REPORT FROM MEGAVIND
MAJ 2013

THE DANISH WIND POWER HUB

Strategy for Research, Development, and Demonstration

MEGAVIND

Content

Preface

Megavind is Denmark's national partnership for wind energy, and acts as catalyst and initiator of a strengthened strategic agenda for research, development, and demonstration (RD&D). Megavind is the Danish equivalent of the European Technology Platform for Wind Energy; TP Wind.

Established in 2006, the role of Megavind is to strengthen public-private cooperation between the state, businesses, knowledge institutions and venture capital to accelerate innovation-processes within a number of areas of technology.

The Megavind steering committee today consists of representatives from the following companies:

- Vestas Wind Systems A/S
- Siemens Wind Power A/S
- DONG Energy A/S
- Technical University of Denmark, Department of Wind Energy
- Aalborg University
- Fritz Schur Energy A/S
- COWI A/S
- Energinet.dk (observer)
- Danish Energy Agency (observer)

The present report is a revision of Megavind's main strategy from 2007. The revision will point out specific initiatives within long and short term research, development, test, and demonstration as well as presenting recommendations for education that can take part in developing Denmark as the hub of the world's leading companies and research institutions within the field of wind energy.

In this way, Megavind has an advisory role to the entire industry and is strengthening the collective Danish innovation and research environment within wind energy. Megavind's ambition is to consolidate the targets for the coming years' strategic research in wind energy.

Key Recommendations

Successive governments of Denmark have confirmed the nation's green ambitions, both in terms of greening the energy sector but increasingly with a focus on creating and developing a strong export of green energy solutions. Lowering the cost of energy from green solutions is key objective in order to fulfill both ambitions.

The wind energy industry is a frontrunner and onshore wind power plants are on windy sites competitive with conventional power plants. Thus, wind power is considered a relatively mature green technology. However, there is still considerable room for lowering costs of energy through developing the technology and especially by further maturing the industry.

At this stage of industrialisation, more than ever, creating new valuable and commercially strong solutions requires science-based innovation and collaboration between research institutions, universities, and industry, as well as between suppliers within the industry.

Megavind's **vision** is for Denmark to continue to develop its position as the hub of globally leading companies and research institutions within the field of wind energy and that these companies will be the first to deliver competitive wind energy on market terms in the dominating wind energy markets.

To support the vision it is necessary to develop attractive innovation frameworks with a strong focus on long and short term research, development, and demonstration (RD&D) in the entire supply chain. The current report establishes an overview of the current situation and provides seven key recommendations. In each of the chapters detailed recommendations are outlined.

The Megavind key recommendations are summarized as follows:

- A **commonly agreed and accepted method for calculating and tracking development in cost of energy from wind power** is needed. The objective is to create a collaborative benchmark tool to track the wind industry's progress in reduction of costs of energy, as well as to enable science-based innovation towards addressing the main cost drivers. Thus, the agreed method must also define main cost drivers in a level of detail that matches the Megavind strategies "Denmark – Supplier of Competitive Offshore Wind" published in 2010, and "Strategy for Wind Turbine Components and Subsystems" published in 2011. Cf. chapter four.

- A **comprehensive strategy for increasing the ability of Danish research and educational institutions** to contribute to maintaining Denmark as a global hub for the development of competitive wind power solutions. The strategy must in particular address collaboration between business and research institutions/ universities, involvement in future long and short term research and development strategies, public-private test and demonstration facilities, and recommendations for educational curriculum. Cf. chapter five (5.1 and 5.3).

- A **revised, comprehensive innovation, test, and demonstration facilities strategy**, including a benchmarking report containing a comparative analysis and mapping of available test and demonstration facilities globally. The revised strategy must include wind turbines (prototypes and pre-series), components and turbines parts, wind power plants and plant infrastructure, offshore installations, offshore service and change of major components, and wind power plants in energy systems. Cf. chapter five (5.2) and chapter six.

- A **strategy for supply chain industrialisation and modularisation**. This strategy should build upon the recommendations outlined in the Megavind strategy for systems and components published in 2012[1]. A key element is to improve the ability of large systems suppliers to enter into RD&D cooperation and drive industrialisation and modularisation. Cf. chapter three and five (5.2 and 5.3).

- A **report on potential technology based solutions for reducing environmental and other local impacts of wind turbines**. Fields of RD&D could include solutions aimed at noise, visual impacts, aviation marking systems, planning procedures, etc. Cf. chapter two.

- A **strategy for increasing the value of wind power in energy systems with high shares of wind energy**. This strategy should include improved wind power plant ability to deliver security of supply, more flexible production, ancillary and system services, and other services that may increase the value and income of wind power plants. The strategy may contain recommendations on how European markets could be designed to take advantage of future advances in technology. Cf. chapter eight.

- A **sustained, shared international approach from public authorities and private actors** is needed. The framework conditions must be continually developed with an aim to attract international activities e.g. students, researchers, demonstration projects, testing, and universities as well as skilled employees and leading foreign companies to the Danish hub. The Danish energy market must stay attractive to foreign actors as e.g. large developers which own and operate wind power plants in Denmark as well as wind turbine manufacturers and the whole range of sub-suppliers.

[1] Megavind, "Strategy for Wind Turbine Components and Subsystems" (2012)

1. Background

The Danish Parliament took a decisive step towards a society free of coal, oil, and natural gas in March 2012 with an ambitious Energy Agreement. The Agreement stipulates that half of the electricity consumption shall come from wind power in 2020 – today it is around 30%. This is an important step towards recognizing the potential of wind power as both a green energy provider, energy system balancer, and a green growth driver, securing employment in Denmark.

In 2012 too, a new testing facility in Østerild was opened. This land-based near coastal location in the Northwestern part of Jutland makes it possible to test and demonstrate wind turbines up to 250 meters tip height and 16 MW nominal power in wind conditions similar to those within a wind power plant located in the middle of the North Sea. Thus, one of Megavind's[2] recommendations from the 2007 strategy[3] has materialized and "Østerild – National Test Center for Large Wind Turbines" is an important element in the strategy for Denmark to maintain and further develop its position as the hub of leading companies and research institutions within the field of wind energy.

There are challenges though. Companies and universities based in Denmark have by some been described as the cradle of the modern wind industry. However, Denmark is no longer the only hub of competence within wind energy.

For the last decade, the wind industry has experienced average annual growth rates of more than 20% and this has attracted the attention of large nations and conglomerates. Research and development facilities and knowledge networks are established in several countries and some of the world's leading universities are participating in the competing centres of competence.

Megavind's **vision** is for Denmark to continue to develop its position as the hub of globally leading companies and research institutions within the field of wind energy and that these companies will be the first to deliver competitive wind energy on market terms in the dominating wind energy markets.

This strategy includes deliberations and recommendations on how to compete with the other global centres of competence.

[2] 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 is the catalyst and initiator of a strengthened testing, demonstration and research strategy within the field of wind power in Denmark.

[3] Denmark's Future as Leading Centre of Competence within the Field of Wind Power (2007)

While low cost of energy has always been a primary goal of the wind energy industry, the 2008 financial crisis has increased the drive towards still more cost-effective wind power plants. Megavind has had a strong focus on reducing levelised cost of energy[4] in the strategies published in 2010-2013[5] and the strategy at hand includes recommendations to this objective as well.

It is – and has been since the birth of Megavind – the ambition that Denmark and Danish based companies develop and deliver the most cost effective wind energy to ensure the best possible integration of wind energy in the accumulated energy system and, also in the future, to provide state of the art technology to energy systems with a very large share of wind energy.

This strategy includes an overview of the current situation and recommendations on how to increase efficiency of the industrial supply chain in order to organize strategic cooperation on long and short term research, development, and innovation in an environment where levelised cost of energy reductions are the overall objective.

[4] Levelised cost of energy represents the present value of the total cost of building and operating a generating plant over an assumed financial life and duty cycle, converted to equal annual payments and expressed in terms of real euro to remove the impact of inflation. Source: IEA. In short, LCOE can be seen as the lifetime cost of the project, per unit of energy generated.

[5] Strategy for Wind Turbine Components and Subsystems (2012), Denmark – Supplier of Competitive Offshore Wind Solutions (2010).

2. A Dynamic Industry

The wind turbine market has always had reductions in cost of energy as a primary driver. The turbine with the lowest projected cost per produced MWh has always been market leading. Trust in the manufacturer is also part of that equation.

And the market focus on lowering levelised cost of energy has never been stronger. The financial crisis since 2008 has had a strong effect, but it is by far not the only reason. Another is more professional customers. While the wind energy market in the 80s and prior was dominated by cooperatives and smaller scale investments, today's market is driven by very large, professional investments made by developers and energy companies e.g. utilities that now often are larger companies than the turbine manufacturer itself. A third explanation is that the cost levels of wind energy have come down very close to so-called grid parity, where support frameworks may no longer be needed as much as in the past. Reaching grid parity will be game changing for the entire industry, as the industry would then no longer depend on getting renewed political support to the same extent as known so far.

2.1 Market Trends

Danish wind turbine manufacturers have since the 1980s been present on the global wind power market, whereas their main international competitors grew with a strong home market with a limited or absent focus on export e.g. Enercon in Germany, Gamesa in Spain, and GE in the US. The Danish market could not sustain the large group of local manufacturers. They were therefore all born with a strong focus on export and global footprint and established themselves on the large, more stable global markets in strong competition with local manufacturers. Today, the two large Danish based wind turbine manufacturers Vestas Wind Systems and Siemens Wind Power have a combined market share just above 25%[6].

Due to stop-go policies some markets are year after year going from full power to slow motion. However, the overall average is still a growing market. For the period 2012-2016 average annual market growth rates are expected to be about 8%[7].

These more "modest" growth rates are replacing many years of a booming market with average annual growth rates of more than 20% and bottlenecks in the production. The industry has suffered from the global recession and increased competition and experienced an overcapacity in the production line with trimming of staff and production facilities as a result. In the second half of 2012, many companies were struggling to meet a large pile-up of orders to be delivered while they simultaneously had to prepare for a significant market reduction in 2013. The US market e.g. is expected to drop in 2013 even though the production tax credit scheme was extended beyond 2012 in the last minute as it is not possible to capitalize on the extension right away.

The competition is fierce among the wind turbine manufacturers and also the Danish component suppliers face increasing international competition as large international companies have discovered that wind energy is an industry with large growth potential. A number of traditional suppliers to the automotive industry have adapted their components to wind turbines and many Asian companies have taken up production of cheaper versions of various components.

The development of new energy technologies has also put pressure on the wind industry as especially the abundant and cheaply exploited shale gas in the US – and other countries – is playing a still increasing role, reaching 23% of the natural gas production over a period of 10 years 2000-2010[8].

However, the offshore wind energy market has picked up speed over the last five years, especially in the waters surrounding Denmark and within reach of the Danish production facilities. Moreover, offshore is expected to be the fastest growing segment in the global wind market with average annual growth rates of around 30% from 2012-2020[9].

The Danish wind industry has a track record of more than 20 years of offshore experience and Denmark is home to a complete and very experienced offshore value chain. Vestas Wind Systems and Siemens Wind Power still dominate the offshore wind energy market with more than 90% of the wind turbines installed offshore combined and Danish based sub-suppliers are benefitting from the offshore development as well. In addition to this the Danish energy company, DONG Energy, is a leading developer of offshore wind power plants and the Danish wind energy market has so far been able to attract large developers as Vattenfall and E.ON who own and operate wind power plants in Denmark.

---

6 MAKE Consulting, 2013

7 GWEC: http://www.gwec.net/global-figures/market-forecast-2012-2016/

8 The International Energy Agency (IEA) 2011

9 MAKE Consulting "Q1/2013 Global Wind Power Market Outlook Update"

2.2 Meeting Political Targets While Reducing Environmental Impact

The 2012 Danish Energy Agreement entails a continued development of both on- and offshore wind energy with a set target of 1800 new MW onshore by 2020. A decisive factor in regards to a fulfilment of the 2020 target will be the ability to ensure continued support for both the overall political targets and for the projects at local level.

At both national and European level public opinion polls show high approval and support of a continued development of wind power[10]. The support for continued wind power development also includes the support of development of wind power projects at local level. In addition surveys carried out among people living close to wind power projects[11] show that the majority of neighbours experience no or very few negative impacts from wind turbines.

In spite of the high general support to onshore wind power development, concerns and opposition towards the installation of wind turbines are not infrequently a factor when it comes to projects at local level. This contributes to lengthening of project lead times and to the shelving of some projects altogether. Such delays, setbacks and uncertainty in regards to return of investments increase the risk for project developers and counteract industry in its efforts to drive down levelised cost of energy.

Onshore wind energy will continue to play a significant role in the continued transformation of the Danish and European energy systems towards still higher penetration of renewable energy sources. In view of this development understanding and mitigation of mechanisms behind concerns at local level as well as development of technologies that reduce negative impacts generated from wind turbines are both foreseen to be important fields of continued research and product development. With a strong home market, production facilities and RD&D competences Denmark is in a unique position to expand knowledge and develop new solutions and technologies within this area.

Megavind recommends:

- **Through a better understanding of the local concerns develop strategies and procedures for a more efficient planning process.**
- **Technology solutions aimed at reducing environmental impact from wind turbines. Fields of RD&D include noise such as noise transmission into houses, measures to reduce noise transmission through e.g. insulation – to include also visual impact, aviation marking systems etc.**

[10] Megafon 2009, Megafon 2012, Eurobarometer 2011

[11] Jysk Analyse: "The perception of wind turbines as experienced by their neighbours" (2012) and Megafon Survey (2012)

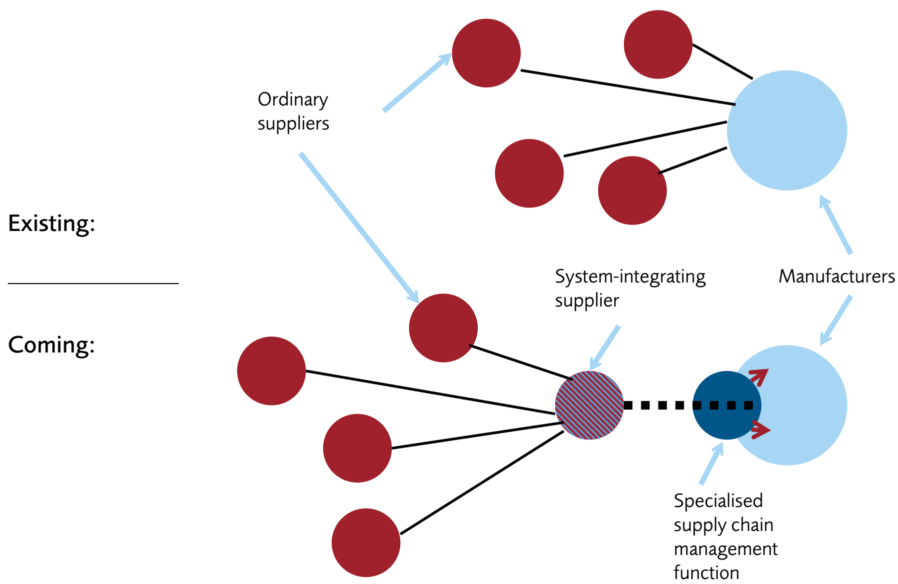

© Keen Press

3. Industry Structure and Supply Chain

The wind industry supply chain is rapidly undergoing change. In 2006, the supplier structure to Danish wind turbine manufacturers was almost flat[12]. Broadly speaking, a majority of companies in the supplier base supplied parts and components directly to the wind turbine manufacturers, and a large share of these had only one wind turbine manufacturer as customer. There were only few shared relations between sub-suppliers.

This has changed and the supplier base is increasingly organised in a more tiered supply chain structure. Key suppliers (tier one) take on responsibility for more than simply supplying parts and components and increasingly become supplier of sub-systems, design, and assembly to provide more value and build more lasting relationships with the wind turbine manufacturers[13].

Figure 3.1
Hierarchised value chains.



Source: "Denmark – the wind power hub; transforming the supply chain" (2012)

The Danish sub-suppliers have developed a stronger RD&D competence and cooperate across the value chain. Furthermore, they include their customers in the RD&D work and the trend is that suppliers and wind turbine manufacturers together focus on industrialisation and modularisation.

[12] Poul Houman Andersen and Ina Drejer, "Danmark som Wind Power Hub – Mellem virkelighed og mulighed" (2006)

[13] Poul Houman Andersen and Ina Drejer, "Denmark – the wind power hub; transforming the supply chain" (2012)

3.1 Consolidation

For the small and medium sized enterprises of the industry, it can be very hard to find the resources to make the right strategic decisions and move activities – sale and production – to new markets. The Danish component- and service suppliers are known and valued in the sector for their long track records and innovative skills – qualities that are highly valued by clients that are newcomers in the sector. But as their existing customers have developed into large international companies, they place new demands on their suppliers with regard to process optimisation and product quality. Tools like Lean and Six Sigma have filtered down to tier one, two and three suppliers over the past 5-6 years.

Demands are thus manifold on the component- and service suppliers and there is a consensus in the industry that the consolidation process that to some extent has already taken place over the past couple of years will escalate. This will also include new roles of responsibilities and risk taking in the supply chain.

3.2 Jobs and Skills

For the last decade, the Danish political debate has had a focus on preserving highly skilled white collar jobs. The argumentation has shifted; over the last couple of years now both industry and politicians agree that the Danish society still needs the production jobs in order to maintain current standards of living. Thus, focus is now also to preserve blue collar jobs mainly through production optimisation.

The wind industry is probably not as challenged in this area as other industries as labour costs are not as dominant in the overall production costs. Also, the blue collar workers in the Danish wind industry are highly skilled (because of training and/or education) and have a great willingness to adapt to new conditions. E.g. the nacelle assembly line where labour hours have been reduced fifteen fold per MW over a period of 20 years and there are still a lot of potential improvements to be realised.

Some Danish component- and service suppliers have chosen to invest heavily in automation of the production to bring down labour costs. But the challenge is that the wind industry produces components in very small quantities compared to other industries e.g. the automotive industry. Components are still designed to fit individual nameplates and manufacturer design and only a couple of thousand units are normally needed in one series. Thus, there are major challenges in achieving gains from large-scale production but some competing component suppliers have started to consider clustering together and sharing a production facility. Another budding idea could be a flexible production line that can be installed and dismantled in different markets according to demand.

The latest development in the industry is a stronger focus on modularisation and standardisation of technological platforms where fewer sub-suppliers are needed and more “plug and play” systems are developed. This development will increase the consolidation process among suppliers even further. However, it is recommended that the scope of components which are beneficial to standardise is defined. Some components will be profitable and relatively easy to standardise. Other components give a competitive advantage to a supplier or a wind turbine manufacturer and will be more difficult to standardise as it is the diversity which makes them unique.

Megavind recommends:

- **That supporting framework conditions for supplier development are established e.g. a focus on creating a strengthened innovation efficiency in the primary production and keeping the production and research and development facilities in close vicinity of each other. It is especially emphasized that tier one suppliers must increase cooperation on RD&D.**

In accordance with the above that the wind energy industry prioritises the development of the following areas:

- **Optimization of the global competitive strengths of manufacturers and sub-suppliers.**

- **Consolidation through structured changes of the industry e.g. merging of sub-suppliers vertically.**

- **More efficient production processes through industrialisation and modularisation, hereunder demands for quality and standardisation of certain products – from energy companies to manufacturers and from manufacturers to sub-suppliers.**

- **Long and short term RD&D cooperation: Sub-supplier <-> sub-supplier and manufacturer <-> sub-supplier.**

- **Further qualifications of the skilled work force.**

4. Offshore Wind Power

The offshore wind energy market is a maturing market in 2013 with app. 5 GW installed in Europe. In 2020 this number will be eight times as high, as the expected number of GW will be app. 32 GW in 2020 in Europe according to the EU-countries' national renewable energy action plans (NREAP). In the same period up to 2020, an offshore market similar in size is expected to be seen in South East Asia[14].

This growth requires a supply chain that constantly is developing and getting more and more efficient alongside with handling different bottlenecks in the supply chain. Some of the main challenges within the offshore industry are to harvest the benefits of economics of scale by delivering the individual products and solutions in sufficient numbers and ensure the needed investment in e.g. new types of foundations, new wind turbine models etc.

Offshore wind power plants are still more expensive than onshore wind power plants and there is still a way to go before offshore wind power plants reach grid parity, which means that it will be possible to build and operate an offshore wind power plant at market conditions without subsidies. The main challenge for the wind industry and other stakeholders – governments, universities and financial institutions – is to reduce the entire cost base for offshore wind power plants in order to reduce the levelised cost of energy.

4.1 Levelised Cost of Energy Reductions

Levelised cost of energy (LCOE) is defined as the levelised cost per produced MWh seen over the entire lifetime of the wind power plant.

LCOE is basically the development cost (DEVEX), the capital expenditures (CAPEX) and the operational expenditures (OPEX) levelised to annual average cost seen over the lifetime of the wind power plant divided by the expected annual energy production (AEP) from the wind power plant.

$$\text{LCOE}\left(\frac{€}{(\text{MWh})}\right) = \frac{\text{DEVEX}(€)+\text{CAPEX}(€)+\text{OPEX}(€)}{\text{AEP}(\text{MWh})}$$

LCOE can as the equation shows be cut down by reducing the development, installation, and operational costs and increase the energy production from the wind power plant.

DEVEX is driven by the complexity and duration of the development period from getting project rights to investment decision is taken and the design of the wind power plant is done.

CAPEX is primarily depending on technology cost but these are influenced by governmental requirements such as available sites, knowledge of wind, seabed and other crucial conditions at the site. CAPEX is also highly influenced by

[14] MAKE Consulting 2013

the needed return on the investment and therefore the lower risk premium and interest rate, the lower financial cost to finance the installation cost.

OPEX is also primarily a technology cost but it does also depend on the accessibility to the wind power plant which is highly depended on the distance to the service harbour and the weather conditions such as wind and waves.

The AEP is primarily depending on the wind conditions at the site and the ability of the technology to harvest the wind and convert it into electricity.

LCOE is therefore not just a question of technology development but also affected by political decisions such as potential sites available, political risk and requirements. Finally, LCOE is affected by the financial sector's evaluation of overall financial risk associated to the entire project – the developer, the employed technology, and the political framework.

4.2 Status of the LCOE Reductions

Megavind defined in 2010 a target of reducing LCOE for offshore wind power by 50% for investment decisions in 2020 compared to comparable sites with investment decisions in 2010. The fulfilment of the 50% target is ambitious cf. figure 4.1. United Kingdom has the largest offshore wind energy market at the moment and the UK government has set a target of a maximum support level at 100 GBP/MWh in 2020. This target has been accepted and embraced by leading offshore market developers. Two UK studies consider how to deliver a LCOE of 100 GBP/MWh or below by 2020 compared to the current level of 140 GBP/MWh (2012) . Both studies find the target achievable; however, they conclude that costs can only be reduced significantly provided pro-active steps are taken. These cover the supply chain, innovation, contracting strategies, planning and consenting, financing, and grid integration.

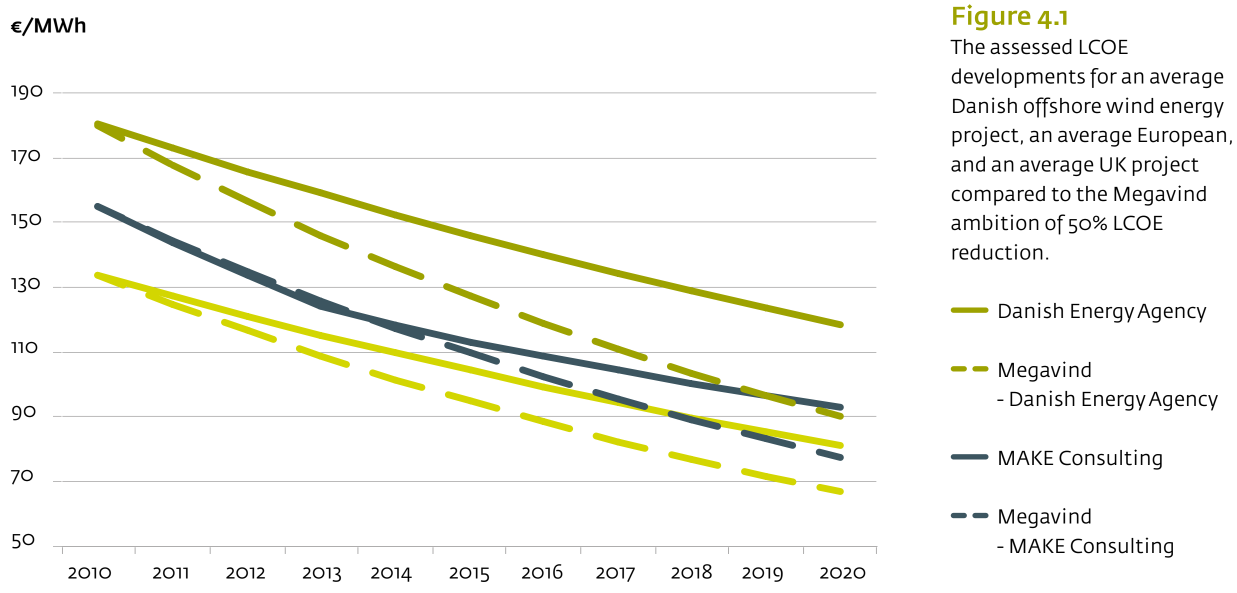


Figure 4.1
The assessed LCOE developments for an average Danish offshore wind energy project, an average European, and an average UK project compared to the Megavind ambition of 50% LCOE reduction.

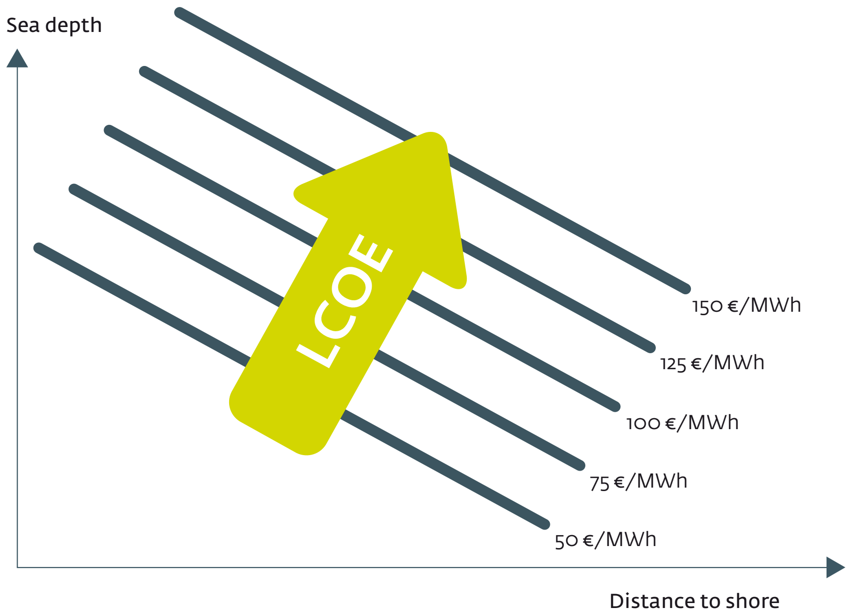
Source: Danish Energy Agency[15], MAKE Consulting, Crown Estate

If Megavind's ambition of 50% reduction of LCOE is applied under the given conditions of the three markets, the costs of an average offshore wind project will

[15] With the adjustment of economic lifetime/concession to 25 years from 20 years as this is standard in the offshore wind energy markets (25 years is used in the assessed development of LCOE in Denmark and United Kingdom)

be in the span of 67 EUR/MWh to 90 EUR/MWh in 2020. The different cost starting points for LCOE reductions are dependent on a range of factors including different planning regimes (terms and conditions), site conditions (e.g. distance to shore as costs increase with distance and depth), and calculation methods as e.g. offshore substation, export cable, and onshore substation is a part of the UK scope for LCOE assets and not included in the Danish scope for LCOE.

Figure 4.2
Relation between distance, sea depth and LCOE.



Source: "Denmark – supplier of competitive offshore wind solutions"

It would be useful with a common baseline for tracking future achievements of LCOE for comparable sites and framework but it is necessary first to analyze and get an agreement on methodology and which parameters make sites comparable before a common starting point and measurement method can be established.

However, the fulfillment of the 50% target sets the line of sight for the offshore wind energy industry and the framework within it has to develop. It is expected that reaching the 50% target will ensure the following requirements for unlocking a great market perspective for the offshore wind energy industry by:

- Being cost competitive towards coal, gas, biomass, solar, nuclear and other major power plant technologies
- Reaching grid parity in the major offshore wind markets app. in 2025[16]

On one hand – it is not enough to ensure competiveness with a 50% LCOE reduction if the other technologies are more competitive and the market for offshore wind power plants will first unlock the large potential, when grid parity is reached. The latter depends on the long run electricity price in the market zone, where the offshore wind power plant is connected. On the other hand the 50% target is a measurable and necessary, but not necessarily a sufficient target to fulfill in contrast to the relative targets of cost competitiveness and grid parity.

Offshore wind energy will in the coming years continue to be more expensive than onshore wind, large scale hydro, and geothermal power but opposite to these technologies offshore wind energy has an almost infinite potential measured in installation and operation of new capacity and therefore offshore wind energy possesses a large market potential.

---

[16] MAKE Consulting have estimated that grid parity can be reached at average EU-level in 2023, Research note, Feb. 2013

Achieving the target requires concerted and collaborative efforts from industry, research institutions, and government with well-defined sub-targets for a range of different focus areas, see below. In order to ensure a clear baseline of the levelised cost of energy in 2010 it is recommended that a baseline and methodology is established with which the fulfillment of the 50% target can be measured in 2020 and onwards to track future achievements of LCOE for comparable sites and framework.

The baseline will be used to follow-up on the progress of the industry regarding delivering the target of reducing levelised cost of energy with 50% in 2020 and within the sub-categories of the industry to focus at the largest potentials in order to continuously harvest the lowest hanging fruits.

Megavind's offshore strategy (2010)[17] designated seven sub-categories of LCOE-areas which were seen as the ones with the greatest potential. With this Megavind strategy, the seven areas are complemented by an extension of one category:

- Consenting and the general policy framework are added to "1. Planning and site selection"

The seven focal points in the Megavind strategy are as follows:

1. **Planning, consenting, policy framework and site selection**
2. **Wind power plants**
3. **Wind turbines**
4. **Foundations**
5. **Electrical infrastructure**
6. **Assembly and installation**
7. **Operation and maintenance**

The seven interrelated focal points are based on the former Megavind offshore strategy from 2010 with the addition of transaction costs such as consenting and policy framework in focal point 1. Financial cost is another important focal point as even small changes in the interest rates and expected required rates of return give significant variations in the final LCOE calculation and need for subsidy to offshore wind power plants. However, it is outside Megavind's scope to include this area in the strategic work.

[17] "Denmark – Supplier of Competitive Offshore Wind Solutions
Megavind's Strategy for Offshore Wind Research, Development and Demonstration"

How the different focal points relate to each other is shown in figure 4.3

Firgure 4.3
Thematic priorities and their relation to LCOE

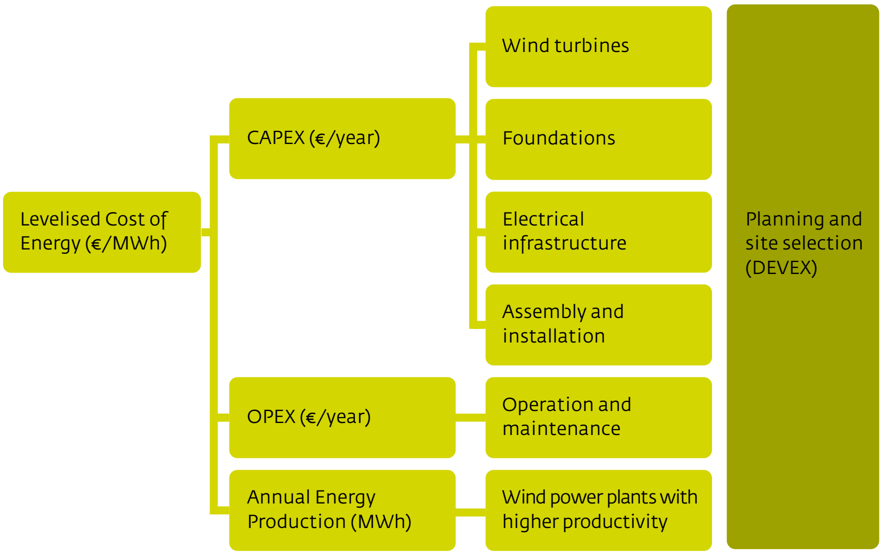


Figure 4.4
LCOE cost components for offshore wind energy directly influenced by the industry

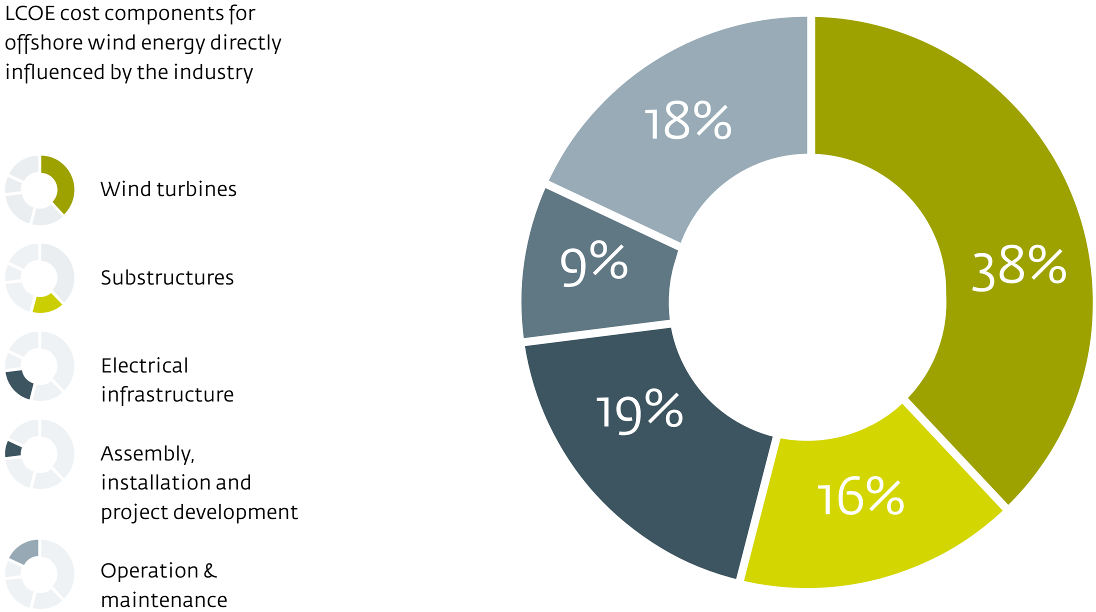
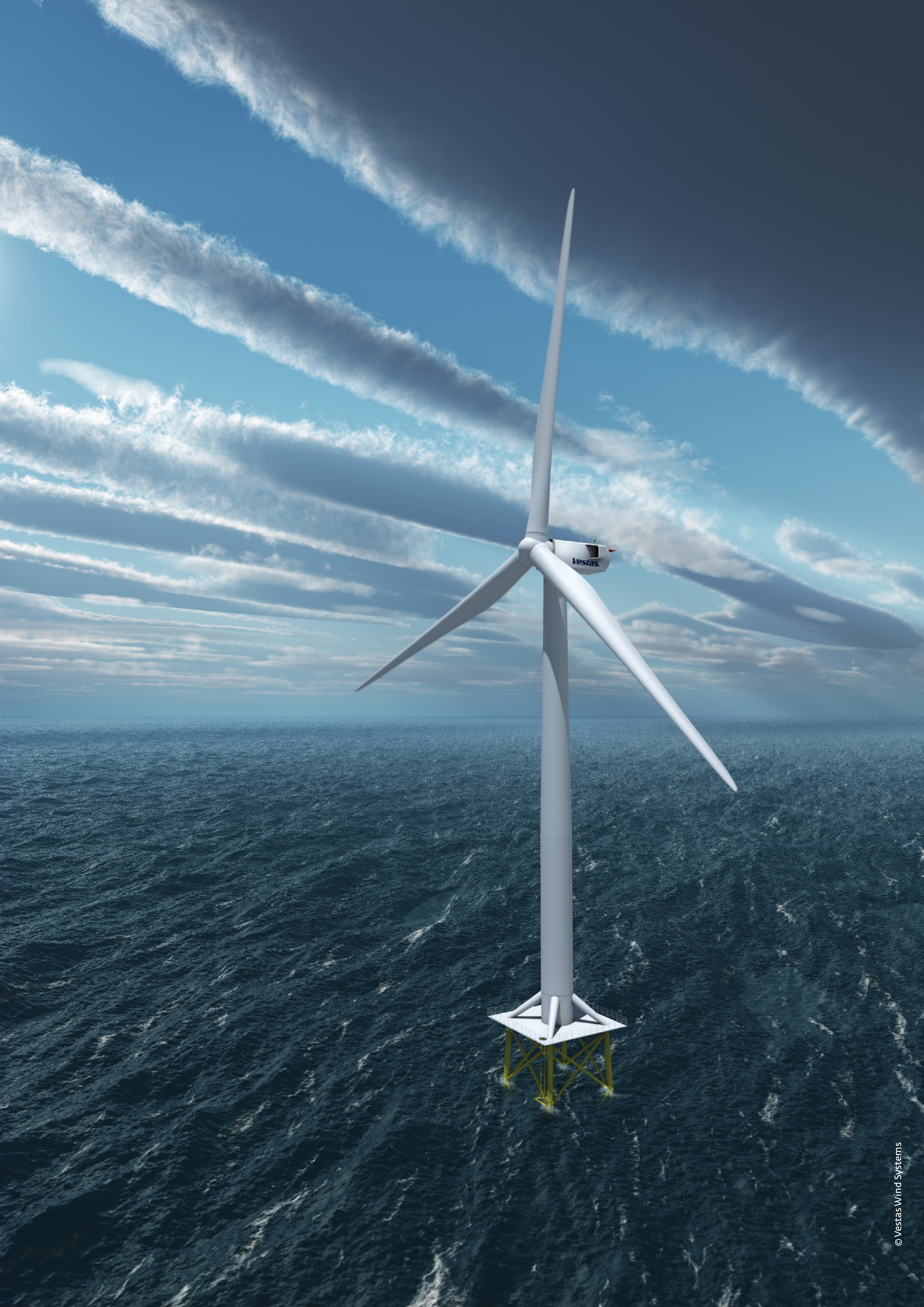


Figure 4.4 above shows a decomposition of the cost-components for offshore wind energy, that the wind industry can influence directly by their RD&D-work.

Megavind recommends:

- **That a commonly agreed and accepted method for calculating and tracking development in cost of energy from wind power is developed. The objective is to create a collaborative benchmark tool to track the wind industry's progress in reduction of cost of energy, as well as to enable science-based innovation towards addressing the main cost drivers.**
- **Thus, the agreed method must also define main cost drivers in a level of detail that matches the Megavind strategies "Danmark – Supplier of Competitive Offshore Wind" published in 2010, and "Strategy for Wind Turbine Components and Subsystems" published in 2011.**



5. Strengths and Weaknesses of the Danish Hub

Denmark is regarded as a strong wind energy hub. There is a strong presence of manufacturers and suppliers and the entire supply chain is available in short distance from each other. This is the case for both onshore and offshore supply chain. This combined with a skilled labour force, experienced universities with wind energy expert knowledge, long history and tradition for wind energy, and a varied range of testing facilities make Denmark an attractive and leading competence centre for wind energy.

The attraction of talented students and future employees is dependent on a well-established university environment with relevant educational offers and world class professors as well as the Danish sub-suppliers, the Danish based wind turbine manufactures, the wind turbine in itself, and the well-known wind turbine pioneers. Foreign companies are settling in Denmark because of the strong Danish wind power hub and the political framework conditions – particularly regarding testing facilities.

In Denmark it is possible for e.g. the manufacturers to have their assembly facilities and research and development (R&D) facilities in short driving range – not only of each other but also of the testing sites for new wind turbines. This is unique and important as production, research and development, and test and verification of the turbines are co-dependent. The Danish set-up supports that development and innovation are speeded up which results in a competitive edge for the companies based in Denmark.

The sub-suppliers are also an important part of the RD&D environment in the Danish wind power hub. The sub-suppliers have strong R&D competences and some have their own R&D facilities. Furthermore, a number of sub suppliers are teaming up on R&D in different ways e.g. LM Wind Power which in cooperation with Svendborg Brakes and kk-electronic has invested in a test site for the next eight years at The Test Station for Large Wind Turbines at Høvsøre. The strong sub-supplier base is even more important as the suppliers have primary production placed in Denmark – adding valuable knowledge of product development and innovation as well as jobs.

However, the development in the global wind energy industry is fast-tracked and the Danish efforts in RD&D, production, education, and innovation must be prioritised carefully. This is the only way that the Danish Hub can maintain its position as a global leading competence centre for wind energy and ensure a competitive and continuously innovative industry. One of the important initiatives which supports this ambition is the MADE initiative[18] which aims to strengthen the innovation culture within production – in order to keep the production and R&D facilities in close geographical vicinity of each other (in Denmark).

[18] Manufacturing Academy of Denmark (MADE) was established in 2012 as a partnership for research in production, education, and innovation.

5.1 Development 2007-2013

In 2007 Megavind made an evaluation of the Danish competence centre for wind energy and estimated its strength as an industrial technology cluster/ competence centre. Now, six years later, Megavind re-evaluate, see below figure. A competence centre can lose ground if the bearing pillars of on-going development change or erode. However, competing competence centres may also grow stronger and take over on some of the strengths normally presumed Danish.

Estimation on a scale from 1 to 5 with 5 as the high performance score.

Description (2007 strategy)	Evaluation 2007	Evaluation 2013	What has changed over 6 years
Critical mass[20] Over the years, wind power has taken a still larger market share of the energy market. The industry continues to invest more in research and the sector as a whole measured in jobs and export has grown. International investors and large multinational companies have invested in R&D and production facilities and the international wind energy sector is aware of the advantages of a Danish business location.	√ √ √ √ √	√ √ √ √ √	The critical mass is still there and international companies continue to establish R&D facilities in Denmark. The sector has been vastly affected by the global financial crisis like most other industries and this has slowed down the installation rate and investments in many markets. Many new wind turbine manufacturers have appeared sharpening the competition. To be competitive globally demands regional production for many companies. This has caused some restructuring and loss of jobs in Denmark. The European market of wind energy is expected to grow approx. 30% from 2012 to 2020 due to national targets from the European renewable energy directive[21]. Strong near-markets for offshore have appeared in England, Germany and France benefitting the many new companies in the Danish offshore supply chain. At the same time, the home market for wind has been secured until 2020 with an ambitious Energy Act.

Figure 5.1
The Danish competence centre for wind energy is evaluated as industrial technology cluster/competence centre on parameters defined by various prominent theorists, the Megavind Steering Committee, and key industry experts.[19]

[19] The evaluation of Denmark as a wind power cluster is developed on the basis of a broad theoretical foundation, drawing on various prominent theorists. These have used extensive empirical findings to develop frameworks for comparing and valuating industry-clusters and their competitiveness. The parameters that are featured in the Megavind strategy have specifically been developed on the basis of the chosen theories and by key experts from the wind energy sector, to best fit the wind energy industry.

[20] FESER E. J. and BERGMAN E. M. (2000)

[21] MAKE Consulting Q1 2013

Description (2007 strategy)	Evaluation 2007	Evaluation 2013	What has changed over 6 years
Industrial locomotive[22] Wind technology has been developed through a combination of strong entrepreneurship and publicly funded research as well as a national and later international demand for wind turbines. Development is driven by industrial locomotives (manufacturers) and a large group of component suppliers. Denmark has many companies that head wind power development. When the framework conditions are attractive also from an international perspective, the industrial presence is strong enough to still drive technology development in Denmark	√ √ √ √	√ √ √ √	In 2012, a new state of the art site for testing wind turbines was inaugurated in Denmark. This – along with a number of other test facilities (drive train, wind tunnel, and grid test) – has contributed to a national infrastructure that helps the industry in maintaining the role as an industrial locomotive. The test facilities are in close vicinity to the R&D departments of the major companies and these have in turn invested heavily in their own test equipment. Foreign companies have also invested in R&D activities in Denmark.

[22] Heinz Hollenstein (2003)

Description (2007 strategy)	Evaluation 2007	Evaluation 2013	What has changed over 6 years
Technological competencies[23] The Danish wind cluster is built on leading research in i.a. wind measurements, meteorology, aerodynamics etc. that has been used by the industry. Industrial innovation has historically been closely tied to university research activities. Threats: ▪ R&D clusters are appearing on many continents and technology competences are no longer centred in Denmark. ▪ Sector competition is becoming increasingly fierce with many newcomers. Core knowledge is sheltered in the large companies reducing the quality of the innovation environment.	√ √ √ √	√ √ √ √	The Danish research institutions are facing harder competition due to many of the new clusters that are appearing in Europe, Asia, and North America. Danish researchers still have an edge when it comes to wind turbine systems, wind measurements, and aerodynamics but other universities have taken the lead in other areas. As a consequence, the companies establish local R&D offices around the world to be close to leading competences. Many of the new test facilities in Denmark are; however, run by universities and pose new opportunities for researchers as they in this way still are a part of the state of the art activities.

[23] Maidique, Modesto A., (1984)

Description (2007 strategy)	Evaluation 2007	Evaluation 2013	What has changed over 6 years
New technology tracks[24] New technology trends pave the way for industrial growth. Over two decades the sizes and effectiveness of the wind turbines have continued to increase. There are still improvements to be made but the international competitors are gaining ground on the Danish technology lead. New potential technology tracks for continued success could be: ▪ Improved integration of wind in the electricity system ▪ New materials ▪ New components – and the interaction between components ▪ Effect electronics ▪ Operation and maintenance ▪ Offshore technology	√ √	√ √ √ √	Danish companies are still in front when it comes to new technology trends e.g. in aerodynamic and control research. The direct drive concept is one new concept as well as a wind turbine with only two blades and partial pitch has been developed in Denmark over the last couple of years. Apart from the wind turbine technology other Danish companies in the supply chain have also introduced innovative, new concepts.

[24] Heinz Hollenstein (2003)

Description (2007 strategy)	Evaluation 2007	Evaluation 2013	What has changed over 6 years
Cooperation[25] In the Danish wind energy sector, many have years of experience in designing wind turbines also in an era where there was a close cooperation in the sector. The Danish sector is still influenced by this spirit but the present interaction between industry and universities is more sporadic. The publicly funded research projects lack an industry presence and the industry finds the research projects to be too detached from their innovation activities. A poor exchange of labour between universities and industry and to some extent also between companies limits the spreading of knowledge and experience.	√ √	√ √ √	The cooperation between industry and universities has still room for improvement. Publicly funded R&D projects do to a larger degree involve both research institutes (universities) and industry. What has also improved is the exchange of labour between universities and industry. It is important though to have the right framework conditions for Ph.D. and industry contracts in order not to limit the scope of the collaboration. Wind turbine manufacturers and large component suppliers have established own offices on university campuses and this has resulted to some extent in a migration from universities to companies. Industry restructuring and trimming of the work force has also lead to more frequent shifts between companies. Danish component suppliers have engaged in new and closer cooperation in relation to technology development. Recently a group of suppliers has rented a wind turbine site at one of the large scale test centres.

[25] Gabriel R.G. Benitoa, Eivind Bergerc, Morten de la Forestd, Jonas Shum (2003)

Description (2007 strategy)	Evaluation 2007	Evaluation 2013	What has changed over 6 years
Education and recruitment[26] A long period of significant growth rates has resulted in a fiercer competition over highly qualified employees. Combined with a low enrolment rate to the technical educations, the result is an increasing shortage of qualified personnel. Universities and engineering colleges have introduced energy technology as a field of focus and the industry plays an active part in ensuring quality and relevance in the student programmes by offering internships and participation in student projects. The results will hopefully appear in the near future.	√ √	√ √ √	The global financial crisis has resulted in a reduction of the work force in some companies resulting in a spill over of trained personnel. There is; however, still a shortage of certain competences in the industry e.g. test engineers. The shortage of the latter is caused by the fact that universities in Denmark have limited focus on research and education of engineers with this background. There is also a regional shortage of qualified personnel e.g. with maritime competences. There is a need for more industry involvement in initiatives in the education sector.

[26] BIERLY P., CHAKRABARTI A. (1996)

To be a strong research community and industrial cluster for wind energy demands high scores in all the above areas. The overall rating of the Danish competence centre for wind energy is depicted in figure 5.2 with the green marking. The Danish competence centre has an imbalance caused by weaknesses mainly in the field of education but also partly when it comes to cooperation.

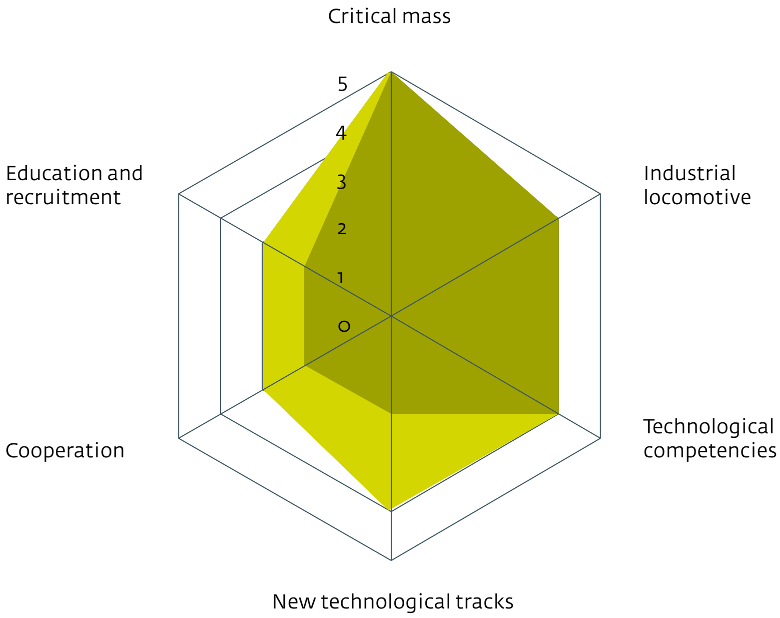
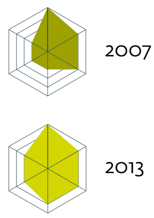


Figure 5.2
Overall rating of the Danish competence centre for wind energy based on information from figure 5.1.



The strengths of the Danish wind energy competence centre (hub) can be summarized as follows: The Danish wind industry has a strong critical mass, large market shares, and major innovation driven companies. This is much alike 2007. It is strengths that have been built through decades of focused efforts in RD&D – and not the least an innovative environment with widespread cooperation. It is the industrial cooperation and knowledge sharing environment which attracts foreign companies to the Danish wind energy cluster. The Danish companies and their employees have a knowledge pool in the field of wind energy that is incomparable internationally and the creative, self-driven working environment is very productive when it comes to innovation.

However, education/recruitment and cooperation stand out as challenges. There is a need to increase the efforts in these areas.

The traditional cooperation between industry and political decision makers is still important to create stable and supporting framework conditions, which is a very important prerequisite for the development of the wind power hub. Public investments in RD&D and innovation are of immense importance. This was present in the early decades of the Danish wind industry development and gave the perfect take-off.

Today, Hamburg is an example of a wind power hub in the making. Though Hamburg lacks the history and universities with wind power knowledge compared to the Danish hub, it has great potential. Hamburg is an attractive work location with an international airport and international companies. A number of wind turbine manufacturers, test and validating institutions, and consultants are already present – and sub-suppliers are the next to join. Hamburg has the potential to become a leading competence centre; it has a strong industrial environment and a German policy that favours renewables e.g. wind power.

A functional home market for demonstrating new technology and the integration of large quantities of wind power in the electricity system is also necessary to be in the lead. In addition to this the industry needs to be able to test and demonstrate new technology and the inauguration of "Østerild – National Test

Center for Large Wind Turbines" and the test bench for nacelles at LORC are important contributions for the Danish industry to maintain its role as an industrial locomotive. Overall the Danish energy act of 2012 is a potential industrial driver if implemented the right way.

Megavind recommends:

- **That a national strategy on long and short term research, education/recruitment, and cooperation is initiated to respond to the found weaknesses in these areas.**

- **To have a strong research community that can be a qualified partner for cooperation in relation to the private companies – the universities and research institutions need to be able to attract public funding on both long and short term research subjects that are focus areas in the industry RD&D, e.g. offshore technology development and LCOE reductions. This has been a challenge in the recent years as the wind energy technology is seen as mature which leads to the wrong conclusion that there is no need of public funding in basic research etc.**

  A Ford T was a mature technology but an enormous technology development has happened since the development of that car. The wind turbine technology is now mature but has still potential for an enormous technology development through long and short term research, development, and demonstration which is crucial to continue for the industry in Denmark in order to develop the necessary competitive strength in the world market. Furthermore, more mature technology improves the efficiency of use of research in the a development of the technology due to the fact that the level of explicit documentation of the technology opens up for new research and development opportunities.

- **Thus, Megavind supports the Government's Growth Team's recommendations. The Growth Team recommends that the public funding to energy research, development, demonstration, and market maturation should be stable, more coherent, and easy to access for companies and research institutions. This requires multiannual political agreements and grants in the public prioritization of the funding of energy RD&D and market maturation as a part of a coherent system.**

5.2 Supporting Framework for the Wind Power Business

The Danish wind industry still holds considerable global market shares partly because of being first to market with new technologies but also because of the industry's ability to innovate and understand the modern green flexible energy system.

However, as mentioned earlier in the report, the Danish position as hub for the world's leading wind energy companies is challenged by other nations. Short descriptions of the competing competence centres, incl. Denmark, are gathered in the figure below.

Country	Industrial Test Facilities	Network/Cluster
Denmark	Østerild – National Test Center for Large Wind Turbines: Test site with 7 test beds – wind turbines up to 250 meters and 16 MW. Advanced Grid Test Facility. Høvsøre test centre: Test site with 5 test beds. Lindoe Offshore Renewables Center (LORC): Nacelle testing up to 10 MW. Blade Test Centre (BLAEST): Testing of blades up 100 meters.	Megavind (national strategy development on RD&D). Danish Research Consortium for Wind Energy (research coordination where the members are The Danish Technical University, Aalborg University, Aarhus University, Force Technology, Delta, and DHI).
Germany	Fraunhofer, Bremerhaven, Kassel, Hannover, Oldenburg: Nacelle testing. Blade testing of 70 meters. Fatigue testing with loads capacity of up to 50 MN-m. Support structure test center. Smart grid test center. Offshore testing.	ForWind alliance (the universities of Hannover, Oldenburg, and Bremen, University of Kassel), Fraunhofer Energy Alliance. Strong industrial cluster in Northern Germany.
United Kingdom	National Renewable Energy Centre (NAREC), Blyth, Northumberland: 100 MW capacity site under development for offshore testing (15 turbine beds on 30-60 meters depth). Blade testing up to 100 meters. Nacelle testing up to 15 MW. Drivetrain testing up to 15 MW. Electrical and Power Take-off Systems. Subsea connections and deployment.	The Carbon Trust (CT) London: Collaborating with organizations such as General Electric and the UK government. They provide consultants to businesses, public sector and policy-makers. Makes environmental impact assessments. Facilitates cooperation on developing sustainable solutions.
Spain	National Renewable Energy Center, Pamplona, Navarra: Blade testing of 75 meters for fatigue testing and 100 meters for static. Nacelle testing. Powertrain testing (8 MW). Generator testing (6 MW). 6 test beds (5 MW). Micro-grid testing.	CENER-CIEMAT Foundation, Collaboration Agreements with: University of Liverpool, BLAEST (Danish test center), University of Grenoble (France) and the National Meteorology Institute.
The Netherlands	ECN wind turbine test center, Wieringermeer: Five Nordex N80 wind turbines. Four metrological towers. A 36 MW grid connection. Data collection equipment and a test site control center.	

Figure 5.3
Short descriptions of the competing competence centres, incl. Denmark.

Country	Industrial Test Facilities	Network/Cluster
Finland	Technical Research Centre of Finland (VTT), located around Finland. Make wind resource assessments. Investigate icing of wind turbine blades. Wind turbine load and control analysis. Simulation of wind turbine and farm behaviour as part of the electrical power system. Simulation of the electricity markets on an hourly basis.	VTT has established ten strategic cooperation agreements with top-rated international universities and research institutes (unspecified) and has a strategic collaboration network with Finnish universities. VTT participates in more than 30 national technology programs.
USA	Massachusetts Clean Energy Center (MASSCEC): Fatigue testing with load capacity of 84 MN-m. Blade testing of 90 meters. Three test beds. National Renewable Energy Laboratory (NREL), Boulder, Colorado: Blade testing up to 50 meters. Large test site with numerous test beds. Control schemes test. Dynamometer test facilities (drivetrain test up to 5 MW). Wind resource assessment.	A cooperative research and development agreement between NREL and the MASSCEC to produce the largest wind turbine blade testing facility in the US. World class universities with aerodynamics knowledge and other competencies.
China	National Energy Key Laboratory for Wind Energy & Solar Energy Emulation and Inspection Certification Technology, under the China General Certification Center, based at Baoding. National Wind Power Integration Research and Test Center (NWIC). NWIC is a grid compliance test facility owned and operated by China Electrical Power Research Institute (CEPRI). NWIC was built in 2010 with 30 wind turbine testing beds. State Key Lab of Wind Power System in Zhejiang Windey Co. IEE CAS is interested in building a public drive train testing facility. According to the Ministry of Science and Technology, the testing center should be built within 2-3 years. Baoding Diangu Renewable Energy Testing and Research Co.,Ltd. Planned national blade test facility. *This is not an exhaustive list of the activities in China which are manifold and continuously developing.*	The state-level R&D centers, engineering technology centers or key laboratories that China's wind energy industry has set up at superior enterprises, including the engineering technology centers or laboratories established with the approval of the Ministry of Science and Technology, cover e.g. wind power blades, generators, wind power systems, control systems, offshore wind power projects, wind power grid-connecting, inspection and certification. China has more than 300 state key laboratories.

Country	Industrial Test Facilities	Network/Cluster
Korea	A 100 MW offshore test bed area in Yeonggwang County in South Jeolla Province is under construction. The existing test beds in Kim-nyeong on Jeju Island will undergo expansion to allow a test run of 5-7 MW wind turbines. The Korean government plans to also enlarge the test beds in Kim-nyeong to test two 7 MW wind turbines. *This is not an exhaustive list of activities.*	

World leading companies have production and R&D facilities in Denmark and are securing both blue collar and white collar jobs

Other nations besides Denmark invest heavily in long and short term research programs, demonstration programs, and test facilities and build knowledge networks to attract global companies in the wind energy industry. The Megavind steering committee can see scenarios where in 5-10 years Denmark might no longer be the only leading wind power hub – but be one out of two, the other being Northern Germany (Hamburg/Bremen). Northern Germany is succeeding in building a wind cluster with a large representation of supply chain and at the same time investing in test facilities (investments in Bremerhaven), knowledge networks, and a huge home market. Foreign global companies who have investigated and looked at Denmark as their European HQ have instead chosen Hamburg. Thus, Northern Germany is the most coherent competitor to the Danish wind power hub.

The other nations' competencies and facilities are more fragmented. Though, in United Kingdom (UK) the Carbon Trust (CT) for some years has ramped up activities and has done so quite successfully. Especially the offshore value chain is attracted to the UK. This is also an effect of the UK offshore market – which is the largest in the world at present – and the UK's investments in offshore test facilities.

The Danish wind power hub's cornerstone is a stable – though not large – home market and the right framework conditions for research, development, and demonstration (RD&D) including testing of prototypes and pre-series/0-series products close to the manufacturers and tier one suppliers. This has resulted in the presence of the full supply chain in Denmark, the world's first offshore wind power plants being installed in Danish waters and Denmark as the world's second largest offshore market, world record in integration of wind energy in the electricity system, and a high export of wind power system solutions. **World leading companies have production and R&D facilities in Denmark and are securing both blue collar and white collar jobs.** A Danish market which displays the newest wind power technology solutions is the strongest business case for both exports to the rest of the world as well as attraction of foreign companies to the Danish wind power hub.

Megavind recommends:

- **That Denmark builds an attractive business and innovation framework with strong support of (RD&D) in the entire supply chain in order to be a leading wind power hub and attractive to future and present Danish based companies.**
- **In addition to this there is a need of a continued focus on maintaining stable and flexible framework conditions for long and short term RD&D, including prototype test facilities and testing of pre-series/0-series products at sites close to the wind turbine manufacturers.**
- **To support the wind industry's efforts to reduce LCOE of offshore wind energy, it is recommended that a national research and development programme is established with a clear focus on reducing LCOE.**

5.3 SWOT and Target Areas

The strengths and weaknesses of the Danish wind power hub are plotted with opportunities and threats by the SWOT analysis below.

Figure 5.4
The Danish Wind Power Hub SWOT

STRENGTHS	WEAKNESSES
▪ Strong industry ▪ Full supply chain ▪ Sub-suppliers with strong R&D competencies ▪ Leading wind power companies ▪ Leading competence centre at wind turbine system level ▪ Strong R&D, innovation environment ▪ Highly skilled blue collar ▪ World class prototype test facilities ▪ Integration of large shares of wind energy in the energy system ▪ Energy act for 2020 in place	▪ Lack of industrialization, modularisation ▪ Lack of certain engineers/ competencies ▪ The challenge of social acceptance as wind turbine size increases (may result in delayed pre-series testing and installation of commercial wind turbines when turbines get above 150 meters)
OPPORTUNITIES	**THREATS**
▪ Offshore market in growth ▪ Stable export ▪ Ambitious Danish energy policy ▪ European focus on renewables ▪ Adaptable supply chain already with an established global footprint ▪ Standardised subsystems	▪ International conglomerates' entry into the wind energy market and supply chain ▪ Low-cost wind turbines from Asia ▪ New R&D competence centres in growth markets ▪ Lack of investors to invest in future wind turbines with larger capacity and larger wind power plants ▪ World financial crisis and politics favouring local content demands ▪ Political instability where shifting governments shift political framework and market conditions

The SWOT analysis shows that the Danish wind power hub is strong but faced with challenges from inherent weaknesses and threats from outside.

Megavind recommends:

- **That a strategy with a long-term scope is developed on how to strengthen and harness the opportunities ahead of the Danish based wind power industry and how to turn the weaknesses into opportunities – or maybe even new strengths.**

- **A separate strategy on universities' necessary competencies and research and development efforts in the field of wind energy is also imperative. It is necessary to develop a strategy on how the research and educational institutions through close cooperation with industry can stay ahead in this area in the global competition among universities and contribute to the Danish knowledge pool. Such a strategy should also take into account how to improve the cooperation between industry and research institutions.**

- **It is recommended that governments enact ambitious energy policies with a high penetration of wind energy in the electricity system. Clear and ambitious targets as well as stable framework conditions are the main drivers of the wind energy sector's development. Investment decisions in the wind energy sector are heavily influenced by political decisions and signals and therefore stability is imperative. The efforts to reduce LCOE on offshore wind power by 50% would be impeded by instable offshore planning e.g. postponement of planned offshore development as this increase the costs (higher risk premium, potential bottlenecks in supply and installation etc.). Thus, a continuous development of offshore wind power is needed to reach the target set by Megavind.**

6. Next Generation Technology

The leap from wind turbine to wind power plant was described in Megavind's first strategy from 2007[27]. Since then wind turbine designs and concepts have developed further to adapt to different challenges. As described in chapter 7 the wind power plant needs to be able to adjust itself and control its production and grid behaviour in a way not seen before as wind energy will play a more dominant role in future energy systems e.g. in Denmark where wind will comprise 50% of the electricity system in 2020. Furthermore, it must be tested and demonstrated how wind energy can be a balancer in the accumulated energy system and co-work with the grid.

The wind energy sector has always strived to make levelised cost of energy (LCOE) improvements and has reduced LCOE by 80% since the first turbines were installed more than 30 years ago[28]. The race to deliver still cheaper technology solutions has been imperative in making wind energy competitive with fossil fuel technologies both in terms of price and efficiency. Increasing the size (capacity and rotor diameter), optimizing efficiency, and minimizing consumption of materials have been the most significant factors in reducing LCOE and new wind turbine designs all focus on how to reduce LCOE in one way or another.

6.1 New Wind Turbine Concepts

New wind turbine concepts focus on reducing either capital expenditure (CAPEX) or operational expenditure (OPEX) – or both – as well as increasing the production of electricity per installed MW (annual energy production). This leads to an overall levelised cost of energy reduction, cf. the equation in chapter 4.
The trends in the new wind turbine designs are the following:

- Increasing the size of wind turbines (capacity in MW and rotor diameter)
- Lighter and more flexible constructions/choice of materials (e.g. towers, generators, blades, foundations etc.)
- New functionalities and fewer components (e.g. direct drive concept, two bladed concept etc.)
- Complementary components for increasing energy production (e.g. adds on blades like Vortex generators)
- Modularisation and system supply, reducing the number of models and number of suppliers

Focus is on flexibility and reliability – especially when it comes to offshore solutions. When offshore wind power plants are constructed further away from shore it is immense that the turbine reliability is increased as it is expensive to go out and repair at sea and in addition to this, it can be difficult to get there in short time due to tough weather conditions.

---

[27] Denmark's Future as Leading Centre of Competence within the Field of Wind Power (2007)

[28] Calculations from the Danish Wind Industry Association

Flexibility covers a broad range of possible adjustments and technology solutions e.g. towers in sections (shells) for onshore turbines which make them easier to transport (normal lorries instead of special transportation) or a two-bladed rotor for offshore turbines which makes it possible to assemble the turbine onshore and transport it standing on the installation vessel and install it by one lift to the offshore foundation.

In addition to this there is a strong focus offshore on building new types of foundations, simpler installation procedures in tougher weather conditions, simpler grid connections etc.

In figure 6.1 a selection of new wind turbine concepts are described.

Figure 6.1
Examples on LCOE initiatives

Concept	Description
Direct Drive e.g. Siemens Wind Power's 3.0 MW and 6 MW	**The "new"** ▪ Gearless ▪ Permanent magnets ▪ Special generator **Advantages** ▪ Fewer components (reduced costs of maintenance) ▪ Lower weight ▪ No gearboxes which are often the wind turbines' Achilles heel and an expensive component (reliability) ▪ Bigger turbines = lower Balance of Plant (BoP)
Two-Bladed Rotor e.g. Envision Energy's 3,6 MW	**The "new"** ▪ Two blades ▪ Partial pitch ▪ Assembly possible onshore, standing position at vessel, and only one lift to offshore foundation **Advantages** ▪ Less steel needed on tower and foundation because of reduced loads (reduced costs) ▪ Fewer components ▪ Less installation time offshore

Concept	Description
Hybrid Drive e.g. Vestas Wind Systems' V164-8.0 MW	The "new" ▪ Large swept area with the 164 m rotor diameter ▪ Leap forward in rated power to 8 MW ▪ Medium speed permanent magnet generator and low ratio gearbox Advantages ▪ Large size reduces the total installation costs due to fewer turbine pads per project ▪ Optimum between high speed gearbox and direct drive technology

When developing new wind turbine concepts it is of vital importance to have access to state of the art modelling and test and demonstration facilities. This applies to both optimisations of proven wind turbine concepts as well as development of new concepts. The wind turbines/wind power plants need to be tested against the complexity of geophysical features which is found at different locations. In addition to this it is important with solid knowledge about loads and materials – also because it is required in relation to design verification and approvals.

The need for test and demonstration facilities covers the whole development chain from prototype and pre-series production to optimisation of the early series production.

Megavind recommends:

- **That a revised, comprehensive strategy on innovation, test and demonstration is developed in order to secure that new wind energy technology solutions' reliability and validity can be tested. New advanced design tools that bring the newest research knowledge into the design process should be part of the strategy. The strategy must include:**
  - **Components and turbine parts**
  - **Wind turbines (prototypes and pre-series) and wind power plants**
  - **Offshore installations (e.g. foundations and grid)**
  - **Wind power plants in the energy system**

6.2 Offshore Wind Power Plants

The Danish wind energy companies are world leading in offshore wind energy. This holds true for the planning, installation, and running of the offshore wind power plants as well as the wind turbines and their components. Offshore wind power plants are more complex than onshore wind power plants as everything is heavily scaled up e.g. geophysical challenges, investment, installation, maintenance. Thus, offshore wind energy is a challenge in itself to make competitive with other energy resources.

Applying new knowledge in the interaction between wind, waves, and wind turbine is essential and so is knowledge on sea bed conditions too. The geophysical challenges increase and get even more complicated when the wind turbines are installed on greater depth at sea which demands development of new types of foundations and installation principles.

A great challenge of offshore wind energy compared to onshore is that costs of balance of plant[29] (BoP) are relatively higher offshore. The wind turbines only account for a third of the cost of an offshore project and consequently BoP (foundations, grid, cabling etc.) is the main key to bringing down LCOE offshore. Harvesting the benefits from increasing wind turbine size (MW capacity) seems like the obvious road to improve LCOE (reduced infrastructure/ BoP); however, the optimum fit between turbine size and installation costs is a prerequisite in order to get the equation right. Onshore, LCOE has been reduced by 40% every ten years (the turbine is the largest cost in onshore projects). Offshore, BoP and installation costs need to be reduced heavily to realise the 50% LCOE reduction in 2020 as the turbine itself is only a small part of the overall costs in offshore projects.

The demands for minimizing operation- and maintenance costs are even more compelling offshore than onshore. High productivity and as few operation stops as possible are required because it is difficult to access the offshore wind turbines to service them. Reliable turbines and the ability to conduct precautionary maintenance are ways to bringing down costs and intelligent IT systems which continuously monitor the wind power plants' technical conditions are needed. This is an area for further development and improvement.

Last but not least, the offshore wind projects are in a heavy investment league; however, the greatest issue with financing is the political environment and if there are stable framework conditions as any uncertainty in these areas can cause the risk premium to rise and thereby make an offshore project more expensive than necessary. Political wavering may also result in offshore projects being omitted because of insecurity about the investment.

The need to test and demonstrate offshore is just as immense as onshore; however, the turbines and components are primarily tested onshore as the best testing environment is found here and the easy access to the testing facility is the key to a successful test and demonstration course. Foundations are tested at sea and development of new concepts of foundation are important elements in reducing LCOE.

[29] Balance of plant is defined as everything but the turbine itself e.g. foundation, grid connection, cabling, offshore substation, onshore substation

Megavind recommends:

- That a revised test and demonstration strategy includes facilities for offshore testing and that a separate strategy on offshore is developed as recommended earlier in chapter four.
- It is also recommended to have a stable energy policy with clear framework conditions and predetermined time horizons for offshore wind power development in order not to impede LCOE reductions.

6.3 Optimized Wind Turbine Configurations

Along with the development of new wind turbine concepts, the industry also optimize existing turbine concepts with special features for the individual markets, considering geographical location, siting conditions (average wind speed, turbulence intensity, wind shear etc.), neighbour dwellings etc. Figure 6.2 reflects some of the solutions asked for in the market.

Geographical and climate conditions	Turbine optimization
Low wind areas	▪ Increasing rotor size without increasing rated power of generator ▪ High towers concept ▪ Lighter blades
High wind areas	▪ Increasing generator size ▪ Maintaining original rotor size ▪ Maintaining medium size tower height
Forest areas	▪ Higher towers ▪ Higher bolted steel shell towers (facilitates transportation) ▪ Optimize relation between high towers and big rotors (tree heights/ wind shear) ▪ Focus on wind class IEC A towers (turbulence “resistant”)
Cold climate	▪ Ice detection ▪ De-icing system ▪ Anti-icing system ▪ Cold climate package (e.g. special oil, special grease, cold climate steel for tower)
Warm climate	▪ Special ventilation/cooling ▪ Warm climate package (e.g. special oil and grease, special batteries and electronics, dust preventing features) ▪ Temperatures alarms
Offshore	▪ Large turbines (MW capacity) ▪ Medium tower heights ▪ Large rotors ▪ Special offshore features (e.g. corrosion class, dehumidifiers, hoist, safety features)
Turbines in populated areas (onshore, near shore)	▪ Wind power plant layout ▪ Curtailment (noise, spacing) ▪ Site specific power curves

Figure 6.2
Some of the solutions asked for in the market with regards to optimized wind turbine configurations.

Danish manufacturers are globally present and adapt well to the local market demands both commercially and when it comes to the technological requirements. The Danish focus on export has laid the ground for a research and development effort that makes the Danish manufacturers and sub-suppliers world leading in wind energy solutions for any geographical location and climate condition.

In the future with the increasing global competition and financial challenges it may become even more important to be able to optimize existing technology platforms to predefined markets and raise the bare for other entrants.

Megavind recommends:

- **That RD&D is conducted within the following areas with focus on reducing LCOE:**
  - **Innovations using new materials, components, and processes**
  - **New functionalities and through a systematic integrated design process (system engineering) reduce the number of components**
  - **Operation and maintenance**
  - **Offshore technology (increasing cost efficiency of offshore infrastructure and foundations and optimizing the size of the wind turbines)**

7. Wind Energy in the Electricity System – 50% and Onwards

Most energy systems will integrate much more wind in the future. In 2013 Denmark accommodates app. 30% wind penetration and during the coming seven years the Danish electricity system will be handling 50% wind energy. The high wind penetration makes Denmark a unique spot for developing and demonstrating the technology and framework that ensures both continuously high security of supply and higher wind penetration.

The three main challenges for integrating high levels of wind energy are:

- Taking advantage of wind power plants' ability to respond to the state of the surrounding grid and be a supplier of ancillary services

- Transport the electricity from areas with high penetration of wind energy to areas with high demand for electricity even though the electricity has to be transmitted over large distances

- Move the energy through time and space – that is, store the energy for later use

"Østerild – National Test Center for Large Wind Turbines" and Lindoe Offshore Renewables Center (LORC) will in the coming years be able to test new solutions for integrating and controlling the connection between the wind power plant and the surrounding grid. Future solutions will make it technically possible to control and optimize the wind power plants output to the grid depending on the state of the grid and the market situation in the power markets, e.g. the spot market and different markets for ancillary services such as frequency control, balancing power, reactive power etc. These coming solutions will contribute to an increasing supply of ancillary services which will support grid stability and security of supply to a cheaper price due to the larger competition between suppliers of ancillary services.

An important part of ensuring a socio-economic integration of large scale wind power in certain areas is to make it possible for the wind power plant owners to reach a large physical and economical integrated market in order to avoid lock-in of wind power in a specific area. An example of this is the challenges for wind power plants from Northern Germany, Denmark and Sweden to reach the demand centres of electricity in the Central and Southern part of Germany.

Megavind recommends:

- **A new strategy that focus on wind power plants' ability to deliver as flexible production as possible and be a supplier of ancillary/system supporting services. The ambition is to support the development of the self-regulating wind power plant that can collaborate with other types of energy in intelligent electricity supply system based both on grid and market signals. The strategy could include identification of relevant projects and tests to be carried out at the test facility at Østerild and LORC. This strategy work involves close cooperation with both the distribution system operators and the transmission system operator.**

- **A strategy with focus on energy system and security of supply will also have to aim at identifying key areas where Denmark may influence the existing and coming European cooperation regarding integrating the electricity market and the markets for ancillary services.**

Glossary

Balance of plant (BoP): Balance of plant is a term for everything but the wind turbine itself e.g. foundation, grid connection, cabling, offshore substation, onshore substation.

Blue collar worker: Member of the working class who performs manual labour. Blue-collar work may involve skilled or unskilled manufacturing, mining, construction, mechanical, maintenance, technical installation, and many other types of physical work.

Grid parity: Occurs when an alternative energy source can generate electricity at a cost that is less than or equal to the price of purchasing power from the electricity grid, meaning that it does not need subsidies to be competitive.

Levelised cost of energy (LCOE): Represents the present value of the total cost of building and operating a generating plant over an assumed financial life and duty cycle, converted to equal annual payments and expressed in terms of real euro to remove the impact of inflation. In short, LCOE can be seen as the lifetime cost of the project per unit of energy generated.

Lean and Six Sigma: The core idea of these management systems is to maximize customer value while minimizing waste, creating more value for customers with fewer resources.

Modularisation: An industrialisation level that enables agreement on the interfaces between components and designing systems that can be constructed from modules.

Partial pitch: The first part of the blade is a fixed stall section, with no pitching, while the outer part of the blade is capable of pitching.

Permanent magnet generator: Is a generator where the excitation field is provided by a permanent magnet instead of a coil. Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines, hydro turbines, and wind turbines into electrical power for the grid.

Prototypes/pre-series: A prototype is an initial version of a product made before commencing the serial production of it. The purpose of a prototype is to demonstrate and test ideas about the function and design of the product. Pre-series wind turbines are the ones that are tested just before commercialization.

Sub-supplier: Company providing various components and/or services to the wind industry (mainly to the wind turbine manufacturers).

Supply chain: A supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities transform natural resources, raw materials, and components into a finished product that is delivered to the end customer.

Wind penetration: Wind energy penetration refers to the fraction of energy produced by wind compared with the total available generation capacity.

Abbreviations

AEP: Annual energy production

CAPEX: Capital expenditure

Cf.: Confer

DEVEX: Development cost

E.g.: Exempli gratia, for example

LCOE: Levelised cost of energy

MW: Megawatt

MWh: Megawatt hour

MN-m: Millinewton/meter

NREAP: National Renewable Energy Action Plans

OPEX: Operational expenditure

R&D: Research and development

RD&D: Research, development and demonstration

SWOT: Strengths, weaknesses, opportunities, threats

EHRHORN HUMMERSTON

MEGAVIND

SECRETARIAT: DANISH WIND INDUSTRY ASSOCIATION
Rosenørns Allé 9, 5
DK-1970 Frederiksberg C
Tel: +45 3373 0330
E-mail: danish@windpower.org
www.windpower.org/da/forskning/megavind.html
http://windpower.org/en/policy/research_and_development.html