REPORT FROM MEGAVIND
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DENMARK - SUPPLIER OF COMPETITIVE OFFSHORE WIND SOLUTIONS

Megavind's Strategy for Offshore Wind Research, Development and Demonstration

MEGAVIND

Content

ABBREVIATIONS

ACER	Agency for Cooperation of European Regulators
CAPEX	Capital expenditure
CoE	Cost of Energy
DOE	Department of Energy (US)
ENTSO-E	European Network of Transmission system Operators for Electricity
EERA	European Energy Research alliance
HVDC	High Voltage Direct Current
HVAC	High Voltage Alternating Current
IPR	Intellectual Property right
O&M	Operation and maintenance
OPEX	Operational expenditure
RD&D	Research, development and demonstration
SET-Plan	Strategic Energy Technology Plan

Preface

In May 2006, the Danish Government presented a report on promoting environmentally effective technology and established a number of innovative partnerships. The partnerships intend to strengthen public-private cooperation between the state, industry, universities and venture capital to accelerate innovation for a number of green technologies. The partnership for wind energy is called Megavind.

Megavind's vision is to maintain Denmark as a globally leading hub in wind power. The following partners represent the sector:

- Vestas Wind Systems A/S
- Siemens Wind Power A/S
- DONG Energy
- Grontmij I Carl Bro
- The Technical University of Denmark
- Risø DTU - National Laboratory for Sustainable Energy
- Aalborg University
- Energinet.dk (observer)
- Danish Energy Agency (observer)

Megavind's strategy for offshore wind describes the offshore challenges and suggests research, development and demonstration (RD&D) priorities to enable offshore wind power become to competitive with other energy technologies. The strategy lists key recommendations as well as key thematic priorities and for each of these a number of RD&D priorities. Under each thematic priority references are made to the European Strategic Energy Technology plan (SET-plan), which prioritises offshore wind RD&D in Europe.

The strategy content and recommendations are based on inputs from a long list of Danish offshore players both from industry and research organisations.

The Danish Wind Industry Association functions as secretariat for Megavind and Risø DTU has co-authored the strategy.

The Megavind Vision and Target for Offshore Wind

Megavind's vision is to maintain Denmark as a globally leading hub in wind power.

The Megavind target for offshore wind is to drive down cost of energy (CoE) from offshore wind farms and to half the CoE from new installations on comparable sites before 2020.

This will make offshore wind competitive with newly built coal-fired power, and in the process most likely achieve cost-competitiveness with all other new-built electricity generation, except for onshore wind.

This ambitious target may be met through concerted effort from industry, research and governments.

Three main achievements must be realised by industry and research between 2010 and 2020. Firstly, newly built offshore wind farms must be able to produce roughly 25% more electricity per installed MW. Secondly, the capital expenditure including costs per installed MW must be reduced by approximately 40%. And thirdly, the cost of operation and maintenance per installed MW must be reduced to about half.

Cost efficiency gains at this scale are considered necessary to maintain public and political support for large-scale implementation of offshore wind in Europe and globally, and to maintain the competitive edge of Danish actors in this market.

Three important preconditions must be met by governments to reap the full benefits of the technology gains proposed. Policy makers and planners have a very direct impact on the future CoE and competitiveness of offshore wind.

Firstly, economies of scale and industrialisation are the main drivers and technology development the enabling factor in reducing CoE. The reduction target presumes a high degree of political certainty for gradually increasing the annual new build rate over the period towards 2020 to allow the industry to make planned investments in industrialisation. Secondly, governments must deliberately improve their planning systems and enable use of more cost-efficient sites. The European pipeline for offshore wind towards 2020 is for political reasons planned further from shore, and at greater water depths, compared to the average operating wind farm installed prior to 2010. The described technology driven cost efficiency gains could well be offset by higher cost related to the site selection. Thirdly, governments must put in place the necessary core funding for RD&D as described in this strategy.

The vision and target achievements are considered necessary and feasible by the key sector organisations.

Main Recommendations

Denmark's stated vision is to continue to be world leading in green energy technologies, including offshore wind. At the same time, other governments in Europe and elsewhere are keen to attract these industries and are raising considerable support.

The strategy report describes 7 thematic priorities and lists specific RD&D priorities for each. These are selected by Megavind on the basis of their potential to contribute to the 50% CoE reduction target. Several of the specific RD&D activities described in this report are about enabling economies of scale and industrialisation. Government funding for these priorities will help drive down the CoE from offshore wind farms and will help increase the competitiveness of actors taking part in the activities.

More than ever it is important for any government to ensure that increased government programmes will in fact attract investments in private RD&D. Therefore, there is an increased need for targeting government programmes towards the specific needs of the sector.

Danish government RD&D programmes are negotiated annually as part of Government's fiscal budget. This creates unnecessary uncertainty for companies planning RD&D investments in Denmark. It is recommended that government RD&D funding programmes instead have a longer term framework, e.g. rolling three-year budgets.

Public RD&D expenditure on wind energy remains low compared to the private RD&D expenditure. Studies indicate a RD&D intensity of 2.6-3.0% of annual turnover in the wind industry. For the Danish wind industry with an annual turnover in 2009 of 51 billion DKK, this would amount to 1.3 – 1.5 billion DKK. Effectively, the sum invested by Danish actors is considerably higher but more precise figures are not available.

In the same year, the sum total of all Danish public energy RD&D expenditure was approximately 1 billion DKK, of which 131 million DKK was granted to wind energy RD&D projects. This corresponds to just 8-10% of the private RD&D wind energy investment in Denmark. The EU Strategic Energy Plan (SET-plan) recommends a 50/50 ratio for public/private investment in RD&D.

Effectively, the Danish government funded RD&D for wind energy is matched 10 times over by private research, development and demonstration activities in Denmark.

While private RD&D investments will continue to be the main source of investments in offshore wind RD&D, a general recommendation is that Danish government RD&D programmes for energy RD&D should be gradually increased from its current approximately 1 billion DKK annually to at least 4 billion DKK annually in 2020.

With a view to drive innovation and demonstrate skills and competences of Danish energy actors, including industry, research institution and public agencies, the Megavind partnership recommends:

- All government funding to energy RD&D priorities should be awarded according to a well-described potential to reduce CoE. For offshore wind, the Megavind offshore strategy may be used as a guideline.

- A substantial share of future new offshore wind capacity installed in Danish waters between 2010 and 2020 should be reserved for offshore demonstration projects, including 10x50 MW smaller projects preferably on near-shore locations. New and innovative solutions in several of the focus areas outlined will not be implemented at a commercial scale before these have been demonstrated in full scale. A mechanism to enable and provide co-funding should be put in place.

- The cross-border offshore wind farm at Kriegers Flak is recommended established as the next large wind farm in Denmark. Notably, this project will develop and demonstrate new and innovative solutions needed to realise the planned future offshore grids in the Baltic and North Sea.

- Special attention should be given to ensure and support investments in world class full scale test facilities for large nacelles and critical components.

- The Offshore Wind Turbine Action Plan should be updated, including potential use of near-shore sites for demonstrations purposes. This planning tool already incorporates considerations for choosing sites with lowest resulting CoE, but more comprehensive data, in particular wind, wave and soil data, are needed to lower risks for future developers on selected sites.

The strategy should also be embraced by educating institutions in order to ensure a relevant supply of competent graduates for the sector matching the thematic priorities.

The Megavind thematic priorities and RD&D priorities are described in detail in the following chapters. An overview is provided in figure 1 below.

Figure 1

Thematic priorities and detailed RD&D priorities

PLANNING AND SITE SELECTION	• Spatial and physical planning methodologies • Models for site assessment and planning • Cost integration and site assessment tools • Accurate wind resource assessment and design models and tools
WIND FARMS	• Tools for wind farm layout and wind farm control • Offshore wind power plant capabilities • Ancillary services from wind farms • Short term wind prediction
WIND TURBINES	• Accelerated full scale test of turbine and components • Design conditions for reliable and multifunctional turbines in farms • Design basis for large offshore turbines in integrated farms • New rotor concepts
FOUNDATIONS	• Optimised manufacturing processes • Optimised, costefficient foundations (gravity based structure, monopile) • New, cost-competitive foundations (jacket, tripod, suction bucket) • Design methods and tools for ground and seabed conditions
ELECTRICAL INFRASTRUCTURE	• Voltage level and turbine rated capacity • Combining grid connection with interconnections between power systems areas • Power system compliance for wind farms
ASSEMBLY AND INSTALLATION	• Pre-assembly of standardised, stackable components at harbour • Modularisation and standardisation of substations and connection • Cable installation on seabed, quality and protection of cables in farms • Optimised installation methods and planning
OPERATION AND MAINTENANCE	• Risk-based cost-optimal O&M planning • Cost-optimal and weather robust mobile access

Cost of Energy Projections

This strategy report's primary target is to reduce CoE for offshore wind by 50%. The formula in figure 2 below describes the basic concept of CoE.

Figure 2

CoE equals costs divided by production

$$\text{CoE} = \frac{\text{Annualised CAPEX} + \text{Annualised OPEX}}{\text{Annual Energy Production}}$$

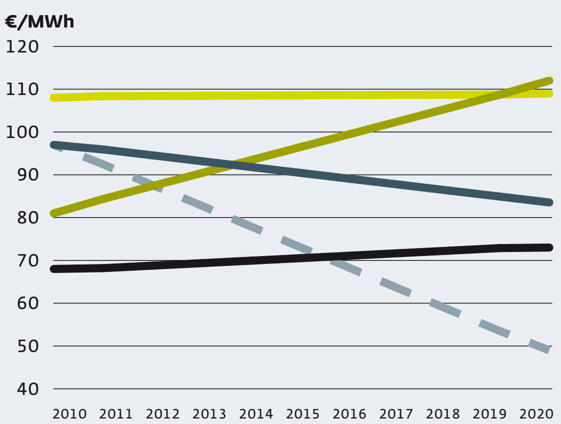
As is shown, three main factors determine CoE: CAPEX, OPEX and annual energy production.

The target to reduce CoE for offshore wind by 50% by 2020 rests on three main achievements to be met between 2010 and 2020. Firstly, newly built offshore wind farms must be able to produce roughly 25% more electricity per installed MW (annual energy production). Secondly, the capital expenditure (CAPEX) per installed MW must be reduced by approximately 40%. And thirdly, the cost of operation and maintenance (OPEX) per installed MW must be reduced to about half.

In figure 3 below, CoE figures are calculated based on data from the Danish Energy Agency and compared to the Megavind target for offshore wind (dotted line). In both calculations for offshore wind CoE a lifetime of 20 years is used, and a discount rate of 10%. As shown, the Megavind target is considerably more ambitious than existing projections.

Figure 3

Projections for CoE from new built power stations



SOURCE: Danish Technology Catalogue, Danish Energy Agency, 2010; Nielsen et al, 2010 and own calculations. CoE is defined as the average CoE measured in €/MWh during the total life span of the electricity production facilities. The calculations for offshore wind power and coal CoE include: Construction costs, discount rate (10%), Operation and maintenance cost, Fuel costs (coal, gas and wood pellets), cost of CO_2 emission quotas, NOx, SOx and other emission taxes. For offshore wind, a life span of 20 years is assumed.

Thematic Priorities

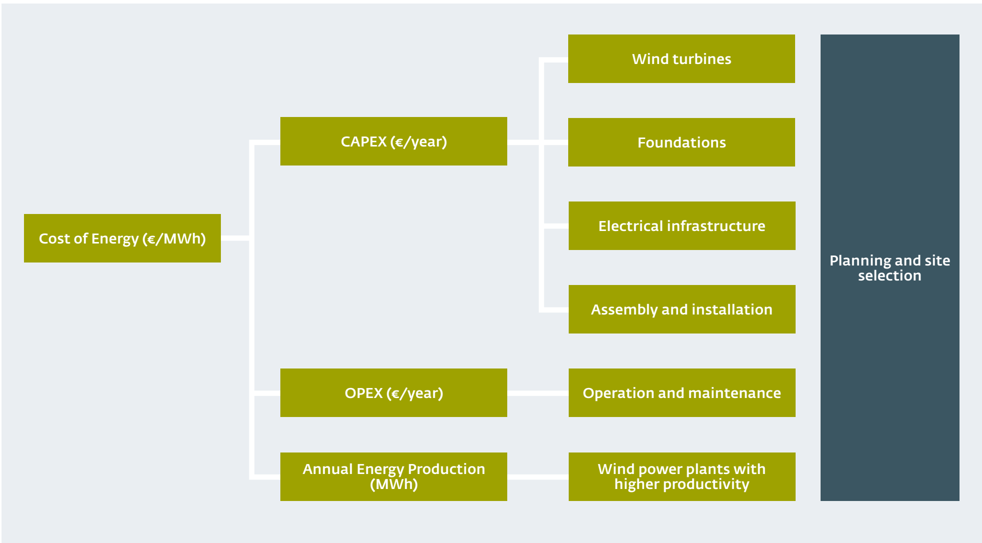
Megavind has identified seven interrelated thematic priorities and specific RD&D priorities, each of which holds considerable potential for driving down CoE over the next 10 years and bring Danish competences at the forefront in offshore wind energy.

1. **Planning and site selection**
2. **Wind farms**
3. **Wind turbines**
4. **Foundations**
5. **Electrical infrastructure**
6. **Assembly and installation**
7. **Operation and maintenance**

The priorities are selected on the basis of their potential for contributing to CoE reduction and each of them represents different challenges. How these relate to each other is shown in figure 4 below.

Figure 4

Thematic priorities and their relation to CoE



The thematic priority "planning and site selection" relates to all other areas, and determines the outer boundaries of what is possible to achieve in terms of CoE. One priority addresses optimising wind farm productivity. Four thematic priorities relate specifically to the initial capital expenditure (CAPEX), and one priority specifically addresses operational expenditure (OPEX).

Thematic Priority 1:
Planning and site selection deserves special mention

The Megavind target is to be able to produce electricity at half the cost per MWh, on comparable sites. A site where costs today are 100 €/MWh should be reduced to 50 €/MWh in 2020.

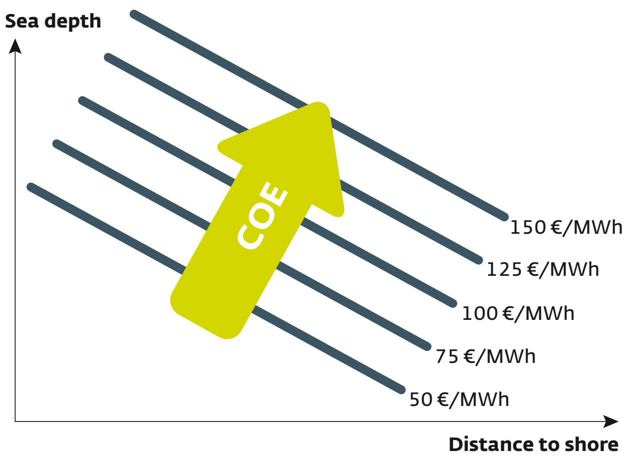
The chosen site for an offshore wind farm determines the harvestable wind resource (annual energy production) and impacts directly on costs per installed MW (CAPEX) and O&M costs (OPEX). Experience so far shows a significant correlation between sea depth/shore distance and CoE. Other met-ocean data, including notably design wind conditions, wave heights, currents and sea bottom, also define the site specific costs. This is primarily a government action area where research and lessons from demonstration projects may be used to improve decision-making.

If government planning pushes offshore wind farms to less optimal sites, the 50% reduction target will not be met. At the same time, selecting more optimal sites prior to 2020 is a short cut to achieving lower costs on those sites and may contribute to reaching the target sooner.

In figure 5 below, the relation between sea depth/shore distance and resulting costs of energy is graphically depicted. Data for offshore wind farms installed prior to 2010 suggest that going from a site located 10 km offshore at 10 m sea depth to locations 20 km offshore at 20 m sea depth adds as much as 30% to CoE. Several other factors influence the resulting costs at a specific site.

Figure 5

Relation between distance, sea depth and CoE.



Thematic Priority 2 – 7:
Improving productivity and lowering costs

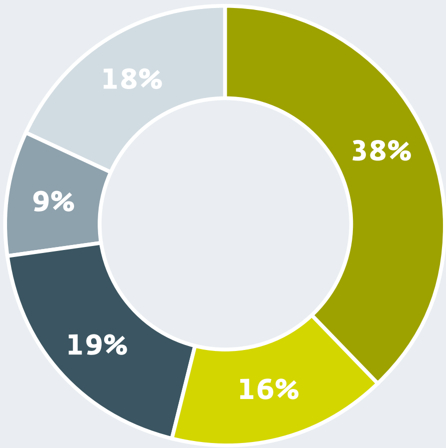
Higher productivity and earnings of the offshore wind farm will contribute positively to reducing CoE of the offshore farm. These gains can be achieved partly through improved optimising design (larger rotors), optimising operation of the farm and exploring potentials within delivery of system benefits, including regulation and stabilisation power to the grid. This area is therefore primarily driven by wind farm developers, suppliers, owners and operators as well as transmission system operators. It is estimated that this action area will be able to contribute by increasing wind farm production by 25% relative to installed MW.

Research, development and demonstration in lowering construction and installation costs (CAPEX), comprised in the four areas "wind turbines", "foundations", "electrical infrastructure" and "assembly and installation", are estimated to contribute significantly and equally to reducing cost per installed MW. The ambition is to reduce CAPEX by approximately 40% of current costs.

Figure 6

Capital and operational expenditures in relation to CoE (own adaptation)

- WTGs
- Foundations
- Electrical infrastructure
- Assembly, installation and project development
- Operational expenditure



SOURCE: Danish Energy Agency, 2010; Nielsen et al, 2010 and own calculations. CoE is defined as the average cost of electri-city produc-tion measured in €/MWh during the total life span of the electricity production facilities. Discount rate is 10%.

Finally, thematic priority 7 "operation and maintenance" is expected to contribute to the 50% reduction of CoE. A combination of an expected 25% increase in annual productivity of newly built offshore wind farms in 2020, and improvements in reliability and O&M strategies will reduce OPEX per produced MWh by 50% - in line with the CoE reduction target

For each of the thematic priorities, references are made to the European Strategic Energy Technology plan (SET-plan), which prioritises offshore wind RD&D in Europe. Cost estimate for the SET-Plan technology roadmap for wind energy is 6 B€ over the next 10 years (2010-2020). Thematic areas include detailed resource mapping and planning, new turbines and components, foundations and grid integration (EU Commission, 2009a: 16-18; EERA Joint Research Programme on Wind Energy, 2010).

PHOTO: SIEMENS WIND POWER A/S

THEMATIC PRIORITY 1:

Planning and Site Selection

Appropriate planning and site selection of offshore wind farms significantly affects the overall economy of the future wind energy development and thus the power system development decisions and CoE in Denmark. Immediate and significant cost reductions are possible by developing better integrated planning and decision-making tools taking into account relevant parameters, including wind resources, grid connection, installation or service harbour, wind farm access, sea depths, design wind conditions, wave heights and seabed conditions.

RD&D priorities

1. **Better spatial and physical planning methodologies**
2. **Improved models for site assessment and planning**
3. **Cost integration and site assessment tools**
4. **More accurate wind resource assessment and design wind condition models and tools**

Spatial and physical planning is carried out by the public authorities. In Denmark, the Danish Energy Agency selects the sites of new offshore wind farms. This decision making is a long process involving increasingly complex planning studies of spatial and temporal distributions of a number of parameters, including wind resources, wind power, grid integration, installation and service harbour, wind farm access, sea depths, design wind conditions, wave heights and seabed conditions.

Spatial planning of the offshore wind farm development plays a crucial role in the final CoE. The experience so far shows a significant correlation between CoE and sea depth/ shore distance. In short, deeper waters and longer distance from shore equals higher construction and maintenance costs.

Site specific costs are also defined by meteorological, ocean and seabed data, including notably wind resources, design wind conditions, wave heights, currents and ground conditions. Furthermore, the combined spatial and temporal distributions of wind power impact power system design and operation and thus decision making regarding geographical distribution of future wind farms as well as requirements to wind farm design and operation and power system design.

Spatial and physical planning should address the need to balance the many and varying sea-use interests while at the same time provide the best technical and economic solution of the offshore wind farm. Installation and operation of offshore wind farms is regarded a new activity in competition with more traditional uses of the sea's resources and possibilities and should address:

- Analysis of different scenarios and how elimination of investment uncertainties and improved planning horizons will affect the overall planning costs. This also includes to what extent site data should be documented and available before the tender issue in order to reduce the electricity price bids.

- Improvement of the planning methodologies and procedures. Conflicts between energy planning and spatial planning are increasing in number and severity. An improved approach to solve these conflicts based on scientific methods should contribute to faster and better decisions regarding the CoE production. List of topics to be analysed include:

    - Visibility (distance from shore and wind turbine height) and public acceptance
    - Mapping (GIS systems) of environmental restrictions
    - Mapping and analysis of diverse interests (fishing, raw material resources, shipping, military)
    - National and international legislation
    - Transmission grid connection and market coupling

Improved models and better knowledge regarding wind conditions and other essential parameters for site assessment and planning tools will support decision-making on identification of optimal areas for offshore wind development. Development of the integration tools will provide a structured understanding of likely effects of wind farm development scenarios at either strategic or project level, and will advise on best locations for future developments of the industry while providing trade-offs between wind resources, economical costs, social aspects, climate change and environmental sensitivity. Thus, this activity can be seen as the development of offshore wind by applications of advanced planning techniques.

A cost integration and site assessment tool could apply advances in GIS technologies covering new analytical frameworks of cost-efficiency and priority setting methods, including handling of uncertainty and low-risk, multi-criteria evaluation techniques. Additionally, the tool will include a wide variety of GIS data layers necessary to inform on the complexity of variables relevant to the planning process of offshore developments, including wind conditions, hydrodynamic conditions (wave and currents), closeness to land and adequate installation and service harbours, sea-depth and seabed, nature considerations (habitats and bird sanctuaries), visibility and cumulative effects of a major expansion of offshore wind farms could have for the marine environment.

More accurate wind resource assessment and design wind conditions aim at estimating wind power production with both high spatial and temporal resolution within an accuracy of less than a few percent. Furthermore, more knowledge and better tools to estimate the climatological effects of placing large wind farms offshore are needed for planning and siting of large wind farms. To obtain this, it is necessary to

- Develop the existing tools for wind resource assessment by combining and developing the model chain from the Global Circulation Models, meso scale and micro scale models coupling the models to the ocean wave models.
- Integrate models of wind variability in power system planning needed for managing fluctuating wind power at high penetration levels
- Combine measurements - both conventional measurements, satellite images and remote sensing data - with the models.
- Integrate feedback on the wind climate for large wind farms in the models and resource assessment tools

Alignment with SET-Plan objectives

The above RD&D lines are closely related to the SET-Plan objectives on resource assesment and spatial planning:

- Assess and map wind resources across Europe and to reduce forecasting uncertainties of wind energy production
- Develop spatial planning methodologies and tools taking into account environmental and social aspects
- Address and analyse social acceptance of wind energy projects including promotion of best practises.

THEMATIC PRIORITY 2:

Wind Farms

PHOTO: SIEMENS WIND POWER A/S

Future offshore wind farms have to provide improved cost efficiency at high wind power penetration levels, including increasing the capacity factor and providing system services and functionalities for wind power integration in the power system. Wind farm layouts, design, controls and operation as a system can be improved and there are unexplored potentials in delivering system services to the grid.

RD&D priorities focusing on higher capacity:

1. **Tools for wind farm layout and wind farm control with specific focus on wake models and advanced control system**

RD&D priorities focusing on higher earnings and integration in the energy system:

2. **Wind power plant capabilities in the energy system**
3. **Ancillary services delivered from wind turbines**
4. **Short term wind prediction and wind power variability**

Tools for wind farm layout and wind farm control focus on dynamic wake models and advanced control systems in order to minimise the wake effects and increase production. There are huge benefits in optimising farm design and developing new operation strategies and tools for the park (instead of individual turbines). Wake losses are likely to be higher than for many onshore wind farms due to lower ambient turbulence levels. Advanced control features should be developed in order to produce electricity in a cost-effective way and to provide ancillary services for the overall grid performance.

Development of wind power plant capabilities aims at defining the needed power plant capabilities for reliable system operation at high penetration level. Some of these may be mandatory, and some may be treated as "ancillary services".

- Development of models for wakes and power production optimisations in small and large wind farms improving models of flow within the wind farm
- Develop standardised communication infrastructure and interface between turbines and farms
- Develop and test automated management
- Multi-optimise operation focusing on higher reliability
- Develop and improve interaction between turbines in normal operation and in failure mode
- Improve modelling of reciprocal impact between turbine and grid

Ancillary services from wind farms - wind turbines can deliver most of the ancillary services that are needed in the power system. In a situation with high wind penetration, wind turbines should be able to deliver most of the ancillary services in competition with other power plants. The payment for delivering these services contributes positively to the overall economy of the wind farm. To obtain this, it is necessary to:

- Demonstrate wind power as an equal participating technology in the market for different ancillary services, such as frequency and voltage support, fault-ride-through and support to black-start

- Develop wind power plant capabilities with novel control and operating modes such as Virtual Power Plants
- Improve regulation and grid activities in decentralised system/Island mode
- Optimise operation versus peak load periods

Short term prediction of resources and estimates of the wind power variability - the focus is to maximise the accuracy of the forecast in order to secure more precise bids for wind power production in the delivery of production. There is need to:

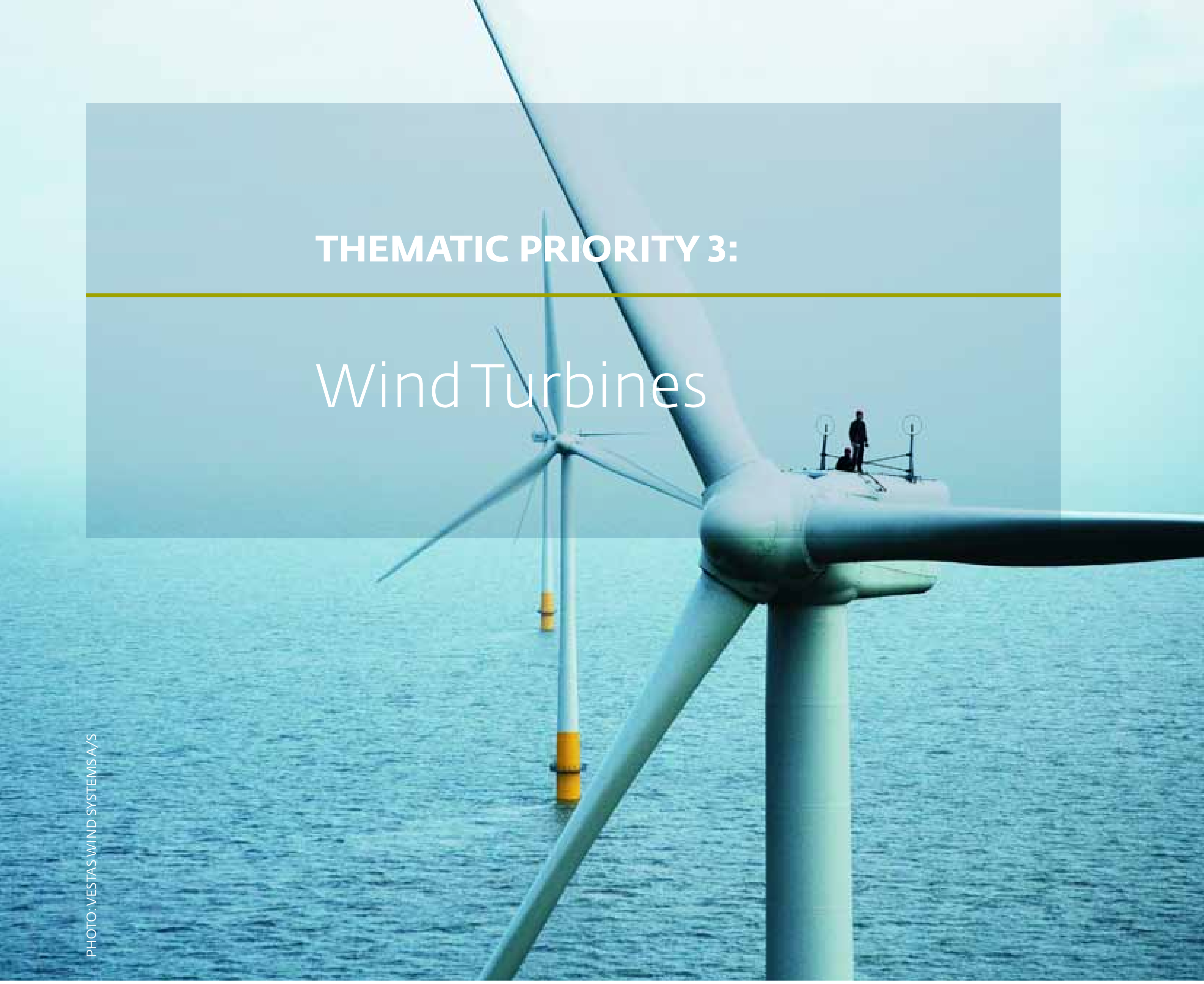
- Develop cost-effective devices for offshore wind measuring (e.g. remote sensing techniques etc)
- Develop numerical tools that combine both statistical and physical modelling i.e. meso scale and micro scale with measurement based statistical tools.
- Improve data collection from various sources of wind measuring instruments to be used for short term wind forecast
- Improve use of probabilistic information in the forecast for trading power and ancillary services
- Adjust the procedures for bidding production and consumption into the power exchange in order to minimise the time lag from the deadline for delivering the bids and the actual production period

Alignment with SET-Plan objectives

The above priorities are closely related to the SET-Plan objective regarding:

- Grid integration techniques for large scale penetration of variable electricity supply and wind farms management as "virtual power plants"[1].

[1] A virtual power plant is a cluster of distributed generation installations which are collectively run by a central control unit in order to increase the system flexibility (EU Commission, 2009a).



Today's offshore turbines are almost identical with the turbines onshore. Offshore wind turbines will, over the next 10 years, become both bigger and more efficient. Bigger and differently designed turbines will simultaneously open up for cost reductions for support structures and electrical infrastructure.

RD&D priorities

1. **Accelerated full scale test of turbines and components (test and demonstration)**
2. **Design conditions for reliable and multifunctional turbines in wind farms**
3. **Design basis and methods for large offshore turbines in integrated park operated with minimum maintenance (up to 20 MW)**
4. **New rotor concepts**

Accelerated full scale test of turbines and components is dedicated test facilities, which are required to manage the risks when up-scaling design and deploying large scale wind. The proposed testing facilities are combinations of full scale wind turbine tests and accelerated component tests under laboratory conditions. The combination makes it possible to experience real operating conditions and transfer realistic conditions to the controlled environment for detailed analysis. Accelerated full scale wind turbine tests could be obtained by increasing the operational loads by a combination of increased rotational speed, dedicated control actions and operation in complex wind conditions including wake from other turbines. By tailoring the operational conditions to generate increased loads relative to the design load basis, the accelerated lifetime of the different components can be reduced to e.g. a test period of 1-3 months. In particular, there is need for:

- Development of methods for accelerated full scale test of turbines, incl. complex wind e.g. wake conditions
- Establishment of reference test facility, including component test facilities
- Data collection, statistical analysis and data evaluation

Design conditions for reliable and multifunctional turbines in wind farms address the overall design requirements for offshore wind. There is need for incremental innovation to improve turbine reliability, increasing component lifetime and developing preventive maintenance strategies. Research and development should address:

- Measurements, description and modelling of external conditions (wind, wakes, waves, geotechnical topics). Investigation of especially external wind conditions such as mean, turbulence and extremes above 100 m is needed as no measurements currently are available for these heights. Joint probability statistics of wind and wave, with respect to both amplitude, phase and directions
- Establishment and verification of design load basis, incl. wakes, transients and multi-functionality (down rating, over rating, ride through, feed forward)
- Develop probabilistic design and verification methods for systems and subcomponents (life-time, extreme incidents, inspection, service, mean time between failure etc.)
- Improved methods for optimising operation and maintenance
- Improved standards for wind turbine systems

Design basis and methods for offshore turbines in integrated park design operated with minimum maintenance involve site specific design process with feedback between turbine, support structure, wind farm design and control, and the impacts on up-scaling. Research and development needs within:

- Optimised design, incl. defining limits and preconditions for up-scaling
- Weight reduction through new materials and innovative tower design
- Integrated and simplified design, less components and low maintenance

New rotor concepts are needed for developing more efficient turbines with respect to reducing the fatigue loads and optimising the power performance. New innovative concepts are needed by designing turbines specifically for the offshore environment as these turbines are larger than onshore turbines. Research and development should address:

- Larger and more flexible rotor blades with built- in structural deformations
- Blades, incl. materials, optimal structure, blade profile, aeroelastic tailoring
- Variable blade geometry combined with detailed inflow and load measurements
- Multifunctional control of turbines and farms
- Remote sensing of inflow wind field combined with control of fatigue and extreme loads

Alignment with SET-Plan objectives

The above RD&D priorities have very close interconnection with the SET-Plan objectives:

- Develop large scale turbines in the range of 10-20 MW especially for offshore applications;
- Improve the reliability of the wind turbine components through the use of new materials, advanced rotor designs, control and monitoring systems.

In particular, the prioritised testing facility aims at being one of the foreseen five testing facilities for large scale turbine concepts, which are expected to be available in 2015 for complete systems and various extreme climate types.

THEMATIC PRIORITY 4:

Foundations

PHOTO: VESTAS WIND SYSTEMS A/S

Offshore wind support structures are relatively immature technologies for wind turbine application, and the potential of increased cost efficiency is therefore significant. Up-scaling is regarded as one of the potential means to reduce CoE (larger turbines means fewer foundations). Finally, there is cost reduction potential through integrated design of foundation and tower, new material technology and more efficient manufacturing processes.

RD&D priorities

1. More efficient manufacturing processes and more fit for purpose procedures for mass production of substructures
2. Optimised, efficient foundations through stackable, replicable and standardised substructures for large-scale offshore turbines (monopile, gravity based structure)
3. New, cost competitive foundations (jacket, tripod, suction bucket)
4. Design methods and tools for ground and seabed condition

Present offshore wind farms are placed in maximum water depths of 30 m. Future offshore wind farms will be installed in water depths up to 60 m. As support structures are a major cost item, especially in deeper water, the optimisation of this subsystem is a powerful source of cost reduction.

Monopile steel or concrete foundations are a tried and tested technology in marine construction. There is a high degree of production automation and no preparation of the seabed is required. However, monopile foundations cannot be used beyond 30 m water depths with 3 MW or heavier turbines. Furthermore, monopile diameters are limited to 5-6 m and are therefore not economical for larger 5 MW turbines beyond 20 m water depths, unless their mass can be significantly reduced.

Therefore other types of foundations and support structures are considered by industry, such as gravity based structures, adaptations of monopiles (tripods and tripiles), jacket structures and suction buckets. In most of the North Sea as well as in Danish offshore waters, water depth rarely exceeds 50 m. Floating foundation structures are therefore of less relevance.

Manufacturing processes and procedures for mass production of substructures address the need for scale, speed and costs in the manufacturing of large foundations, including cost-effective processes and standards, efficient welding processes and robot technology, installation etc.

Optimised, cost efficient foundations address the need for standardised substructures for large-scale offshore turbines (gravity based structure, monopile) and make them stackable and replicable. The foundations are optimised by means of new, more advanced and integrated design tools. The aim is to bring down costs and to take into account installation and logistical challenges.

Development of new cost competitive foundations (jacket, tripod, suction bucket) focuses on support structures in water depths up to 60 m and installation in problematic soil profiles. More knowledge is needed on more accurate models for soil stiffness and damping, reliable modelling of loads and global dynamics of the full structure and new engineering design tools for fatigue resistance.

Foundation designs have to be done in parallel with installation strategies to optimise time, cost and complexity of the installation phase.

Design methods and tools for ground conditions address erosion of nearby seabed caused by offshore foundations. There is need for more knowledge of scouring processes and scour protection, including improved concepts of dynamic scour protections, constructability and physical model testing.

Alignment with SET-Plan objectives

The above RD&D priorities have close interface with SET-Plan objectives, aiming at improving the competitiveness of wind energy technologies, to enable exploitation of the offshore resources and deep water potential:

- To develop new stackable, replicable and standardised substructures distant for large scale offshore turbines such as: tripods, quadropods, jackets and gravity-based structures;

- To develop manufacturing processes and procedures for mass-production of sub-structures.

Not included in the Megavind RD&D priorities is the SET-Plan priority to develop floating structures with platforms, floating tripods, or single anchored turbine. These structures are not relevant in the 2020 time frame of the Megavind strategy as floating structures will be too immature a technology to be cost effective.

PHOTO: DWIA

THEMATIC PRIORITY 5:

Electrical Infrastructure

The electrical infrastructure in between the wind turbines and to the farm's transformer station and from the transformer station to transmission connection points are areas where new technology could contribute significantly to the reduction of total costs, and to the creation of the farm's total availability and creation of value.

RD&D priorities

The offshore specific RD&D priorities have been grouped in priorities which concern the internal electrical system of the wind power plant (i.e. the wind farm), and priorities which concern the transmission system to which the wind power plant is connected:

1. **Voltage level and wind turbine rated capacity**
2. **Combining grid connection of wind farms with interconnectors between power systems**
3. **Power system compliance of wind power plants**

Future offshore wind farms are expected to contribute significantly to the European power system (40 GW by 2020) and this requires a dedicated offshore electricity system, providing access for the more remote offshore wind farms and also additional interconnection capacity to improve trans-border electricity trading. The geographically distributed offshore wind farm generation will be pooled, increasing the predictability of aggregated energy output.

Voltage level and wind turbine rated capacity concerns the internal electrical system of the wind power plant. The rated capacity of wind turbines is steadily growing, and this development is making a higher voltage level on the internal wind farm power collection grid more feasible. The growing wind turbine size itself leads to savings in cables, because e.g. a 200 MW wind farm will require less cabling if it is built by 20 wind turbines of 10 MW than if it is built by 100 wind turbines of 2 MW. A higher voltage level means lower currents. With large wind turbines, the cables will carry more power, and therefore it is attractive and feasible to increase the voltage level and thereby reduce the currents and consequently the need for cobber in the cables. The drawback is that this will increase requirements to insulation, not only on the cables but also on the transformers inside the turbine. But the higher voltage level will contribute to increase wind turbine sizes, and this will lead to savings in costs for cables in the wind farm power collection grid.

Combining grid connection of wind farms with interconnectors between power system areas concerns the transmission system. The background for this is the combination of the large scale offshore wind power development and increased need for interconnectors to strengthen power market coupling. There is a large system potential if rather than using dedicated cables from each wind farm to transmit offshore wind power to the shore, the offshore wind farm is connected directly to a nearby offshore transmission grid. Multi-terminal High Voltage Direct Current – Voltage Source Converter (HVDC-VSC) may be the most promising technology to develop such grids as the HVDC-VSC technology offers the controllability needed to allow the network to both transmit wind power and to provide the highway for electricity trade, even between asynchronous zones. Moreover, the technology is able to provide flexible and dynamic voltage support to Alternating Current and therefore can be connected to strong and weak onshore grids. The drawback is that HVDC-VSC technology is more expensive, requires larger platforms and some may require more maintenance. More knowledge is needed on the optimal balance between when and where to use High Voltage Alternating Current (HVAC) and HVDC-VSC in the overall grid connection and power market coupling of offshore wind power.

Power system compliance of wind power plants, i.e. the ability of wind power plants to meet requirements that are specified – typically in grid codes – to ensure a safe and secure operation of the power system. The requirements to compliance will be demanding to the wind power plants with the increasing wind energy penetration levels planned. Continued development, validation and standardisation of simulation models for wind power plants is essential to ensure confidence in simulation of power system stability in power system with large scale wind power. Facilities to test this compliance create opportunities for dedicated technological development in combination with power system modelling.

Alignment with SET-Plan objectives

The Megavind RD&D priorities for electrical infrastructure focus on the technical challenges addressed by the EU's SET-Plan objective for onshore and offshore grid integration:

- To demonstrate the feasibility of balancing power systems with high share of wind power using large-scale systems with HVAC or HVDC interconnections.
- To demonstrate grid integration techniques for large scale penetration of variable electricity supply with focus on offshore wind farms interconnected to at least two countries and combined with the use of different interconnection techniques; long distance HVDC; and controllable multi terminal offshore solutions with multiple converters and cable suppliers.

THEMATIC PRIORITY 6:

Assembly and Installation

PHOTO: BENT NIELSEN

Developing more efficient construction and assembly methods, with a higher degree of standardisation and scale benefits to follow, is needed. As an increasing number of installation vessels are built, the price pr. installed MW is gradually going to decrease.

RD&D priorities

1. **Standardised, stackable support structures and pre-assembly of components at harbour**
2. **Modularisation and standardisation of substations and cable connections**
3. **Optimised cable installation on seabed, including quality and protection of cables in park**
4. **Optimised installation methods and planning**

The challenge is how to assemble, transport and install such large structures in a cost-effective way. Heavy lift vessels from the offshore industry are not intended for serial installation of turbines offshore. Therefore, fast moving speciality vessels for turbines have been designed to transport multiple turbines in order to exploit the weather window. However, the type of vessel depends greatly on which fabrication and assembly strategy is chosen. Three well known strategies are:

- Pre-assembly of turbines, substructures and towers at the harbour where after speciality vessels transport the turbine to the site.
- Manufacture and pre-assembly at the harbour differs from the above by both manufacture and assembly of the components at the harbour.
- Assembly offshore implies that feeder vessels supply an offshore jack-up vessel to the installation site.

Market volume means will make it economically viable to design purpose-built vessels. At the moment, one *all-round* type of vessel installs foundations, turbines and cables. Both vessel design and installation process can be optimised significantly if the vessel is used exclusively for one type of installation

Especially adapted harbours are also considered to manage the manufacturing, assembly, storage and shipping of these heavy offshore wind structures and turbines. Such integrated approach enables the turbines to be manufactured on-site and shipped directly to the site by speciality vessels. Bremerhaven has opted for that strategy.

Development of standardised, stackable support structures and pre-assembly of components at harbour has to take place in tandem with foundation designs, if time, cost and complexity shall be optimised.

Modularisation and standardisation of substations and cable connections address the need for standards and cost-effective installation of the electrical infrastructure[2]. To date there is no standard for offshore substations. The installation process typically takes place after the foundation and cable work and prior to the mounting of the turbine.

Optimised cable installation on seabed, including quality and protection of cables in park covers a variety of topics, including investigation of the external conditions, site investigations of the seabed properties, burial protection indices, scour protection, cable route selection, cable transport and choice of vessel and equipment. Efforts should in particular focus on optimising the process by construction of purpose-built installation equipment, drilling spreads and cable ploughs and by developing safe, efficient, reliable and repeatable processes.

Optimised installation techniques and planning aims at reducing installation cost by advanced site specific information services, high volumes, speed and economies of scope. There is need for improved planning and logistics tools, new organisational and management tools as well as innovative business models.

Alignment with SET-Plan objectives

The two first priorities are to some extent linked to the SET-Plan priority to demonstrate advanced mass-manufacturing processes of offshore structures. The industrialisation of the substructures not only brings down the cost of the structure but also enables the development of modularised and standardised structures and substations. The third and fourth priorities are not reflected in the SET-Plan.

THEMATIC PRIORITY 7:

Operation and Maintenance

PHOTO: KEENPRESS

Offshore wind turbines have to resist harsh conditions at sea. Several farms have been in operation for 5-10 years, the experiences and the lessons learned can be used for future development, which will increase the reliability and thereby decrease costs for operation and maintenance of future wind turbine farms. The wind turbine accessibility has to be improved in order to increase the amount of possible service days and bringing down the periods with turbine stop.

RD&D priorities

1. **Risk based cost-optimal planning of O&M**
2. **Cost-optimal and weather robust mobile access**

O&M costs for the few existing newer offshore wind farms have been much larger than expected, mainly due to many unforeseen failures requiring corrective repair and expensive access related to bad weather conditions. There is a large potential for cost reductions by improving the reliability/availability and introducing better access systems / methods.

Maintenance consists of three categories: corrective, preventive and condition based maintenance. Today, corrective maintenance dominates the O&M costs. Development of a maintenance strategy is a key issue as it is widely acknowledged that it is better to invest in reliability to avoid maintenance than to facilitate maintenance through better access. To reduce O&M costs, it is therefore necessary to minimise corrective maintenance and instead shift to predictive maintenance and for some parts to condition based maintenance.

Future offshore wind farms offer new challenges, being larger and much further offshore. This will require improvements in vessels used, landing stages on the offshore wind turbine structures (for helicopters), and transport and safety procedures. Although some technology solutions may be used and adapted from the offshore industry, there are also major differences such as access patterns and costs.

Risk-based cost-optimal O&M planning combines both reliability and cost aspects. This life-cycle approach can be used for rational and optimal planning of operation (services, inspections, etc.) and maintenance (incl. repair and exchange) for offshore wind turbines. Research and development efforts should address:

- Improved methods, tools and procedures to assess and determine the reliability (failure rate) of the wind turbine and its components in their individual environment and to determine parameters for O&M and reliability optimisation.
- Data collection and analysis of failure of main components (incl. blades, gearbox, generator, other electrical components, tower and foundation), failure rates, root causes, failure modes, consequences of failure (downtime) and damage accumulation for relevant components.
- Improved methods for load monitoring, especially application and testing of a low cost system for blade and drive train monitoring
- Improved structural reliability models to be used for decision-making on O&M for other components and wind turbines in the farm.
- Improved use of probabilistic information in the forecast for O&M of the farm including condition monitoring

Cost-optimal and weather robust mobile access deals with requirements for and design of O&M infrastructure for offshore wind. There is need for:

- Improved systems of access (vessels, helicopters and other airborne planes), including also development of craft systems.
- Development, improvement and adaptation of safety regulation and procedures for different mobile access for offshore wind farms.
- New, innovative business, legal and ownership models and services for O&M taking into account the trade-off between common O&M infrastructure interests and individual business interests.

Alignment with SET-Plan objectives

Offshore wind O&M is only indirectly addressed in the SET-Plan objective for new turbines and components, more specifically:

- To develop innovative logistics including transport and erection techniques, in particular in remote, weather hostile sites.

Furthermore, offshore O&M is an integrated part of the EERA Joint Programme on Wind Energy, which a.o. focuses on developing tools for predictive maintenance, models of component degradation, and developing a database with operational and failure data for validation of tools.

Danish RD&D Activities in Offshore Wind

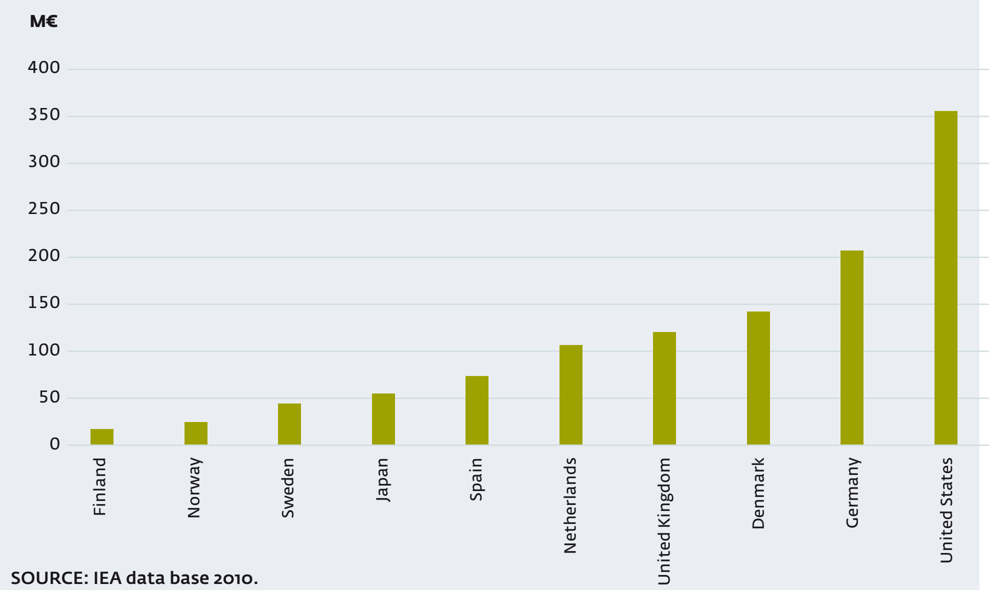
Strategic Outlook and RD&D

The Danish wind energy sector has a year long tradition for developing RD&D strategies. It started with the R&D strategies developed by the Danish Research Consortium for Wind Energy in 2002 in close co-operation with industry. Since 2007, the public-private partnership of Megavind has developed RD&D strategies for wind energy in order to maintain Denmark's position on the global market for wind energy and continue to be a leading knowledge centre for wind energy.

Although global public wind energy RD&D expenditure has been subject to decreasing public R&D expenditure since the start 1980s, Danish wind energy R&D has remained relatively stable. As illustrated in the figure below, over a ten-year period Danish wind energy R&D is with 130 M€ the third largest investor after the US and Germany.

Figure 1.

1997-2007 accumulated public wind R&D expenditure. M€ in 2008 prices.



SOURCE: IEA data base 2010.

In general, public RD&D expenditure on wind energy remains low compared to the private RD&D expenditure. The literature indicates a R&D intensity of 2.6-3.0% of annual turnover in the wind energy industry (EU Commission, 2009b: 44). For the Danish wind industry with an annual turnover in 2009 of 51 billion DKK, this would amount to 1.3 – 1.5 billion DKK. In the same year, the Danish public wind RD&D expenditure was 131 million DKK or just 8-10% of the private RD&D wind energy investment in Denmark.

Recent studies demonstrate that Denmark is lagging behind in terms of wind energy RD&D. The UK gives high priority to wind energy and has in the last years invested heavily in wind RD&D and hence comes out as number one before Germany and Denmark (EU Commission, 2009b: 44). For example Carbon Trust has launched the Offshore Wind Accelerator, a ground-breaking research and development initiative worth up to 30 M£, in foundations, wake effects, access and electrical systems. Also, The Research Council of Norway has recently invested more than 250 million NOK in two offshore wind energy

RD&D centres – NOWITEC and NORCOWE. In addition, the centres have received 66 million NOK for test facilities and research infrastructure.

RD&D on offshore wind is included in Danish wind RD&D expenditures 1997-2007. Highlights from a mapping of Danish offshore wind energy projects show:

- *A broad range of RD&D offshore projects.* Since 1995, more than 100 RD&D projects have focused on different aspects related to offshore wind, including planning and siting, cost optimisation of large scale offshore wind farms, wind models, wave prognosis, lightning protection, aquaculture, bird collision, wake effects, recycling, power fluctuation, aero-hydro-elastic simulation, transmission, foundations etc.
- *Many Horns Rev related projects.* 19 RD&D projects are related to Horns Rev Offshore Wind Farm in the period from 2000-2006 with a total of budget of 59.87 million DKK, all with funding from PSO. Elsam was project manager of 14 of the projects. Approximately half of the expenses are spent on projects focusing on the offshore wind farms' environmental impact.
- *The total RD&D expenditure amounts to 496 million DKK*, of which 275 million DKK is from public RD&D support (55%). The total expenditure per year has generally increased over time and in particularly since 2006.
- *Resources and resource assessment* havethe largest budget share with 135 million DKK, followed by wind turbine technology with 107 million DKK and foundations with 103 million DKK. Electrical systems and infrastructure get 42 million DKK and environmental aspects 38 million DKK.
- *Public RD&D programmes* supporting offshore wind include PSO (Public Service Obligation, Energinet.dk), The Strategic Research Council (Danish Agency for Research and Innovation), Energy Technology Development and Demonstration Programme (EUDP, Danish Energy Agency) and Advanced Technology Foundation (Danish Agency for Research and Innovation). The largest contributor is PSO with a total support of 123.55 million DKK. The second biggest donator is EFP/EUDP with a total support of 67.53 million DKK.
- *A variety of technology providers and users are actively involved* in most RD&D offshore wind projects.

International RD&D Cooperation

In addition to Danish RD&D projects, Danish public and private research communities have from the very beginning been deeply involved in international RD&D cooperation.

While Danish wind turbines manufacturers and an increasing number of suppliers have complemented the Danish R&D departments with R&D ditto abroad, close to emerging markets and competences, a number of international companies have established R&D departments in Denmark to gain access to cutting edge competences and skills.

In general, Danish stakeholders are successful in getting EU funding in the area of energy, with 8.2% of total EU funding in the area (the average success rate is 2.3%)[3] . This is in particularly the case for wind energy, where Danish stakeholders often have a leading role. As an example, Risø DTU is project manager of the large EU project called Upwind which has more than 40 partners. The project looks towards the wind power of tomorrow, more precisely towards the design of very large wind turbines (8-10 MW), both onshore and offshore. Recently, the DeepWind project on a new floating offshore wind turbine concept was launched, also led by Risø DTU, and with partners from five EU member states, Norway and close interaction with NREL in the US.

Danish stakeholders are deeply involved and lead the strategic technology development fora such as the Technology Platform for Wind (TPWind) and its SET-Plan equivalent the European Wind Initiative. This also includes the technology roadmap 2020 for wind energy to comply with the 20% renewables target by 2020.

Likewise, the European Energy Research Alliance established in 2009 with Risø DTU as one of the founding fathers has developed a Joint Research Programme on Wind Energy, which provides the necessary research for most of technology roadmap activities. The programme is coordinated by Risø DTU and includes leading R&D partners from EU members and associated states. This widens the overall competence pool, creates synergy in the R&D activities, attracts and thereby gears national funding and is hence expected to improve the international attractiveness, as a global competence and skills centre.

[3] *http://www.fi.dk/internationalt/eus7rammeprogramforforskning/statistik-og-analyse/statistik-om-fp7/samlet-taloversigt/DK%20i%20FP7%20-2010%20maj.pdf*

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Appendix A: Market Outlook

Global Wind Energy Markets

The global market for wind generation is expected to expand in the future. While land based wind energy will remain dominant in the immediate future, offshore wind will become increasingly important.

Today wind energy represents 1.6% of global electricity consumption. It is the world's fastest growing renewable energy with annual growth rates of nearly 30% over the last ten years. The total installed capacity was in 2009 160 GW with US at the top of cumulated capacity.

Table 1.

Annual and cumulated wind energy capacity, 2009.

ANNUAL CAPACITY, 2009, MW		CUMULATIVE CAPACITY, 2009, MW	
China	13,750	US	35,155
US	9,994	China	25,853
Spain	2,331	Germany	25,813
Germany	1,917	Spain	18,784
India	1,172	India	10,827
Italy	1,114	Italy	4,845
France	1,104	France	4,775
UK	1,077	UK	4,340
Canada	950	Portugal	3,474
Portugal	645	Denmark	3,408
Rest of World	4,121	Rest of World	22,806
Total	**38,175**	**Total**	**160,080**

SOURCE: BTM CONSULT, 2010; DOE, 2010

In 2009, China more than doubled its capacity from 12.1 GW to 25.8 GW and became number one market with 36% of total new installed capacity of 38.3 GW.

As a region Europe is the world's leader in total installed wind energy capacity with 74.8 GW and more than 10 GW of new installed capacity in 2009. The wind power capacity installed by the end of 2009 will in a normal wind year produce 162.5 TWh of electricity, equal to 4.8% of the EU's electricity consumption.

Offshore Markets

The actual offshore wind energy is located almost entirely in Northern Europe due to large sea areas with water depth < 50m and good wind resources, while land resources with good wind conditions are scarce. Although the European offshore wind energy is still in its infancy with 2.1 GW in installed capacity, it is expected to increase to 40 GW or 25% of European wind power by 2020 similar to 3.6-4.3% of EU electricity consumption (EWEA, 2009: 13).

Today, the largest offshore accumulated installed capacity is UK (883 MW) and Denmark (646 MW). Other leading countries are The Netherlands (247 MW), Sweden (164 MW), Germany (42 MW), Belgium (30 MW) and Ireland (25 MW). Currently 16-17 wind farms are under construction, totalling more than 3,500 MW. In addition, a further 52 offshore wind farms have been fully consented, totalling more than 16,000 MW, and more than 100 GW of offshore wind farms proposals have been identified in European waters, spread over 15 countries (GWEC, 2010: 39; EWEA, 2010).

The actual annual and accumulated capacity is illustrated in the figure below.

Figure 1.

Annual and cumulated installed offshore wind capacity, 2009

The total of 834 installed and grid connected offshore wind turbines in primarily European waters are spread across 39 wind farms in nine countries[4]. The table below gives an overview of the operating offshore wind farms in Europe and very recently also in China.

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[4] Not included in these figures is the recently inaugurated offshore wind farm off Thanet in Kent (UK) by 23 September 2010. The 100 Vestas V90 turbines have a total capacity of 300 MW and are expected to supply 20,000 homes per year. Likewise Rødsand II (DK) with its 200 MW is not included.

Table 2.

Operating offshore wind farms in the world, 2009

PROJECT NAME (COUNTRY)	WTGS	MW	TYPE FOUNDATION	CON-STRUC-TION
Vindeby (DK)	11 x 450 kW Siemens	4.95	Concrete caisson	1991
Lely (NL)	4 x 500 kW, NEG Micon	2.0	Driven monopile	1994
Tunø Knob (DK)	10 x 500 kW, Vestas	5.0	Concrete caisson	1995
Dronten Isselmeer (NL)	28 x 600 kW, NEG Micon	16.8	Driven monopile	1996
Bockstigen (SE)	5 x 550 kW, NEG Micon	2.75	Drilled monopile	1997
Utgrunden (SE)	7 x 1.5 MW, GE Wind	10.5	Driven monopile	2000
Blyth (UK)	2 x 2 MW, Vestas	4.0	Drilled monopile	2000
Middelgrunden (DK)	20 x 2 MW, Siemens	40.0	Concrete caisson	2000
Yttre Stengrund (SE)	5 x 2 MW, NEG Micon	10.0	Drilled monopile	2001
Horns Rev (DK)	80 x 2 MW, Vestas	160.0	Driven monopile	2002
Palludan Flak (DK)	10 x 2.3 MW, Siemens	23.0	Driven monopile	2002
Nysted Havmøllepark (DK)	72 x 2.3 MW, Siemens	165.6	Concrete caisson	2003
Arklow Bank Phase I (IE)	7 x 3.6 MW, GE Wind	25.2	Driven monopile	2003
North Hoyle (UK)	30 x 2 MW, Vestas	60.0	Driven monopile	2003
Scroby Sands (UK)	30 x 2 MW, Vestas	60.0	Driven monopile	2004
Kentish Flat (UK)	30 x 3 MW, Vestas	90.0	Monopile	2005
Barrow (UK)	30 x 3 MW, Vestas	90.0	Monopile	2006
NSW (NL)	36 x 3 MW, Vestas	108.0	Monopile	2006
Burbo Bank (UK)	25 x 3.6 MW, Siemens	90	Monopile	2007
Lillgrund (SE)	48 x 2.3 MW, Siemens	110.4	Concrete caisson	2007
Inner Dowsing (UK)	27 x 3.6 MW, Siemens	97.2	Monopile	2008
Lynn (UK)	27 x 3.6 MW, Siemens	97.2	Monopile	2008
Q7 (NL)	60 x 2 MW, Vestas	120.0	Monopile	2008
Thornton Bank (BE)	6 x 5 MW, RePower	30.0	Concrete caisson	2008
Greater Gabbard Ph. 1(UK)	42 x 3.6 MW, Siemens	151.2	Monopile	2009*
Gunfleet Sands 2 (UK)	18 x 3.6 MW, Siemens	64.8	Monopile	2009
Rhyl Flats (UK)	25 x 3.6 MW, Siemens	90.0	Monopile	2009
Horns Rev 2 (DK)	90 x 2.3 MW, Siemens	207.0	Monopile	2009
Hywind (floating) (NO)	1 x 2.3 MW, Siemens	2.3	Floating	2009
Great Belt (DK)	7 x 3 MW, Vestas	21.0	Monopile	2009
Alpha Ventus (DE)	10 x 6 MW, RePower & Alstom Wind	60.0	Monopile	2009
Donghai Bridge Offshore Phase 1 (CN)	21 x 3 MW, Sinovel	63.0	Monopile	2009
Väneren Gässlingegrund (SE)	10 x 3 MW, WinWInD	30.0	?	2009
Total	**Number of WTGs: 834**	**2.112 MW**		**1991-2009**

SOURCE: BTM CONSULT, 2010

*DELAYED, UNDER CONSTRUCTION

In terms of cumulative installed units, Siemens (386 WTGs) and Vestas (349 WTGs) are the largest suppliers representing 89% of the market. Other suppliers are Winwind (18 WTGs), GE (14 WTGs), Repower (8 WTGs) and others (55 WTGs) (EWEA, 2010).

Just in 2009, 199 wind turbines in eight offshore farms were installed and grid connected, totaling 577 MW of new capacity. The dominant suppliers were Siemens (146 WTGs/405 MW) and Vestas (37 WTGs/110 MW). Others were WinWind (10 WTGs/30 MW) and Multibrid (6 WTGs/30 MW) (EWEA, 2010). The foundations types were primarily monopiles (88%), the water depth was in average 12 m with 30 m (Alpha Ventus) and 5 m (Rhyl Flats) as the two extremes. The distance from shore was in average 14.4 km with 42 km (Alpha Ventus) and 2 km (Great Belt) as the two extremes.

Other Offshore Wind Energy Markets

Although Europe has a first offshore mover advantage, two countries outside Europe are in particular determined to exploit offshore wind potential – USA and China.

To date all wind power projects built in the USA have been sited on land. Nonetheless, there is some interest in several states. A total of 13 offshore projects equal to 2,476 MW have advanced significantly in the permitting and development process and are primarily located in the Northeast and Mid-Atlantic, though some projects also exist in the Southeast, Great Lakes and the Gulf of Mexico. Three projects have signed or proposed power purchase agreements – Cape Wind in Massachusetts (468 MW), NRG Bluewater in Delaware (200 MW) and Deepwater Wind in Rhode Island (28.8 MW) (DOE, 2010: 12-13). In 2008, DOE released a feasibility report on wind energy providing 20% of the US electricity by 2030. Out of 300 GW new capacity, 54 GW would be offshore (EWEA, 2009: 17).

The development of offshore wind in China is still at an early stage, but can rapidly take off. In 2005, the nation's Eleventh Five Year Plan encouraged industry to explore offshore opportunities in Shanghai, Zhejiang and Guangdong Province, including a target of 1-2 farms of 100 MW by 2010. Also, offshore wind development is one of the major R&D priorities in the Renewable Energy Industry Development Guideline in 2005. At provincial level, offshore planning has started in Jiangsu, Shanghai, Zhejiang, Hainan and Shangdong. Jiangsu is the most advanced with the target to reach 7,000 MW offshore by 2020 and 18 GW in the long term. The first offshore 1.5 MW test wind turbine was installed and grid connected in 2007, located in Liadong Bay in the north east Bohai Sea. The Donghai Bridge Wind Farm is a 102 MW wind farm close to Shanghai. The first three turbines were installed in April 2009 and the farm was completed in June 2010. There is no specific policy or regulation for offshore development and grid constraints remains another major issue (EWEA, 2009: 18-19).

Other international activities include a large offshore wind farm in British Columbia, Canada, with a total of 1,750 MW in five phases, of which Siemens will supply 110 turbines (3.6 MW) for the first phase. In Taiwan, a 600 MW Changhua Offshore Wind Farm will soon be operating in the Taiwan Strait (EWEA, 2010).

Markets Prospects in Europe

Offshore wind is expected to contribute largely to the EU renewable energy target of at least 20% of final energy consumption by 2020. In terms of electricity consumption, renewable should provide about 34% of the EU's power by 2020 to meet the EU target, with wind set to contribute 14-17%[5]. As outlined in the national action plans, offshore wind is expected to provide app. 40 GW by 2020. More specifically, UK is expected to lead with almost 13,000 MW, closely followed by Germany's 10,000 MW. Interesting is also France with 6,000 MW in 2020 from absolutely zero.

5 The recently launched European Wind Industrial Initiative expects a wind energy penetration level of 20% in 2020 (EU Commission 2009a: 8).

Table 3.

Selected EU national RES action plans for offshore wind, 2010 – 2015 – 2020

	2010		2015		2020	
COUNTRY	MW	GWH	MW	GWH	MW	GWH
UK	1390	4630	5500	18,820	12,990	44,120
Germany	150	271	3,000	8,004	10,000	31,771
France	0	0	2,667	8,000	6,000	18,000
Netherlands	228	803	1,178	4,147	5,178	19,036
Spain	0	0	150	300	3,000	7,753
Denmark	661	2,485	1,251	4,920	1,339	5,322
Italy	0	0	168	453	680	2,000
Greece	0	0	0	0	300	672
Sweden	76	208	129	354	182	500
Portugal	0	0	25	60	75	180
Total	**2,505**		**13,568**		**39,744**	

SOURCE: HTTP://EC.EUROPA.EU/ENERGY/RENEWABLES/TRANSPARENCY_PLATFORM/ACTION_PLAN_EN.HTM, 27 September 2010. No data available for Finland, Belgium, Baltic countries, Poland.

Appendix B: Denmark as Offshore Wind Power Hub

Historically, Denmark has a position as a global competence centre for wind energy but other countries are investing heavily in RD&D in wind energy in general and offshore wind in particular.[6]

First mover in wind energy: Denmark was the first country in the world to develop and implement wind power in its energy system – and to integrate a large share of wind power. Wind power in Denmark supplies the equivalent of 25% of Denmarks domestic electricity consumption. Denmark's leading position in the global (and booming) wind energy technology market rests on a unique combination of internationally leading manufacturers, a solid supply chain, a proactive national transmission system operator and a strong and intertwined RD&D environment. A broad political and societal vision to obtain self-sufficiency in terms of energy has since the oil crises in the 1970s guided the development of regulatory framework, smart green taxes and support schemes combined with strict environmental, climate and energy conservation policy measures. First mover in offshore wind energy: The first ever offshore wind energy farm was set up in Vindeby in 1991. In 1997, the Offshore Wind Turbine Action Plan was published by the Danish Energy Agency and following the Danish government's 2025 Energy Strategy in 2005, this Action Plan was updated in 2007 to reassess the future expansion of offshore wind farms. In addition to some demonstration projects, the two first large offshore farms were established in Horns Rev I and Rødsand in 2002 and 2003 respectively. Offshore wind supplies more than 13% of Denmarks domestic consumption of electricity – no other country has penetration levels above 1%.The largest cumulative offshore installation today is in UK (883 MW), closely followed by Denmark (646 MW). More than 90% of the offshore turbine market is dominated by the two wind turbine manufacturers – Siemens Wind Power and Vestas Wind Systems.

Long track record in offshore installation and support structures: Danish industry, engineering companies, contractors and R&D institutions have a strong track record in designing, producing and installing foundations and support structures. This is partly due to solid business relations among developers, industry and R&D institutes. Since mid 1990s research has focused on offshore foundations, wave load and seabed conditions, something which has put Danish RD&D communities at the forefront of developing modern offshore support structures. This together with the practical experiences in supplying support structures to offshore wind farms constitutes a unique knowledge pool and a valuable technical dataset.

Cross-border electricity markets: Denmark and the other Nordic countries have long ago developed and implemented framework conditions for an internal electricity market where power is traded across national boundaries and diverse control zones. This political priority and practical experience is regarded as a strong asset when developing the technologies, systems and markets for a larger European offshore wind energy connection system and power market. Likewise, this has also enabled Danish RD&D communities to be well ahead on this topic. Further, the Danish power sector has a tradition for good co-operation between grid operators, energy companies, developers, wind industry and research. Danish companies have good reputation and practical experiences in building and installing substations for offshore wind farms in the North Sea. Being at the forefront of

6 Draws on MandagMorgen 2010 and Jørgensen, B.H & Münster, M. 2010.

the development of large scale offshore grids and a pan European electricity market offers great opportunities and Danish industry, developers and operators are all well placed to profit from that.

Growth industry: Today, the Danish wind turbine industry has enjoyed an average annual growth rate of app. 15% over the last ten years. The total number of employees is app. 25,000, half of them work in the production, 21% RD&D, 10% with marketing and sale and the remaining 18% with consultancy, O&M a.o. In 2009, the total revenue of the wind turbine industry was 51 billion DKK, of which 42 billion DKK was exported. Exports of wind energy technology constitute an increasing part of the total export, reaching more than 9% in 2009.

Producer-user technology development: Technology was from the very beginning regarded as a key measure to provide new solutions to transit to a low carbon energy future. Businesses, often small and medium sized companies, research communities and local communities contributed to the development, testing and advances in manufacturing. RD&D was subject to an extensive dialogue and interaction between the wind industry, research, the energy companies and developers, including local communities. The practical knowledge of the industry was integrated in research based development of the wind turbine design and operation from the very beginning. The exceptional cooperation also distinguishes between precompetitive R&D and the industry's need for restricted knowledge sharing. Competitors may enter into strategic technology platforms and partnerships while at the same time being able to protect the IPR of the company.

A unique supply chain: A very strong feature of the Danish wind energy industry is the large number of suppliers to the industry, which has grown along with the major wind turbine manufacturers. The suppliers constitute a competitive part of the Danish wind energy industry, and with advanced test facilities the suppliers have the opportunity to set technical standards, codes and norms for the mechanical and electrical components making up the modern offshore wind energy farm and its integration in the grid. When deciding where to locate their operations, global players address at three parameters – closeness to the market, access to a supporting network of suppliers within immediate vicinity, and specialised workforce and specialised knowledge on wind energy.

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