radar					
BE	1	Highly dependend on location			
DK	2	Towers can disturb radio signals but problems can be avoided by links	No		
FI	1	Not presently known.			
FR	1	Real impact on radar used for marine safety. Impact equivalent to a mid sized boat	Breedt offshore, THOMSON DETEXIS, 1999		
GE	2	there are considerations that are concerned with scatter effects on ship radar	oral information at hearing organised by planning authority	--	
GR	2				
IR	-				
IT	3				
NL	3				
PL	2	There are radio/radar stations on the coast			
SE	1	Very suitable areas for offshore windpower are closed because of defence interests. Good studies are needed to show that windpower and national defence can co-exist and still better to show that windpower is a part of the total national defence. A big Swedish study concerning impacts on radar and radio system is finalised this year.			
SP	3	No information			
UK	2	Siting must be cleared by CAA, MOD and/or DTI Radcom			

2.c ii.	training grounds				
BE	3				
DK	1	Impossible to move these areas, but they are well-known	No		
FI	1	Will not be accepted.			
FR	3	No feasibility for wind farms			
GE	2	there are large areas designated as training grounds while training ground status does not exclude traffic or fishing use; this will change with wind farm installations as they will discard these areas for military training use this represents a matter of political will whether or not to give up military training grounds for offshore wind energy use.	oral information at hearing organised by planning authority and authors perception of the discussion	--	
GR	1	Restricted areas near borders and on remote islands of the Aegean/Ionian Seas	Ministry of Defense		
IR	-				
IT	2				
NL	2	Will preclude certain areas. Egmont is an ex-military area, which was released for other use. [iv]			
PL	1	Major grounds for training on the southern coast of the Baltic sea			
SE	1	See above			
SP	2	No information			
UK	2	MOD may object in specific training areas (firing ranges, low flying zones) or in specific air corridors.	1	Y	

2.d Fishing interests					
BE	1	Major public opinion issue			
DK	1	Important for acceptance. Fishing organizations claim losses, but can be paid.	No		
FI	1	Trawling might limit possibilities. Also some flatfish interest might limit the use of banks and low water depths.			
FR	1	Conflict in use of the sea. Very power ful lobby (one boat can block the port of Dunkerque or Calais !)			
GE	2	loss of fishing grounds must probably financially be compensated for	oral information at hearing organised by planning authority and authors perception of the discussion	--	
GR	1	Nearshore fish farms, fishing navigation	Ministry for Shipping		
IR	2	There are concerns regarding loss of trawling ground, loss of areas for pot fishing, damage to spawning grounds resulting in economic loss to fishermen with consequent social impacts. The policy of the Minister of the Marine and Natural Resources is to maximise the value of offshore resources to the State, and to protect the rights of other users. In this regard, He will have regard for competing demands in granting leases.	[2],[9]	A	English
IT	2				
NL	1	Can be resolved with compensation [iv].			
PL	2	Entire coat is a ground for small fisheries		N	
SE	2.	Important spawning areas must be avoided. But with careful planning windturbie foundations can serve good as artificial reefs	Report to Swedish national survey on offshore windpower.	n	Swedish
SP					
UK	1	Important interest-group with substantial public sympathy and a lot of power to disrupt projects			

2.e Bird interests (designated areas)					
BE	2				
DK	1	Important in relation to acceptance – restricted areas are to be avoided. Still discussion about how far away from the area border farms can be placed	Maps		
FI	1	Is a limiting factor. Bird interest also important outside designated areas.			
FR	3	No feasibility for wind farms			

2.e Bird interests (designated areas)					
GE	1	biggest problem here is that the Important Bird Areas have not yet been officially designated	oral information at hearing organised by planning authority and authors perception of the discussion	--	
GR	2	Main considerations concern endangered species living onshore	15, 16, 17	N(*)	GR
IR	1	Designated areas for the protection of birds are not specifically excluded for offshore wind farms currently.	[9]	A	English
IT	2				
NL	1	see previous			
PL	1	Vistula peninsula is a region for several species of birds in the region, these either will stay at that location or will deteriorate	Seminar “Wind Power Onshore and Offshore”	A	PL
SE	2	See 1a. Even if there is no evidence of impact on birdlife it will give provocing signals if developers want to use special designated areas for birds.			
SP		No studies available. Information about organisations	www.seo.org		
UK		RSPB will be key consultee in areas where avian issues are of importance.	1	Y	

2.f					
	3	**Dredging :** extraction of sand and dumping of canal-dredging waste can be accommodated			
BE		Designated RAMSAR areas should be excluded for Windparks			
GR	1	**Oil drilling :** Oil platforms (Northern Aegean Sea)	Ministry of Development		
IR	1	**Dump sites :** Licensed dump sites for the disposal of dredge spoil will be prohibited	[9]	A	English
NL	2	**Cables and Pipelines:** 1km maintenance-access corridor needed around pipelines and power/communication cables (both existing and prospective). Avoid the four locations where pipelines are allowed to landfall. [iv]			
UK	1	**2.f Coastal amenity :** Wind turbines must be assessed and shown to have acceptable effect on amenity Grid connection will have to be assessed and shown to have acceptable effect on amenity and environment Construction, maintenance and decommissioning work will have to be assessed and shown to have acceptable effect on amenity and environment	1	Y	

Table A.3. Social Acceptance

<u>3. Social Acceptance</u> (Public Acceptance and Press Reactions): Please specify national experiences and/or considerations concerning social acceptance regarding *Offshore Wind Farms* during construction and after installation in relation to the topics listed below:				
	Main Conclusions	**References**	**A/N**	**Language**
3.a Does the acceptance in general differ from the reactions known from onshore farms?				
BE	General attitude seems to be somewhat more positive towards off-shore wind energy. Nevertheless NIMBY syndrome exists locally, especially due to fishery interests.(Watch for the BANANA syndrome : Build Absolutely Nothing Anywhere Near Anybody)			
DK	Positive in Denmark compared to onshore	No		
FI 1	Yes and no! Some oppose onland WE and wants it offshore, other the opposite. Offshore is not out of everyone's sight. I.e. summer recreation.			

FR	Not really, but different public : "marine people" are less aware about energetic issues especially offshore ("develop first onshore" is a main issue in France). Difficulty linked to the fact that "terrestrian developers know nothing about the sea and its harsch environment". Lack of communication because of no common language.	Development of offshore projects in Normandy, Brittany, Mediterranee and North Sea, 1998-2000	A	French
GE	Generally not: the closer the more concerned – not in my back yard phenomenon reaction of public living close to development i.e. island communities is rather sceptic with the expectation of negative impact on the touristic attractiveness of the islands otherwise people living far from coast have mostly no or a positive conception of the issue; positive feelings arise from a rather high environmental awareness in Germany and the wish to avoid fossil fuels	oral information and authors perception of the discussion	--	
GR	There are no LSOWE plants installed yet. Onshore WE installations have not caused remarkable public reactions yet, as wind energy is exploited up to date in less frequented or uninhabited areas.	9, 11, 12	N(*)	GR
IR	Some of those who object to onshore wind farms see offshore wind farms as the solution due to the reduction in visual impact. This may change as the farms are developed offshore.			
IT				
NL	generally similar; the main points are impact of birds and landscape			
PL	Not yet known	Seminar "Wind Power Onshore and Offshore"	A	PL
SE	Bockstigen/Valar. Very high acceptance all the time. Utgrunden: Still better acceptance. Very good opinion and very good press. Yttre Stengrund: The constructionperiod has just started. The acceptance has been very good during the planningperiod. Klasården (a 42 MW windfarm under planning outside the Näsudden peninsula): Some criticism because of vicinity to the shore (2 km to the nearest turbine) In general offshore windpower is more accepted than onshore.			
SP	Not available data			
UK	Too early to judge, as only Blyth Harbour (2 turbines) has been realised to date.			

3.b **How is the organization behind offshore wind farms?**				
BE	Currently known projects are developed by consortia consisting of utilities, offshore contracting companies and wind energy developers.			
DK	Mostly utility owned, but efforts to involve cooperatives in order to raise public consciousness about energy and environment.	No		
FI 1	Largely bit utilities that can afford large EIAs but lack "real" local connection.			
FR	The main problem is that there is no rule for building permission. A study has been launched in Languedoc Roussillon in order to define a framework for authorization.			
GE	mostly private investors, some companies noted at stock exchange	oral information and authors perception of the discussion	--	
GR				
IR	The planned offshore wind farms will be privately owned, in some cases consortia. The Irish Wind Energy Association recently established an Offshore Committee to promote and support the development of offshore wind energy in Ireland.	[10]	A	English
IT				
NL	business consortia			
PL	No any offshore farm at all hence difficult to predict.	Seminar "Wind Power Onshore and Offshore"	A	PL

3.b **How is the organization behind offshore wind farms?**				
SE	Development by small developing companies like Vindkompaniet and Eurowind. Constructing by german or danish windturbine manufacturers. Financing by private investors.			
SP	Not available data			
UK				

3.c. Does public involvement influence on public acceptance?				
BE	Unknown			
DK	We think so, but have no investigations to confirm this assertion. The Middelgrunden offshore farm has received broader acceptance than many wind Farms in Denmark – we believe the explanation to be the public involvement in the cooperative.	No		
FI 1	Not experienced			
FR	Yes. An offshore requires the support from all “terrestrian” communities : local community, General Council (department), Regional Council (region). But public is not involved directly in the project (no specific law ind France for public involvment).			
GE	no experience available as there has been no wind farm built yet financial involvement might be more difficult than onshore as investment volumes are expected to be much larger offshore, if a positive effect is to be achieved local public must become involved in the projects	oral information and authors perception of the discussion	--	
GR				
IR				
IT				
NL	not known			
PL	Yes	Seminar “Wind Power Onshore and Offshore”	A	PL
SE	Yes			
SP	Not available data			
UK				

3.d Others				
FI	**How is the public acceptance in relation to environmental impacts? (Please specify cases):** 1Not yet offhsore experiences. On Åland the next to the closest neighbor to a windfarm has lifted a case. All other neighbors (~20) are in favor. Some summer residents have objected to other installed windfarms but cases have been overthrown. In Espoo, outside Helsinki, an initiative was withdrawn after fierce opposition by neighboring summer residents. This has happened also elsewhere.			

3.d Others				
PL	**Barriers obstructing development of RES including offshore power onshore and offshore :** **Legal and financial barriers** Lack of applicable legal solutions describing the strategy in the RES utilisation, Inadequate economical mechanisms, particularly fiscal ones, Relatively high investment costs of RES technologies **Information barriers** Lack of general access to information about distribution of energy potential of particular kinds of renewable energy, Lack of information on manufacturing companies and design engineers and consultants from that area, Lack of generally accessible information on procedures in entering investments, typical costs and benefits from RES utilisation **Lack of state-of-the-art knowledge on RES** Insufficient amount of domestic organisations involved in the process of serial production of equipment utilising the renewable energy, Lack of tax preferences for imports and exports of equipment utilising the renewables **Educational barriers** Inadequate scope of educational curricula, Lack of educational and training programmes on RES addressed to interested parties **Principle of landscape preservation barriers** Lack of developed methods of refraining conflicts with the protection of environment and landscape			

Table A.4 National Policies

4. Politics: Please specify national experiences and/or considerations concerning policies regarding *Offshore Wind Farms* during construction and after installation in relation to the topics listed below:				
	Main Conclusions	**References**	**A/N**	**Lang.**
4.a How is the general reaction and attitude to offshore wind farms?				
BE	Important political support for off-shore wind energy development (and for renewable energy development in general).			
DK	Positive	No		
FI 1	The general opinion is in favor but there is a nimby effect. Opposition not organised but loud.			
FR	Appears as a “new frontier” and a technological challenge for terrestrian politics. Why in the sea for marine organizations.			
GE		authors perception of the discussion	--	
GR				
IR	None built yet but political support does exist in general. No specific targets for offshore wind energy yet.	[9],[11]	A	English
IT 3				
NL	* Positive : The Government has planned to provide 10% of the total energy consumption by renewable energy by the year 2020. The contribution of wind energy is about 2750 MW, and 40-50% of this must be offshore. To create a deeper insight concerning the environmental impacts, among other things, several study projects were done in the recent past. * Many eco-organisations, local as well as international, are participating in these studies. Their attitude is generally positive within a certain corridor of environmental requirements. Imp. : High.	Report [viii]	Y	Yes
PL	Rather positive. A positive response due to a rather scarce knowledge on wind energy in general.	Seminar “Wind Power Onshore and Offshore”	A	PL
SE	Positive except when developers propose provocative projects in highly appreciated recreational areas.			
SP	Very bad attitude in Cadiz. No problems in Huelva			
UK	Much more positive than in the case of on-shore wind farms but it is difficult to judge as developments are at a very early stage.			

4.b Which national planning rules and regulations do exist?				
BE	Off-shore wind energy legal framework is clearly defined, in : • Law on concessions for off-shore wind and wave energy plants (as part of general electricity regulation law). • Law on (environmental) authorisations for all off-shore installations • Law on environmental impact reporting for all off-shore installations Some remaining uncertainties due to necessity of regional autorisations for grid connection.			
DK	The Danish Energy Agency is authorising offshore wind farms inside as well as outside territorial waters. Planned 4000 MW before 2030. A national committee has pointed at specific potential areas of which 750 MW will be utility developed and serve as pilot projects to be established before 2008. There are ongoing negotiations to have 150 MW of these 750 MW owned and developed by cooperatives. After 2008, the offshore wind energy sector will be subject to the same rules as for offshore gas and oil exploitations, i.e. open bidding procedures.	Ref. Nr. 9 Ref Nr. 1 The Danish National Budget 2001	A A A	UK UK DK
FI 1	EIA requested from >50 MW power plants. Suggested for > 10 MW wind farms. Regional planning authorities. Protected areas Local planning permission needed. (Depending on regional land use plan) National "Waters Act" "Environmental Protection Act"	http://www.pvo.fi/merituuli/svenska/index.asp www.vuh.fi	A	
FR	No specific rules. Our work is taken as a guide for future rules (like for onshore wind farms in the 80's)			
GE	Within 12 to 200 miles zone the national authority for sea traffic and hydrography is the entity for permissions, legal basis is the international bill of sea rights together with a national regulation for building and operation of plants in the 12 to 200 miles zone for developments near shore and grid connection through coastal sea the regional governments of the german countries bordering the North Sea are the permitting authorities, regional planning procedures are required in which all relevant national laws and regulations are to be applied – may be rather time consuming	oral information at hearing organised by planning authority and authors perception of the discussion [9]	-- A	 German
GR	Legislation for RES applies also to large-scale offshore wind energy	22, 23, 24	A	GR
IR	Procedures for applying for foreshore licenses (to investigate site suitability) and foreshore leases (to develop wind farms) published. Applications made to Department of the Marine and Natural Resources Offshore wind farms will not, as a general rule, be allowed within 5 km of shore. Certain areas are identified as prohibited to ensure safety at sea, protection of established shipping lanes, air navigation, telecommunication needs and defence requirements Planning permission required from relevant local authority for onshore infrastructure associated with offshore wind farms.	[9]	A	English

4.b Which national planning rules and regulations do exist?				
IT 3	Planned 2500 MW on- and offshore within 2010 according to the National White Paper of 1999. Only a small fraction of this target expected to be offshore. Total offshore potential is about 3000 MW. The Italian Navigation Code (INC) and the Application Guide of INC (AGINC) are the reference legislation for offshore wind farms installation in the Italian national waters; specifically art.36 and following of INC and art.5 and following of AGINC (for the type and format of application documents). Special permits should be considered for offshore Wind Farms, because of the long time limitation related to their presence for the activity of navigation, fishing, marine sport, and others. Many other Administrations are involved in processing the installation permits: Ministry of Transport, of Defence, of Environment, of Industry, of Civil Works, of Sea and Terrestrial Resources (General Direction of Maritime Fishing) and others. The Environmental Impact Evaluation should be considered necessary, even though no clear policy is applied today. At the end of the procedure the Permits are issued by the Compartment of Maritime Transport and shown to public office of interested Municipality and Province for public information and possible opposition. The installation of Offshore Wind Farm and Permit applications is under the control of the local Harbour Authorities by their presence Coastal Guard. Safety features for navigation and aviation are requested in the Permit. Information on the offshore plants is due to Marigrafico office for its inclusion on the nautical charts.	Oil platforms		
NL	Within the 12-mile-zone, apart from a near shore wind farm pilot project (NSW), no wind farms will be allowed. There are practically no Dutch regulations and rules existing for large-scale offshore wind energy outside the 12-mile-zone. This could be positive or negative depending on political will. However, there are several laws and regulations that have to be considered when licenses in the Dutch Exclusive Economical Zone of the North Sea must be gained. These regulations are: • Sea Water Pollution Law (Wet Verontreiniging Zeewater) • Environmental Administration Law (Wet Milieubeheer) • Spatial Arrangement Law (Wet Ruimtelijke Ordening) • Environmental Protection Law (Natuurbeschermingswet) • Governmental Water Works Administration Law (Wet Beheer Rijkswaterstaatswerken) • Wreckage Law (Wrakkenwet) • Monuments Law (Monumentenwet) • Excavation Works Law (Ontgrondingenwet) • North Sea Installations Law (Wet Installaties Noordzee) • (Sea) Bottom Protection Law (Wet Bodembescherming) • Mining Laws 1810, 1903 & EEZ (Mijnwetten 1810, 1903 & NCP buiten 12 mijl – From recent studies, it seems that this law has no implications for offshore wind farms) Route Law (Tracéwet – This law is important for the seaways to be chosen)	[viii] pg.16		No
PL	Very broad planning rules of the Construction Law referring to constructions at sea, Energy Law pointing at the necessity of implementation of renewable resources.	Seminar “Wind Power Onshore and Offshore” Energy Law Construction Law	A	PL

4.b Which national planning rules and regulations do exist?				
SE	Legal framework under construction. In a recently published study carried out by the Swedish Energy Agency (, and initiated by the government with aims to make standards for the future offshore wind power, it is proposed that 3,300 MW of offshore wind power is to be developed within the next 10 to 15 years. Seven offshore areas have been suggested as locations of special interest, first of all in the Southern part of Sweden. For the moment a number of pilot projects are planned, and the intention is to follow these carefully during the whole planning and construction-process. It is expected that the current regulations (2001) are soon to be revised and simplified: • Building Permit required from local authorities' (municipality) building and planning committee, according to the Planning and Building Act. • Permit required from local County Administrative Board concerning environmental issues (according to the Environmental Code). For projects larger than 10 MW, permits are issued by the Environmental Court concerned. • Application for water operation permits shall be considered by the Environmental Court • The government shall assess the permissibility of wind farms inside territorial waters if they are consisting of clusters of three or more wind turbines with a total output of not less than 10 MW. • Construction of wind farms outside territorial waters requires permission from the government. The Swedish Energy Agency issues permits regarding cabling	The governmental directives are available.		
SP	Neither national off-shore plans nor regulations			
UK	Procedure for obtaining consents is being formulated and probably includes [2,3] but may also include [4,5,6] • Defined procedure for obtaining site lease from Crown Estates (who is the "landowner" of most areas within the 12 nautical mile limit). First round of site allocations was made April 2001, where the location of 13 potential offshore wind farm sites was announced. Each site will consist of 30, 60 or 90 turbines. Consents process still evolving but expected to include: • Dept of Trade and Industry (DTI) provide "one-stop" consenting assistance but Dept for Transport Local Government and the Regions (DTLR) and Dept for the Environment Food and Rural Affairs (DEFRA) also involved. • Undertake Environmental Assessment and consultation leading to EIS. • Apply to DTI under the Electricity Act 1989. • Apply to DEFRA under Food and Environmental Protection Act 1985 • .Apply to DTLR under the Coastal Protection Act 1949, or Transport and Works Act 1992.	2,3,4,5,6	N	

4.c Which national incentives do exist and how have they worked? (Give a brief evaluation)				
BE	Currently existing incentives are limited to IPPs and to projects smaller than 10 MW. A new system based on green certificate trading and a renewable energy quota with penalties for the 2 main Belgian regions (Flanders and Wallonia)is expected soon.	Flemish decree from July 17 2000		Y Flemish

4.c Which national incentives do exist and how have they worked? (Give a brief evaluation)

DK	1. Utilities have until now been obligated to buy the energy produced by wind turbines. 2. The feed-in tariff is currently DKK 0.33/kWh (EUR 0.044/kWh) plus green certificates varying from DKK 0,1/kWh to DKK 0,27/kWh (EUR 0.013-0.036/kWh) running for the first 42,000 hours of an offshore project with the rated power in typical places, app. 10 years. For the Horns Rev and Rødsand projects, a tariff of DKK 0,453/kWh (EUR 0,06/kWh) has been set. After 42,000 hours with the rated power the price will be based on the day-to-day market electricity prices plus green certificates. The green certificate system has been progressively delayed and following the outcome of a public hearing on the subject (September 2001), its introduction is postponed for minimum two more years starting up from 2005. 3. Public support for feasibility studies for cooperatives The uncertainty not knowing the prices (due to the introduction of green certificates) makes people reluctant.	Departmental order about Grid Connection	A	DK
FI 3	Investement subsidy of 25-30 % given by the Ministry of Trade and Industry. A part of the energy tax is refunded (0.04 FIM/kWh).			
FR	No specific incentive for offshore, onshore: Guaranteed access, fixed feed-in tariff at app. 0.07 over 15 years			
GE	There is no firm governmental planning to develop offshore wind energy in Germany; Germany's Renewable Energy Sources Act (EEG – Erneuerbare Energien Gesetz) [10] continues the reimbursement at a fixed feed-in tariff. The Development of wind energy in Germany under the umbrella of a fixed feed-in tariff system is seen as a major success and as an appropriate tool to develop a strong market. In the reformed EEG a specially raised tariff is foreseen during the first nine years of operation of an offshore wind farm. This regulation is limited to projects coming online before the end of 2006; no evaluation as of yet – indication for attractiveness is the large number of projects applying for permissions in the German Bight	oral information at hearing organised by planning authority and authors perception of the discussion [3,10]		
GR	i) Subvention of up to 50% of the capital investment, ii) subsidization of loan interest, iii) tax-exemptions			
IR	No specific incentive for offshore wind farms. The Alternative Energy Requirement (AER) competitive bidding process is open to offshore wind energy. The target in AER V for wind energy is 240 MW, 40 MW of which is reserved for small-scale (≤ 3 MW) wind farms. There are also plans for a Grid Upgrade Development Programme to accommodate additional renewable energy based generating capacity. While AER V is open to offshore wind energy projects, planning permission must be evidenced in order to participate in the competition, which will effectively exclude offshore wind farms.			
IT 3	Moving from relaxed fixed price system, with 2001 buy-back prices being EUR 0.124/kWh for the first eight years and EUR 0.069/kWh for the remaining lifetime, to green certificates market in 2002	Green certificates, region structural funds		
NL	* System of Green Certificates : More stability in the renewable energy market, which is a main requirement for potential investors. * Spotmarket mechanism combined with a "Balancing Market" in the Amsterdam Power Exchange will positively affect the windenergy market. (ref. Funtionele eisen van offshore windparken, Kema, dec. 1998, pg. 15) * Fiscal incentives: Subsidies, REB (eco-tax), Vamil, Fiscal incentives do not yet apply outside the 12 nm zone.	[viii] pg.16		
PL	None.	Seminar "Wind Power Onshore and Offshore"	A	PL

4.c Which national incentives do exist and how have they worked? (Give a brief evaluation)				
SE	There are no earmarked incentives focused on offshore windpower. The general support for introducing windpower in the powersystem is: 1. Investment aid, 15% of the total investment in a windpower plant is paid as a state subsidy. 2. Environmental bonus which is connected to the tax system for electric power , from 1 jan 2001, 0,181 SEK (0,02 EURO) 3. Special support in order to make relief the consequences of fast decreasing power prices after deregulation 0,09 SEK (0,01 EURO) 4. Right to connect a small scale power station to the electric grid (small scale < 1,5 MW) 5. Special pay for decreasing losses in the electric grid up to 0,02 SEK (0,002 EURO). A recent study initiated by government shall investigate how the above mentioned support system can be replaced of a green certificate system 1 Jan 2003. Brief evaluation: The support system has been working the way it was intended – to develop an annual production of 0,5 TWh electric power from wind- but it has not given the long time security which is needed to interest investors and creditors. For example, todays support system finishes 31 december 2002 with only promises of a new one which nobody knows how it will be designed.	Law and regulations texts edited by the Parliament, the Government and the energy Board	some	english
SP	No differences with onshore farms: The strategy of the Spanish government is summarized in the new "Program for Promotion of Renewable Energies" (Reference 1) approved by the Parliament to maintain the situation of the Royal Law 2818/1998-23 December 1998, about the Electrical Special Regime for Renewable Energy Plants connected to the grid. That law fixed the price and the bonus of the electricity produced by renewable energy plants, price that will be up-dated every year by the Spanish Ministry of Energy and Industry according to the annual variation of the market price. All owners of installations using renewable energies as primary source, with an installed power equal to or lower than 50 MW, have two choices, one is a fixed priced for the kWh generated, and a second option is a variable price, calculated from the average price of the market-pool, plus a bonus per kWh produced. In 2000 the bonus added to the base price was 0,0288 Euro/kWh and the fixed price was 0,0626 Euro/kWh. This program was prepared by IDAE (the national Diversification and Energy Saving Agency) and is the response to the undertaking Law 54/19976 on the Electricity Sector which defined the target of achieving at least a 12% of contribution to electricity demand in Spain from renewable energies by the 2010. The work was, at the same time, the Spanish incorporation of the European recommendations made in the White Paper on Renewable Energies.			
UK	Primary market is likely to be Licensed UK Electricity Suppliers to fulfil their Renewable Energy Obligation commitments. Revenue will consist of: • Energy sale to supplier on a "negative demand" contract or through amalgamation mechanism on NETA power exchanges. • Sale of Renewables Obligation Certificates (ROCs). • Sale of Climate Change Levy Exemption Certificates • Use of system charge or benefit Net value of the above expected to be around GBP 0.05/kWh (EUR 0.08/kWh). Internationally traded Green Certificates may also play a role. Capital grant budget recently announced of £39m from DTI plus £50m from National Lottery for offshore wind power (mainly) and biomass. Distribution method under discussion.	7	Y	

Country specific list of relevant references:

Ref. Nr.	References	Content
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DK 1	Danish Ministry of Environment and Energy (1996): *Energy 21. The Danish Government's Action Plan for Energy*, Danish Energy Agency - Copenhagen	The Danish government's action plan for energy in the new century
2	EC Directives 85/337/EEC and 97/11/EEC	On documentation and monitoring of environmental impact from large public and private construction projects.
3	Elkraft Power Co./SEAS A.m.b.a. (1997): "Offshore Wind Farm at Vindeby, Lolland", Final Report to the EU-Commission, 2nd Ed.	Experiences from designing, installing, servicing and operating the Vindeby Offshore Wind Farm, installed 1990 to 1991 with 11 450 kW wind turbines.
4	Elsam (2000) Høring om Havvindmøllepark ved Rødsand (Environmental Impact Report on offshore wind power park at Rødsand)	Case Study: Report on environmental Impact of an offshore wind power project prepared for the public hearing process. Available at http://www.ens.dk/nyt/Hoeringer/VindRoedsand/hoering_Roedsand.htm with English summary
5	Elsam & Eltra (2000): Høring om Havvindmøllepark på Horns Rev (Environmental Impact Report on offshore wind power park at Horns Rev)	Case Study: Report on environmental Impact of an offshore wind power project prepared for the public hearing process. Available at http://www.ens.dk/nyt/Hoeringer/VindHornsRev/hoering.htm with English summary
6	Energistyrelsen (1995): Vindmøller i danske farvande. Kortlægning af myndighedsinteresser, vurderinger og anbefalinger. (Wind turbines in Danish waters. Survey of public authority interests, evaluations and recommendations). Danish Energy Agency - Copenhagen (In Danish)	Includes a map of areas that must not, areas that might, and areas with priority to be used for offshore wind power, including which of the technical barriers above are valid for each area. Only available in Danish.
7	Energistyrelsen (1998): Retningslinier for udarbejdelse af miljøredegørelser for havmølleparker (Guidelines for environmental impact analyses for offshore wind power parks) Rambøll - Copenhagen (In Danish)	Implementation of the environmental directives for offshore wind power in Denmark
8	Nielsen, B. et al. (1996): ”Wind Turbines & the Landscape", Birk Nielsens Tegnestue - Aarhus	Different visualizations
9	The Offshore Wind Farm Working Group (1997): "Action Plan for the Offshore Wind Farms in Danish Waters"	Action plan for the offshore wind Farms in Danish waters
10	Sørensen et. al. (1999): VVM redegørelse for vindmøllepark på Middelgrunden (Environmental Impact Assessment Report of the Wind Farm Middelgrunden), Copenhagen Utility and Middelgrundens Vindmøllelaug - Copenhagen (In Danish, with English summary)	Environmental Impact Assessment Report of the Wind Farm Middelgrunden
FI	-	
FR 1	Offshore identification in Nord-Pas de Calais, EED, 1997 (for regional Council)	GIS, environmental and technical constraints, wind potential, identification of potential sites
2	Development of a 7.5 MW offshore wind project in Dunkerque, EED for SAEML/Shell Renewable/Total and Jeumont, 1998-2000	Technical and economical definition of the project. Approval in EOLE 2005 call for tender.
3	Offshore identification in Brittany, EED, 1998 (for ADEME)	GIS, environmental and technical constraints, wind potential, identification of potential sites, pre-development of one site
4	Development of offshore site in Northern Finistere, EED/Total, 2000	Development of the project. Wind measurement in progress. Measures on site (bathymetry, geotechnics)
5	Offshore identification in Normandy, EED, 1999-2000 (for ADEME and regional Council)	GIS, environmental and technical constraints, wind potential, identification of favourable zones for offshore (3 zones)
6	Development of offshore site in Normandy, EED/Total, 2000	Development of the project. Wind measurement in progress. Measures on site (bathymetry, geotechnics)
7	Offshore identification in Normandy, EED, 1999-2000 (for ADEME and regional Council)	GIS, environmental and technical constraints, wind potential, identification of potential sites, pre-development of one site
8	Development of offshore site in Normandy, EED/Total, 2000	Development of the project. Wind measurement in progress. Measures on site (bathymetry, geotechnics)
9	Offshore identification in Languedoc Roussillon, EED, 1999-2000 (for ADEME and regional Council)	GIS, environmental and technical constraints, wind potential, identification of favourable zones for offshore (3 zones)

10	Development of offshore site in Languedoc (Port La Nouvelle), EED/Total, 2000	Development of the project. Wind measurement in progress. Measures on site (bathymetry, geotechnics)
GE 1	Merck, Th: Mögliche Konflikte zwischen der Offshorewindenergienutzung und dem Naturschutz. In: Offshore-Windenergienutzung: Technik, Naturschutz, Planung.Deutsches Windenergie-Institut (Editor):Workshop Proceedings. Wilhelmshaven: DEWI, 2000, p. 49-58.	see previous pages
2	Garte, St.: Möglicher Einfluß der Offshorewindenergienutzung auf die Avifauna. In: Offshore-Windenergienutzung: Technik, Naturschutz, Planung.Deutsches Windenergie-Institut (Editor):Workshop Proceedings. Wilhelmshaven: DEWI, 2000, p. 71-76.	see previous pages
3	Söker, H. et al.: North Sea Offshore Wind – A Powerhouse for Europe. Technical Possibilities and Ecological Considerations. A Study for Greenpeace. Hamburg, Germany: Greenpeace, 2000.	see previous pages
4	Lucke, K.: Möglicher Einfluß der Offshorewindenergienutzung auf marine Lebewesen. In: Offshore-Windenergienutzung: Technik, Naturschutz, Planung.Deutsches Windenergie-Institut (Editor):Workshop Proceedings. Wilhelmshaven: DEWI, 2000, p. 59-70.	see previous pages
5	Ehrich, S.: Auswirkungen von Offshore-Windkraftanlagen auf Fische. In: Fachtagung Offshore-Windparks 30.05.2000. NNA Alfred Toepfer Akademie für Naturschutz (Editor):Workshop Proceedings. Schneverdingen: NNA, 2000.	see previous pages
6	Heuers; J.: Mögliche Auswirkungen von Offshore-Windkraftanlagen auf die Lebensgemeinschaften am Meeresboden. In: Fachtagung Offshore-Windparks 30.05.2000. NNA Alfred Toepfer Akademie für Naturschutz (Editor):Workshop Proceedings. Schneverdingen: NNA, 2000.	see previous pages
7	Schörshusen, H.:Offshoreplanungen des Landes Niedersachsen. In: Offshore-Windenergienutzung: Technik, Naturschutz, Planung.Deutsches Windenergie-Institut (Editor):Workshop Proceedings. Wilhelmshaven: DEWI, 2000, p. 94-100.	see previous pages
8	Braasch,W., Freese, T.:Kollisionsrisiko Schiffahrt. In: Ökologische Auswirkungen durch Offshore Windenergie-Anlagen – Workshop, Ministerium für Umwelt, Natur und Fosrten des Landes Schleswig-Holstein: Oral Presentation at Workshop, Kiel, 12.December 2000.	see previous pages
9	*Hübner* 2000:Offshore Windenergieanlagen: Planungs-und Genehmigungsrechtliche Grundlagen für die errichtung und den Betrieb von Windenergieanlagen in Küstengewässern und in der Ausschließlichen Wirtschaftszone –ZUR 2/2000.	see previous pages
10	Germany's Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act).	see previous pages
GR		
1.	Αβούρη, Α., Β. κ.ά «Η ελληνική νομοθεσία για το περιβάλλον», Αθήνα, ΤΕΕ, 1993, τόμ. 2, σ. 214-232	Greek legislation for environment (overview)
2.	Βαλιάτζα-Αφτιά, Ε, (1981) «Θεσμός εκτίμησης περιβαλλοντικών επιπτώσεων: Πόσο αποτελεσματικός για την προστασία του περιβάλλοντος», Αθήνα-ΤΕΕ, ΤΕΠ ΜΕΛ-Μ651	Legislation for assessment of environment impact
3.	Βασιλόπουλος, Μ. (1998) «EMAS ή ISO14000 ? Μία συμβολή στο θέμα», Αθήνα-ΤΕΕ	Evaluation of different environmental standards
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5.	Δαγρές, Δ. (1981) «Μελέτη της νομοθεσίας περί αιγιαλού και παραλίας», ΤΕΠ ΜΕΛ-Μ727	Environmental legislation for shoreline
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8.	Μπούρα, Α., Μουσιόπουλος, Ν. (1998) «Η ανάλυση κύκλου ζωής (LCA) ως εργαλείο περιβαλλοντικής διαχείρισης», ΤΕΠ ΜΕΛ-Μ1674	Life cycle analysis

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10.	Βουρδουμπάς, Γ. (1995) «Εφαρμογές ΑΠΕ στα ξενοδοχεία σε νησιωτικές περιοχές της χώρας», ΤΕΠ ΜΕΛ-Μ1490	Application of RES in recreation areas on the Greek islands
11.	Γκούμας, Θ., Καράλης, Γ. (1993) «Νέες ενεργειακές τεχνολογίες και περιβαλλοντικές επιπτώσεις – Η συμβολή του προγράμματος THERMIE και των οργανισμών ΟΠΕΤ», ΤΕΠ ΜΕΛ-Μ1229	Environmental impact of new energy systems
12.	Καράγγελος, Ι. κ.ά. (1993), «Η συμβολή των ΑΠΕ στη μείωση της ρύπανσης του περιβάλλοντος – Ελληνική πραγματικότητα», ΤΕΠ ΜΕΛ-Μ1229	The contribution of RES to pollution reduction
13.	Παπαστεφανάκης, Δ., Γαρυφαλάκης, Σ. (1989), «Δυνατότητα εκμετάλλευσης της αιολικής ενέργειας από φορείς της τοπικής αυτοδιοίκησης στην Κρήτη», ΤΕΠ ΜΕΛ-Μ982	Application of wind energy on Crete
14.	«Βασικοί υγρότοποι της χώρας (εκτός συμβάσεως RAMSAR). Α' φάση», (1979), Υπ. Συντονισμού, 242 σελ.	Water biotops in Greece
15.	Διαχείριση και προστασία σημαντικών οικοτόπων στην Ελλάδα: μέσα από προγράμματα του WWF Ελλάς» (1995), WWF Ελλάς, 20 σελ.	Protection of biotops in Greece
16.	«Κατάλογος φυσικών προστατευόμενων περιοχών της Ελλάδας» (1992), Περ. Η Φύσις, τεύχ. 58, σελ. 23-25	Catalog of natural protected areas in Greece
17.	«Σημαντικές περιοχές για τα πουλιά της Ελλάδας: μία γνωριμία με τους σημαντικούς βιότοπους της Ελλάδας» (1994), Ελληνική Ορνιθολογική Εταιρία, 271 σελ.	Bird biotops in Greece
18.	Σφήκας, Γ. (1995) «Βιότοποι της Ελλάδας», Εκδ. Πατάκης, 40 σελ.	Biotops in Greece
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20.	«Η μεσογειακή φώκια κινδυνεύει άμεσα με εξαφάνιση: βοηθήστε μας να την σώσουμε», Αθήνα-ΕΟΤ	The Mediterranean seal monachus-monachus is endangered! Help protect them!
21.	Κατσακιώρη, Μ. (1995), «Κατάλογος περιβαλλοντικών οργανώσεων της Ελλάδας, χωρών της Ευρώπης και της λεκάνης της ΜΕσογείου», Θεσσ/νίκη ΕΚΒΥ, 54 σελ.	Catalgue of environmental-ecological organizations in Greece, Europe and othr Mediterranean countries
22.	Υπουργική Απόφαση. Δ6/Φ1/ΟΙΚ.8295/19.4.1995, Εφημερίς της Κυβερνήσεως, Αρ. Φύλλου 385, 10/5/1995	Council resolution governing energy production-distribution incl. RES
23.	Νόμος Αριθ. 2773, Εφημερίς της Κυβερνήσεως, Αρ. Φύλλου 286, 22/12/1999	Law governing energy production-distribution incl. RES
24.	Νόμος Αριθ. 2601, Εφημερίς της Κυβερνήσεως, Αρ. Φύλλου 81, 15/4/1998	"
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2	Marine Institute (2000) *Assessment of the Impacts of Offshore Wind Energy Structures on the Marine Environment*	Environmental impacts restricted to those "below the water"
3	Madsen P. (1996) *Tuno Knob Offshore Wind Farm* Proc EWEC 1996	
4	Percival S. M. (1999) *Ornithological Impacts of Offshore Wind Farms.* University of Sunderland	
5	Percival S. M. (1998) *Birds and Wind Turbines: Managing Potential Planning Issues.* Proc BWEA 1998	
6	Percival S. M. (1998) *Assessing the Ornithological Effects of Wind Farms: Managing Potential Issues.* Proc BWEA 1998	
7	Percival S. M. (2000) *Ornithological Impacts of Offshore Wind Farms.* Irish Sea Forum Seminar Report No. 23	
8	Guillemette M., Larsen J.K., and Clausager I. (1999) *Assessing the impact of the Tuno Knob wind park on sea-ducks: the influence of food resources.* National Environmental Research Institute, Denmark. Technical Report no. 263	
9	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.*	How to apply for a foreshore license and foreshore lease for an offshore wind farm or wave energy plant
10	Irish Wind Energy Association (2000) *In the Wind*	IWEA newsletter
11	Department of Public Enterprise (1999) *Green Paper on Sustainable Energy.* Available at http://www.irlgov.ie/tec/energy/renewinfo.htm	National policy on sustainable energy
IT	-	

NL i	On foraging birds, *Pedersen & Poulsen*,(IBN-DLO, 1992)., 1991	
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iii	Wind mee of wind tegen, a preliminary study to the ecological effects of an offshore windturbinepark *Grontmij groep*, 1998	
iv	Milieu-effectrapport, Locatiekeuze Demonstratieproject 'Near Shore Windpark', *Ministerie van Economische Zaken* en *Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer*, 2000	
v	Een windpark op zee - een kwalitatief onderzoek, *Infomart*, 1999	
vi	North Sea Atlas, for Netherlands Policy and Management, Amsterdam, *Interdepartmental Co-ordinating Committee for North Sea Affairs (ICONA)*, 1992	
vii	van de Sande A.M.C., Windfarm Lely - first off-shore project in the Netherlands, *OWEMES Conference*, 1997	
viii	Haalbaarheidsstudie Demo. Project, Near Shore Windpark, *Novem*, 1997	
PL 1	Energy Law, 10th April 1997, with changes -June 2000	**Art. 15, p. 7.** Foundations for national energy policy are required to designate development of renewable energy sources utilisation. **Art. 16, p. 3.2.** Energy plans prepared by energy companies are required to include renewable energy sources. **Art. 19, p. 1 & 2.3.** Municipal authorities are required to prepare projects of energy plans foundations including utilisation of renewable energy sources **Art. 32, p. 1.1.** Power production in sources of more than 5 MW capacity requires obtaining a concession in the Energy Regulation Office. **Art. 9, p. 3.** The Minister of Economy is required to issue a decree obliging energy utilities to buying power from renewable energy sources
2	Spatial Planning Law, 1994	
3	Protection and Shaping the Environment Law, 1980	
4	Nature Protection Law , 1991	
5	Regulations on Transport and Communication Safety	
6	Construction Law	**Art. 3, p. 3.** Structures serving as energy producing devices are so called constructions. This means that it is necessary to fulfill all the investment process requirements for constructions of that kind to construct, exploit and take them into pieces. **Art. 34, p. 3.** Applications for construction permits for structures that are not included in the Polish Norms and legal regulations, should be supplemented by a specialised expertises issued by an organisational body or a person, pointed by the Minister. **Art. 59, p. 1.** A constructing supervision organ in the construction permit may oblige an investor to obtain a utilisation permit. **Art. 56, p. 1**. Investor should inform an appropriate National Environmental Protection Inspection organ about finishing construction works.
7	**Decree on obligation of buying power and heat from non-conventional energy sources and the scope of the obligation** ***Ministry of the Economy,*** February, 2nd, 1999	**Paragraph 1.** Energy utilities carrying on economic activity in the field of power or heat trade, described further on as "turnover companies", are obliged to buying, from domestic producers, proposed amounts of power and heat from non-conventional sources, including renewable energy sources, described further on as "sources", in particular heat and power from: hydro power plants, wind turbines, biogas produced in particular in: animal waste utilisation systems, waste water treatment plants, local waste dumps, biomass, photovoltaics, thermal solar collectors, geothermy.

		Paragraph 2. Obligation in question in Par.1, does not refer to buying power nad heat produced in: sources belonging to the turnover companies or being under turnover companies' control, sources which rated power is higher than 5 MW, sources using fissile fuels in production process, sources constructed within national investments. **Paragraph 3.** Turnover companies are not obliged to buying power and heat from the sources, if the price: of a power unit is higher than the highest valid price of a power unit in the company, binding in the tariff for a power unit supplied to the end-users, connected to the low voltage grid, of a heat unit higher than the highest price of a heat unit offered by other suppliers producing heat from conventional sources.
8	Proceedings of a international seminar: Wind Power Onshore and Offshore, Sopot, 15-17 December 2000	
SE 1	STEM (Swedish Energy Agency), 2001: Vindkraften i Sverige [Wind Power in Sweden]	
SP 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	Saenz García de Albizu, J.C., 1995. El Desvío de Ruta en el Transporte Marítimo. Servicio Central de Publicaciones del Gobierno Vasco. 158 p.	
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7	The 1999 IEA Wind Energy Annual Report, Published by NREL, Colorado, USA	
UK	1. UK DTI. An assessment of the environmental effects of offshore wind farms. ETSU W/35/00543/REP. Contractor Metoc PLC, Published 2000. 2. Transport and Works Act 1992. 3. Food and Environmental Protection Act 1985. 4. Coast Protection Act 5. Electricity Act 1989 6. Town and Country Planning Act 1990. 7. UK DTI. The Renewables Energy Obligation – preliminary consultation. October 2000. Additional DTI, Ofgem and ministerial statements October – December 2000.	

APPENDIX 3:

GENERAL BIBLIOGRAPHY

Cluster 1 : Offshore Technology

R&D plans/needs

- Offshore Wind Energy Network. OWEN (Research Requirements Workshop, Final Report of G.Watson RAL April 1999

Papers from journals and conferences

- Wind Engineering 1989 vol. 13, n.8 ("Cost modelling of HAW Turbines" F. Harrison page 315)
- WEGA 1 : Hau,J. Langenbrinck, .Palz-Springer Verlag 1993
- European Wind Energy Conference 1994 in Thessaloniki (Economic Optim. of HAWT Design Parameters of Collecut-Univ Ukland , page 1244; Tecnic.and Economic Develop.of W.E.in Germany of Molly, DEWI page. 1251)
- OWEMES 94 Conference Rome – (Cost of offshore wind energy in UK North Sea, Simpson-WEG, page 267)
- European Wind Energy Conference 1996 in Goteborg ("Wega II Large wind turbine Scient. Evaluation Project" Christiansen Elsam page 212)
- WEGA2, EUR 16902 EN-1996
- OWEMES 97 La Maddalena ("Opti-OWECS preliminary cost model" of Cockerill/Harrison-Univ. of Sunderland; "Structural and economic optim. Of OWEC" of Kuen pag 165)
- OWEE website (Opti-OWECS Final Report Vl.0 .August 1998 of Kuehn et Al.-TUD)
- EWEC 1999 in Nizza ("Struct. and economic Optim of Bottom mounted OWECS" of Kuehn TUD page 22; "Techn.Develop. for Offshore" of Jamieson GH&P page 289; "Experience with 3000 MW w.Power in Germany" of Durstewitz et Al. ISET page 551)
- Wind Engineering vol. 24, n.2,2000 ("Wind Energy Technology: status review" of D. Milborrow page 65)
- Technology Development For Offshore, P. Jamieson & D C Quarton. EWEC 99, Nice, March 1999

standards

- American Petroleum Institute (API), Fixed offshore platforms, Working Stress Design, 1993
- American Petroleum Institute (API), Fixed offshore platforms, Load Resistance Factor Design, 1989.
- Draft ISO 13819-2 Petroleum and Natural Gas Industries - Offshore Structures - Part 2: Fixed steel structures.
- IMO, MODU-Code, Code for the construction and equipment of mobile offshore drilling units, 1989.
- Cap 437, Offshore Helicopter Landing Areas.
- Det Norske Veritas, Rules for classification of fixed offshore installations.
- IMO, Safety of Life at Sea Convention (SOLAS).
- Health & Safety Executive: Offshore installations: guidance on design, construction and certification (fourth edition) HMSO 1990 ISBN 011 4129614.

electrical systems

- Variable Speed Drives: VALLIADIS SA (? ? ? ? ?? ? ? S AE): Manufacturer of electrical generators for wind turbines; Contact: Mr. G. Koulepis; tel: +1-2817217, 2832602; valiadis@hol.gr; www.valiadis.gr; Research conducted at the National Technical University of Athens focuses on permanent magnet generator design, gearless generator design, artificial intelligence techniques, a.o.
- Flexible Cables: FULGOR – GREEK ELECTRIC CABLES SA; Production & deployment of submarine power cables; Contact: Mr. N. Boutopoulos; tel: 6852100; nboutopoulos@fulgor.gr; www.fulgor.gr

Cluster 3 : Resources and Economics

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

Projects

- MORE CARE - more advanced control advice for secure operation of isolated power systems with increased renewable energy penetration and storage (EU Contract number 1999/C 77/13).
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