WIND POWER

ANNUAL RESEARCH AND INNOVATION AGENDA 2017

MEGAVIND

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INSTALATION OF VESTAS WIND TURBINE. ØSTERILD NATIONAL TEST CENTER FOR LARGE WIND TURBINES.

PHOTO: MHI VESTAS, V164

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EXECUTIVE SUMMARY

Wind power is big business for Denmark. In 2016, the total value of Danish exports of wind energy products and services was DKK 55.6 billion, an increase of 16% from 2015, and the Danish wind industry today employs more than 30,000 people. Denmark can not only maintain but also develop its global leadership in wind energy, if politicians, industry and academia agree to continue working together, as it has been the case over the past 40 years in a unique public-private collaboration.

Earlier this year, Energikommissionen published a report with recommendations for the future energy policy in Denmark. Under the headline "Denmark's leading position in energy technology must be strengthened" the report gives three specific recommendations[1]:

- There must be a national strategy to ensure a coordinated approach with a common strategic vision;
- The funding for energy research must be increased and its continuity must be ensured;
- Priority must be given to unique demonstration projects and testing platforms.

Megavind agrees with the overall direction set by these recommendations. However, the wind energy sector also sees a vital role for increased research at lower technology readiness levels (TRL[2]) to foster future innovation and development. Industrial research is clearly focused on research and innovation with a shorter time to market, but a high-tech research-intensive industry, such as wind energy, needs substantial new insight, knowledge and ideas to feed the innovation pipeline. This is aligned with the Mission Innovation goals to revolutionise energy systems throughout the world over the next two decades and beyond[3]. Furthermore, in line with the Forsk2025 recommendations, R&D should also be translated into more and better education and training[4].

Working together, the sector will have to successfully navigate the global megatrends that are currently sweeping across technologies, including wind energy. The development of wind energy to become a mature and globalised industry has changed the modes of collaboration and the solutions needed for the sector to stay competitive. Digitalisation opens up for new opportunities for rethinking the entire lifecycle of wind power plants from turbine design through to decommissioning. An integrated energy system will create opportunities for new technologies and services for wind energy. Furthermore, technology-neutral tenders and achieving subsidy-free wind power will require new industry standards for cost and reliability to deliver truly price-competitive solutions.

Megavind recommends a more programme driven approach to the Danish wind energy research funding that gives priority to the following R&I fields:

- Improved understanding of the underlying physics of wind energy;
- Development, test and demonstration;
- Wind Power Plant life cycle optimisation.

1. http://efkm.dk/media/8275/energikommisionens-anbefalinger_opslag.pdf
2. For explanation of TRL see annex 2 in this rapport
3. http://mission-innovation.net/the-goal/
4. https://ufm.dk/publikationer/2017/filer/forsk2025.pdf

PHOTO: MHI VESTAS

OUR RECOMMENDATIONS

Improved understanding of the underlying physics of wind energy

Development, test and demonstration

Wind Power Plant life cycle optimisation

MEGATRENDS AND CHALLENGES FOR THE DANISH WIND ENERGY SECTOR

The development witnessed over the past 30 years in wind energy with respect to scale, innovation, technology development, deployment and cost has been impressive. The speed with which the development is continuing demonstrates that the sector still has a lot of potential for further development. Today, wind energy provides 4% of the global electricity production, and with the current pace of installation of new capacity, that figure will double every five years. If that development continues, wind energy could provide up to 30% of the global electricity consumption by 2030!

Danish companies and universities have pioneered and refined technologies that have helped wind power become a global industry and be recognized as a key player in modern energy systems, e.g. exemplified by Denmark where electricity from wind will surpass 50% of consumption in a few years.

Since the first modern turbines were brought to the market in the late 1970s, the technology has developed dramatically: from the first small kW turbines to the latest 9.5 MW turbine that single-handedly can supply more than 8,000 homes with electricity and form the backbone of a new, green energy system. During that time, the industry has moved from relatively low-tech machine manufacturing to today's exciting, intensively high-tech, and large-scale industrial production of advanced wind power systems.

The success of the Danish wind energy sector is built on a unique collaboration between academia, industry, society and the political system that has evolved over the last four decades. It is the combined availability of a **supply chain** with decades of experience, a **strong academic system** producing a first-class education to future employees and **state-of-the-art research** as well as a **political system** providing a good framework that continues to make Denmark the preferred place for the largest players in the industry.

The success and growth of the wind energy industry is driving fundamental changes in the sector. Wind power has gone global, big and high-tech. Denmark must have an ambition to continue to be a leading global hub for wind energy, but that will only happen if the strong Danish public-private R&I collaboration understands and responds adequately to the development and new global conditions.

PHOTO: MHI VESTAS

FOUR MEGATRENDS THAT THE SECTOR MUST NAVIGATE SUCCESSFULLY

MATURATION, INDUSTRIALISATION AND GLOBALISATION

The wind energy industry has reached a new plateau of development as a sector. The technology is reaching price competitiveness, the value and supply chains are developed and global hubs with decades of experience have emerged. This maturation of the sector is visible in all aspects of the development of wind turbines and wind power plants, from design to decommissioning.

A clear example is the enhanced industrialisation of the sector. As the market volume of wind energy has grown, the wind energy sector is increasing its efforts to industrialise production, especially through standardisation, regulatory market requirements and supply chain development.

Globally, Europe still has the industry lead followed by the US, but especially Chinese manufacturers are learning fast and building on the industrial capacity in China, combined with a stronger presence in Europe to tap into the well-established R&I communities of the continent.

Globalisation increases the competition between European countries and across the entire value chain to attract and ensure excellent framework conditions for the entire industry from R&I to developers and operators of wind power plants.

Globalisation also means global markets. Wind energy deployment started in Europe (primarily Denmark, Germany, Spain) and the US, but today there are several large markets outside of Europe and the US. This increases the demand for technological solutions tailored to different climate conditions, including extreme weather conditions such as typhoons, heat, cold, earth quakes, etc., as well as transport and installation in developing countries with poor infrastructure.

SUBSIDY-FREE WIND POWER AND TECHNOLOGY-NEUTRAL TENDERS

During the past few years, we have seen a very significant decline in the cost of offshore wind power and even subsidy-free bids in European tenders for offshore wind power plants to be constructed in 2024 and beyond. The dramatic drop in the levelised cost of energy (LCOE) has repeatedly exceeded expert predictions. It follows the trend of onshore wind energy, which makes up more than 95% of the installed wind power capacity worldwide and is subsidy free in several markets. Simultaneously, new auctions are moving towards technology-neutral tenders, where wind energy is competing head-to-head with other energy sources. This development is also a demonstration of the maturing of renewable technologies and markets.

It should be observed, though, that special conditions are attached to the subsidy-free offshore bids, including an expectation of the availability of larger turbines than those currently on the market today. Delivering subsidy-free wind power at increasingly challenging sites, while at the same time beating competition from other technologies, can only be achieved by continuous technology research, innovation and development, as well as innovation and optimisation in all parts of the supply chain and regulatory framework conditions.

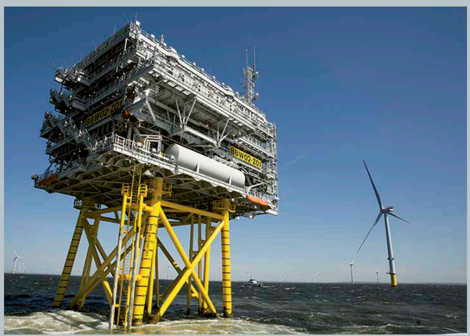


PHOTO: BURBO BANK

DIGITALISATION

Industry 4.0. Big data. Internet of Things. Nowhere is the global competition in wind energy fiercer than in the use of digitalization to deliver advanced wind power systems. The application of digital technology influences all parts of wind power projects from early planning (based on geodata, meteorological and soil data), through consenting, design, manufacturing, transportation, installation, operation, maintenance and decommissioning based on a complex web of data.

A modern wind turbine is assembled from up to 8000 components and up to a thousand sensors, providing data about the state of the turbine and external conditions. This web of turbine components embedded with electronics, software and sensors is creating an Internet of Things (IoT), which is producing a massive amount of data every minute. This generated data can be used to optimise engineering tools, processes and designs, as well as operation and maintenance, business processes and technical and financial reporting.

Combining the wealth of data from the wind turbines and wind power plants is what creates "big data". This will enable better and faster validation and optimisation and will improve opportunities for important capabilities such as early warnings of faults or root cause analysis.

The downside of the opportunities that digitalization offers is the increasing risk of cybercrime and cyber-attacks. This could have serious consequences for energy systems, and therefore cybersecurity needs to be part of the design process and requires constant attention and development.

ENERGY SYSTEMS INTEGRATION

Wind power is pushing towards 50% of total electricity consumption in the Danish energy system and other European countries are following suit with significant shares of wind power in the energy mix. As wind power varies, the electricity system needs to be flexible enough to be able to balance the supply and demand at all times.

An inflexible system influences the value of wind power directly, as it will either be worth less when provided, or wind turbines will be curtailed to produce less power and hence generate a lower revenue. It follows that, the more flexible the system is, the higher the value of the wind power.

In order to provide flexibility, energy systems around the globe are becoming more and more sophisticated, moving towards increased integration of the different system components, driven by increased electrification. Flexibility can be achieved with controllable production from other sources (gas, coal,, etc.), transmission to other countries, energy storage, demand side management, or by assigning wind farms to operate below the maximum power at any given point in time. However, wind power plants can also contribute actively to the system flexibility by offering so-called ancillary services that help keep the energy system stable.

Integrating today's large amounts of renewable energy into the grid changes the role of the wind farm from simply delivering electricity, to providing a service to the system. Wind farms are already being referred to as wind power plants, precisely because they have to deliver services comparable to a traditional power plant. The responsibility towards the energy system of providing not only active power but also ancillary services will only increase in the coming years. This will affect the design of turbines and the control systems of wind power plants so they can deliver the full suite of services required.

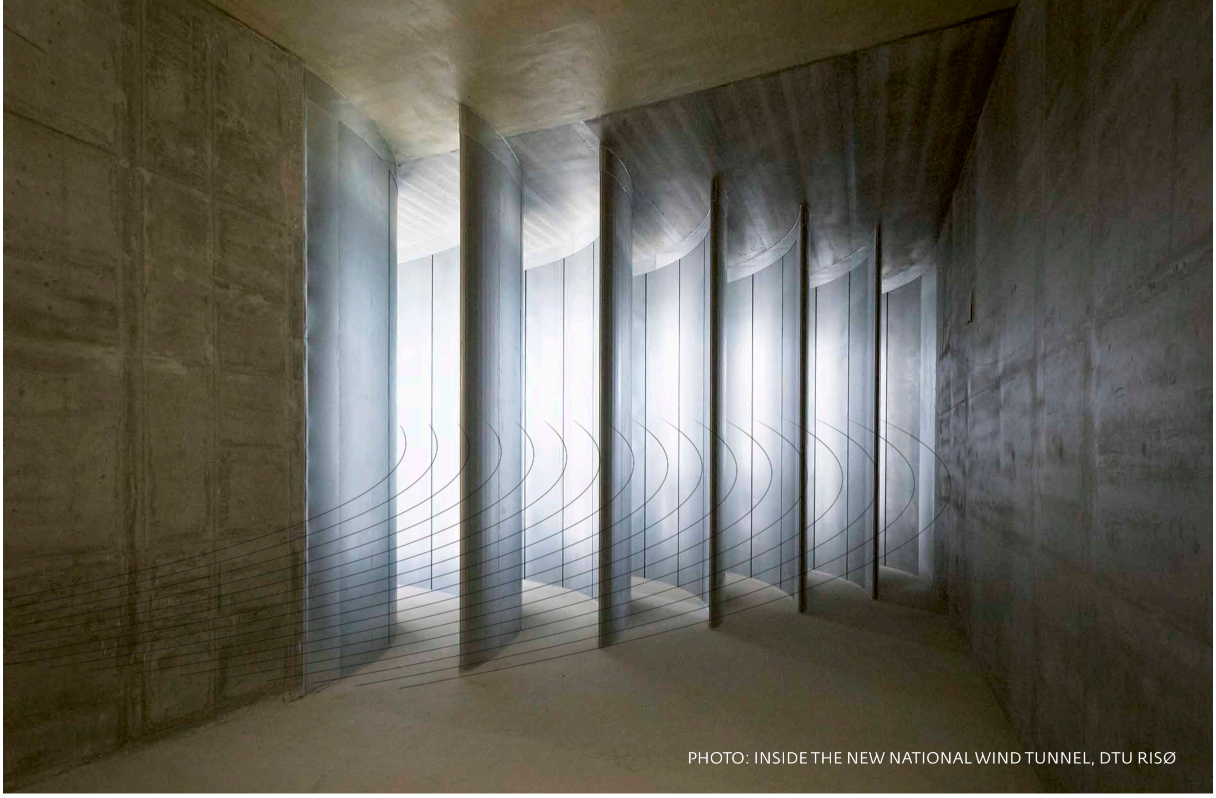


PHOTO: INSIDE THE NEW NATIONAL WIND TUNNEL, DTU RISØ

THE DANISH PERSPECTIVE

We are well positioned for the megatrend challenges and opportunities

The Danish industry is well positioned to exploit the market opportunities that are emerging as a consequence of the megatrends. Indeed, the Danish sector has been a driving force in creating the megatrends. Danish wind turbine manufacturers are leading the technological development and Denmark is home to one of the world's largest and most proficient organisations in wind power development. Both developers and manufacturers are supported by an experienced supply chain and world class universities and R&D organisations.

The technologically advanced wind power systems that the Danish sector can offer have a number of competitive advantages. They include the ability to:

- Offer a wide range of services to an integrated energy system;
- Deliver wind turbines to site specific conditions and tailor-made wind power plants around the globe;
- Lower the levelised cost of energy throughout the wind turbine lifetime by exploiting smart design, high quality components and real-time data from sophisticated sensor systems.

However, the success of the wind energy technology, the recent wave of industry mergers and the rise of Chinese manufacturers have created a global industry that is very competitive across the whole value chain.

We have had a head start in Denmark and our products, services and solutions are grounded in the unique Danish public-private collaboration. Maintaining this collaboration at a competitive level requires continuous support and state-of-the-art R&I facilities. The necessary research, test and demonstration facilities must be available to develop, test and validate new solutions. At the same time, the Danish educational system from vocational training to higher education must continue to educate and train a highly skilled work force suitable for all levels of the value chain.

NEW STRATEGY AND OBJECTIVES FOR THE WIND ENERGY SECTOR

In recent years, the development in wind energy has to a large extent been driven by a common goal in the sector: Lower the levelised cost of wind energy to make wind energy cost competitive with fossil fuels.

The sector has come a long way in achieving this and now is the time to set new ambitious goals for wind energy and the role that Denmark should play in driving the development.

In Megavind we believe that wind power can continue on the cost reduction trajectory, which will enable an even larger share of wind power in the electricity systems. Accelerated deployment of wind power will require greater attention at both R&I and at implementation level to tackle a number of wider issues.

In April 2017, Energikommissionen published its report with recommendations for the Danish energy sector. The headline on one of the recommendations is: "Denmark's leading position in energy technology must be strengthened"[5]. It offers three specific recommendations:

- There must be a national strategy to ensure a coordinated approach with a common strategic vision;
- The funding for energy research must be increased and its continuity must be ensured;
- Priority must be given to unique demonstration projects and testing platforms.

Megavind agrees with the overall direction set by these recommendations. Denmark should have a new comprehensive strategy and roadmap for achieving the wind power solutions of the future. The strategy should combine R&I policies and activities with industrial strategies. The strategy should be supported by increased investments in R&I and ensure greater continuity in setting priorities.

An ambitious Danish strategy for public-private collaboration in wind energy R&D will support the Danish research priorities set out in Forsk2025[6] as well as the globally ambitious targets outlined in Mission Innovation[7] and the wind energy sector in reaching the following objectives:

- Continue the dramatic reduction in LCOE for both on- and offshore wind power being installed in the next decades;
- Development of a 20-25 MW capacity turbine between 2025 and 2030;
- Deployment of the first commercial floating wind farms between 2025 and 2030;
- Enable increased penetration of wind power in already high penetration markets by construction with other countries of a strengthened offshore and onshore grid infrastructure;
- Increase the market value of wind power in high penetration markets through a range of system integration measures (Smart Grid, virtual storage, Demand Side Management, energy storage).

A national strategy for the wind energy sector should build its R&I priorities on three pillars:

- Intensified R&I activity across the innovation and supply chains. This includes basic and applied research which is vital for industry to enable the next generation technologies to be deployed and integrated into the electricity market and wider society;
- A continued investment in public-private collaboration in large scale test and demonstration;
- Increased uptake and strengthened high quality education and training.

5. http://efkm.dk/media/8275/energikommisionens-anbefalinger_opslag.pdf
6. https://ufm.dk/publikationer/2017/filer/forsk2025.pdf
7. http://mission-innovation.net/the-goal/

NEW R&I RECOMMENDATIONS

The Danish wind energy industry leads the global sector through advancing the technological development and over the years it has been able to make good use of high-quality research input by translating it into cutting-edge solutions and innovative products.

Manufacturers face new challenges, though, in understanding the complex physics of mega turbines, their foundations and their interaction with both wind and waves. As SMEs increase their research capacity they require better testing facilities to supply quality components to their customers. Furthermore, the manufacturing, logistics, financing, operation and maintenance as well as end of lifetime decisions take up an increasing share of the cost and hence call for innovative solutions.

Today, industry's investment in R&I is significantly larger than public investments in wind energy. Vestas alone spent more than 1.6 billion DKK on R&D in 2016[8]. That is more than the combined budget of public funding programmes in Denmark for all types of energy research. Nevertheless, public investments remain the key to continuing the success of the Danish sector by:

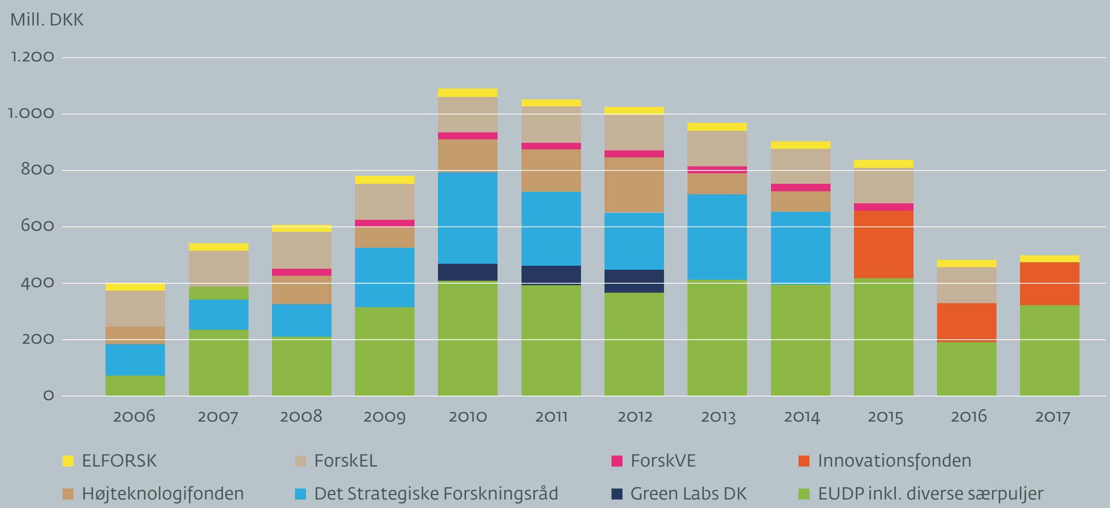
- Providing the right conditions for public research organisations to deliver excellent insights for next generation technologies;
- Educating the human resources to implement it;
- Supporting the R&I activities of our growing base of technology-intensive SMEs;
- Enabling the de-risking of new innovations to develop them to a point where commercial partners can step in and bring a new product or service to the market;
- Ensuring the opportunity for the investigation and evaluation of non-technical issues such as societal acceptance, market mechanisms or policies, and regulations.

It is therefore imperative that the downward trend in public funding for energy R&I (as seen in the figure below) is reversed. Investments in energy R&I is not only good business for Denmark in the short run; it is also essential to maintain knowhow, competences and companies in Denmark by ensuring a stable framework for R&I.

Megavind recommends to prioritise three R&I areas as particularly important, in order to realise the ambitious targets while navigating the megatrends[9].

8. Vestas, Annual report 2016, page 54: https://www.vestas.com/~/media/vestas/investor/investor%20pdf/financial%20reports/2016/fy/170208_03_annualreport2016_uk.pdf
9. The Wind energy research strategy" from the Danish Research Consortium for Wind Energy (DFFV) and the Strategic Research and Innovation Agenda of the European Technology and Innovation Platform for Wind Energy (ETIPWIND) offer an extensive outline of the research and innovation key for future growth and competitiveness.
   In Appendix 1 of this strategic agenda, a list of R&I areas are included to demonstrate the width and depth of relevant topics to explore.

Development in grants for research, development and demonstration of energy technology (in Danish)



Kilde: Energistyrelsen (2017)

Note: EUDP Særpuljer omfatter: VE teknologier (brint og BIPV), Energieffektiv transport, Bølgeenergi, Geotermi og store varmepumper

THE RESEARCH AREAS RANGE FROM HIGH TO LOW TRL'S THAT ARE ESSENTIAL FOR THE DANISH WIND ENERGY SECTOR'S COMPETITIVENESS AND THE CONTINUED GROWTH OF WIND ENERGY IN THE ENERGY SYSTEM

IMPROVED UNDERSTANDING OF THE UNDERLYING PHYSICS OF WIND ENERGY

Understanding and accurate modelling of the external wind, wave and soil conditions for wind turbines, foundations, cables, etc. Turbines of 20MW and more will reach heights of up to 330 meters and rotor diameters of up to 280 meters and this requires the updating of existing, and the development of new, models and tests. The upscaling of wind turbines changes the inflow conditions and aerodynamic behaviour in ways that cannot be derived from our current models. Advanced computer models and the use of lidars are required to investigate the limitations and opportunities for upscaling wind turbines Similarly, larger turbines will influence the design of foundations and the electrical infrastructure, which also need to be investigated in depth. Larger turbines and foundations also demand new solutions for transportation, installation and O&M operations.

DEVELOPMENT, TEST AND DEMONSTRATION

Wind power components such as blades, gearboxes, generators, converters, towers, substructures, etc. are developed individually and optimised with a view to the function in the full system. The combination of high performance computers (HPC) and -knowledge and experience gained over decades has enabled the research community to develop new physical models. These models can then form the basis for the next generation of design tools that integrate the relevant parameters, such as aerodynamics properties, interaction with waves and soil, structural loads, O&M requirements, etc.

HPCs and digitalisation will also enable the development of more advanced computer models for verifying new turbine designs, using so called digital twins. This will reduce the need for expensive physical demonstration models of the wind turbines.

New prototypes need to be tested and demonstrated before commercial deployment. This requires state-of-the-art testing facilities, which need to be updated to keep pace with prototype developments.

Appendix 1 provides a more comprehensive list of research areas that demonstrate the width and depth of the research challenges.

WIND POWER PLANT LIFE CYCLE OPTIMISATION

The international competition is constantly intensifying and costs are being driven down. This development is seen throughout the value and supply chain: i.e. design, manufacturing, transportation, installation, O&M and decommissioning. Important key drivers for this include the digitalisation of wind farms, development of smart sensors, better control algorithms and using preventive health monitoring. More attention will also need to be put on designing the turbines and wind power plants for all phases of the lifetime, particularly the improved planning of logistical operations during installation and O&M. Last but not least, significant R&I is needed to improve wind power system's integration into the grid and develop wind power plants' capability to provide ancillary services.

PHOTO: FORCE TECHNOLOGY AND LINDO OFFSHORE RENEWABLE CENTER (LORC) HAVE ESTABLISHED LINDO COMPONENT AND STRUCTURE TESTING A/S FOR THE OFFSHORE RENEWABLE INDUSTRY - A TEST CENTRE WITH FOCUS ON FULL-SCALE TESTING OF COMPONENTS AND SYSTEMS MACANICALLY AND IN CLIMATIC CHAMER - AND LINDO WELDING TECHNOLOGY (LWT) DEVELOPING NEW WELDING TECHNOLOGIES.

FUNDING MECHANISMS TO SUPPORT THE SECTOR'S R&I NEEDS

Addressing the research areas outlined on page 16 + 17 should be done in a collaboration between public research organisations and the industry, making use of the breadth and depth of expertise and facilities available in Denmark and drawing on both public and private R&I funding.

The R&I activities in Denmark should be highly programme-driven to address the most relevant trends and facilitate better knowledge sharing between public and private partners.

In-house industrial research and innovation in the wind energy sector is focused on activities at higher Technology Readiness Levels (TRL – see annex 2) with a time to market perspective of 3-5 years. The vast majority of this research is done in industrial labs or through bilateral agreements with universities or research organisations.

However, profiting from the market opportunities, the industry will require breakthrough research with a longer time perspective and higher risk profile. Danish universities and research organisations are world leading and have decades of experience in conducting ground-breaking research that is tailored to industrial needs and requirements. The increased level of R&I activities in the Danish wind industry has increased its capacity and need for high-quality low-TRL research that can a) pave the way for the next generation of advanced solutions to maintain our technological leadership, or b) address social, regulatory and political challenges that fall outside the scope of industrial research activities. This research is driven by public research organisations with industry participation often being limited to providing data, solving a few specific tasks and acting as advisors to ensure the industrial relevance of the research and solutions developed.

The table on page 19 shows the research and innovation chain from low to high TRLs and the relative involvement of public and private organisations in publicly funded research.

The combination of decreased public funding for energy research and a trend towards the public funding that is available favouring closer-to-market research, has been counterproductive. Research at low TRL levels is, by its nature, high risk and quantifying the impact (such as impact on LCOE) is more difficult to assess. Nevertheless, it is a mistake to decrease support to these activities. It has therefore been encouraging to see Innovation Fund Denmark develop a more nuanced view of impact and the requirements for research collaboration at different TRL levels. Megavind encourages continuing this development and is ready to engage with funding agencies to continue the refinement of impact assessment criteria.

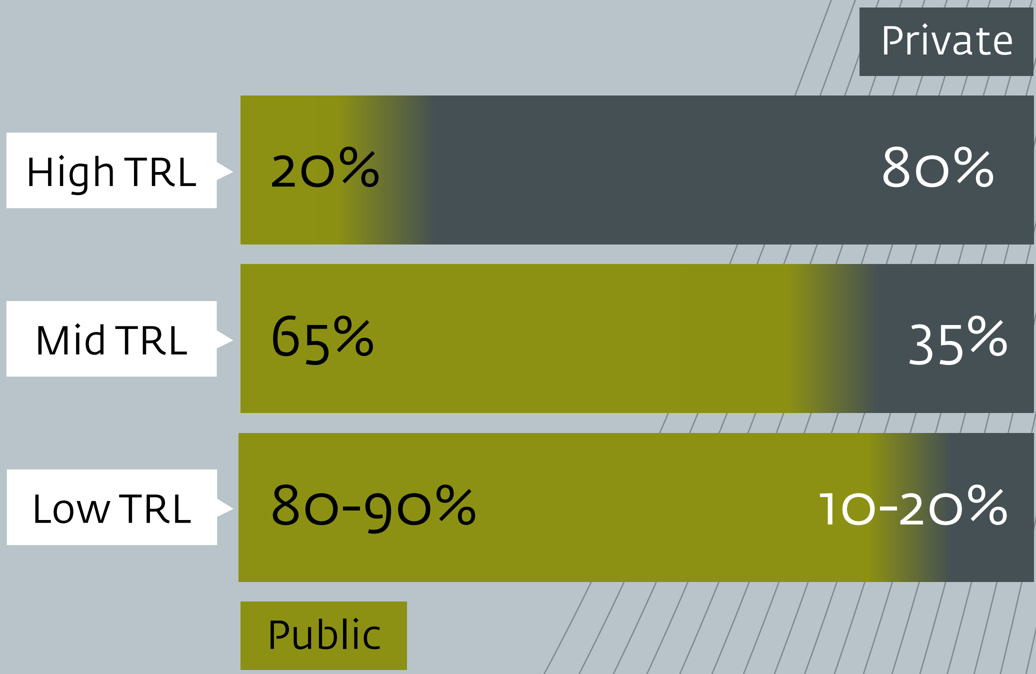


PHOTO: WITH A PATENTED WIRE SYSTEM, LIFTRA'S BLADE WAY INSTALLS AND UNINSTALLS SINGLE BLADES WITHOUT THE USE OF LARGE MOBILE CRANES.

TEST AND DEMONSTRATION FACILITIES

The wind industry is characterized by fierce global competition and several countries are aspiring to be home to leading companies in the industry. To maintain Denmark's position as a global hub for wind energy, it is essential that Danish-based industries continue to have access to world-class state-of-the-art test and demonstration facilities and test competencies.

The test and demonstration facilities in Denmark are among the best facilities globally. For example, The National Test Centre at Østerild is currently hosting the largest wind turbines in the world. It is the only place in Europe where prototypes of wind turbines up to a total height of 250 meters can be tested.

However, neighbouring countries in the North Sea region are investing heavily in large test facilities with an aim to attract industry players.

An important component in Denmark's ability to compete in providing test facilities, is the intelligent use of various different models to finance the establishment and operation of these facilities. The National Test Centre at Østerild is an excellent example of how a public-private partnership in Denmark is able to create unique framework conditions at a low cost to both taxpayers and the industry. Østerild was established by DTU and financed by DTU and the industry together, with a significantly lower proportion of state financing than is the case in other European countries. The setting up of the test centre demonstrates the political willingness to take a bold decision to pass a law establishing the test centre and thereby creating an attractive framework for the continued development and production of wind energy systems in Denmark.

In other countries, such as Germany, the Netherlands, the UK and the US, full-scale test pads for wind turbines have primarily been financed by the state. In Denmark, we have also seen a similar positive attitude to public investments in LORC, while the large-scale blade test facility BLAEST is another example of a facility driven by public and private organisations and financed by the use of the facility by the industry.

Test and demonstration facilities need to develop constantly and need to adapt to match the increasingly challenging requirements of the industry. Fortunately, Denmark has seen continuous political support that allows this.

At the moment, a process is underway to expand the test facilities and adjust the relevant regulations at Høvsøre and Østerild to accommodate the next generation of wind turbines. The plan is to increase the maximum allowable height at Test Centre Østerild to 330 meters and at The Wind Turbine Test Centre for Large Wind Turbines at Høvsøre to 200 meters. This shows a commitment from our national and local politicians to maintain the wind energy industry in Denmark.

Looking 3-5 years ahead, Danish wind turbine test facilities will cover 80-90% of the current needs. The only major gap in the test and demonstration facilities is the need for a converter-based grid test facility for field-testing of wind turbines. This is described in the Megavind report on test and demonstration facilities, which was published last year[10].

Looking beyond the next five years, several of our test and demonstration facilities will need to be up-

10. See https://megavind.windpower.org/downloads/2652/megavind_test_and_demonstration.pdf

dated to meet the requirements from industry. One clear example of this is the blade test centre, which must be able to test the next generation of blades with lengths of more than 140 meters. Upgrading the test facilities to accommodate this will require a constructive dialogue between all public and private stakeholders to find the right model for financing.

COMPETENCE BUILDING THROUGH TRAINING AND EDUCATION

Denmark's strength is in the ability to provide the full range of formalized education up to the highest academic and vocational levels. We have decades of experience in both university education for the next generation of employees and continuing education for those who are currently in the work force. The high quality education that we can deliver in Denmark is another result of the Danish public-private partnership.

Students are educated and trained in an environment that helps encourages them explore radically new ideas and engage in the improvement or addition to industry tools and models.

There is currently a high demand from the Danish wind energy sector for all competencies, from skilled labour to highly qualified R&I specialists in areas such as ICT. Furthermore, the demand for these skills will go up as digitalisation continues and new advanced techniques for measurement and testing are introduced.

To meet the requirements for the number and competencies of trained personnel, the universities need to exploit all platforms for training and education. This includes e-learning, European joint degrees and compact training courses. Globalising education through e-learning and joint degrees is not only about new markets for universities; it is also a good way to attract new talents world-wide to the wind energy sector and to Denmark in particular. As wind energy technology is increasingly being designed and manufactured as part of a wider energy sector, education and training courses will also have to adapt to new technologies, such as virtual and enhanced reality.

Megavind thus recommends that industry and academia develop a better and more nuanced common understanding of the competences required.

PHOTO: GLOBAL WIND ORGANISATION (GWO) SENARIO TRAINING ON FIRST AID IN THEIR BASIC SAFETY TRAINING.

FINAL REMARKS AND PERSPECTIVES

This document aims to set the direction for R&I collaboration in the Danish public-private partnership for wind energy. The strategy and priorities outlined here express the consensus of Megavind, which is a partnership of the entire wind energy sector. The strategy will be updated annually and is expected to form the basis for discussions both internally in the sector and with public authorities and funding bodies.

In the Megavind consortium, the strategy will be executed in the same way as previous Megavind initiatives to lead to tangible outcomes. The National Test centre for large turbines at Østerild, the industry-standard model for calculating the levelised cost of energy[11], the LORC test centre and the Danish Offshore strategy are all examples of important outcomes from processes that started in Megavind. In all these examples, Megavind engaged with the relevant stakeholders to implement the recommendations.

Together, we will continue the success of our national partnership leading the way in the green energy transition.

PHOTOS: MHI VESTAS AND ØRSTED

11. https://megavind.windpower.org/megavind/lcoe_calculator_model.html

GO TO
APPENDIXES

APPENDIX 1

Headlines for specific R&I technology areas

Below is an overview of the wide variety of research areas that are requiring significant R&I efforts to meet industry's need to stay competitive.

Materials

- New or improved materials for blades, nacelle components, coatings, etc.;
- New layouts for better use of fibre materials strength and lifetime;
- New methods for manufacturing of fibre materials.

Wind, waves and lay-out – Measurements and calculations

- Next generation lidars and Wind farm design assumptions;
- Optimisation of wind farm layout.

Blades

- Optimised design of larger blades;
- New testing methods for blades;
- Aerodynamic robustness towards pollution on blades;
- Physical understanding of leading edge erosion (root cause analysis) and solutions to solve the problem;
- Modelling and self-repairing materials for blades.

Wind turbine and components

- The 20MW turbine design considerations and solutions;
- Site specific turbine design;
- Gearboxes, bearings and generators with long life for 15-20 MW turbines, e.g. sliding bearings, multi-pole generators, magnetic gears, etc.;
- More advanced condition monitoring systems and intelligent use of data;
- Measurement of use of lifetime of materials and identification of when 90% of lifetime is reached;
- Calculation of actual loads, remaining lifetime, and adjusted stop wind speeds;
- 3D print of spares/components for repair;
- Control of turbines and wind farms;
- Standardisation of specifications and interfaces for hydraulics systems, yew systems, flanges between blade/hub, hub/main shaft, main shaft/gearbox, nacelle/tower; tower/foundation.

Substructures and geoscience

- Seabed interaction in regions with earth quakes and soil conditions different from Northern Europe;
- Efficient manufacturing, transportation and installation of substructures.

Electrical systems

- Development of extended use of HVAC;
- Variable AC in transmission;
- Transients in arrays and transmission;
- HVDC turbines and arrays;
- New concepts for transmission, e.g. HVDC multi-terminal principles;
- Substation design optimisation;
- Wind farm ancillary services;
- Integration of wind power in the electricity system.

Logistics

- Floating installation of foundations and turbines;
- New concepts for O&M for offshore wind farms far from shore.

Operations & Maintenance

- New solutions for inspection and repair of blades, e.g. flying or "driving" drones for inspection of blades;
- Measurements and scanning of materials with scanning equipment;
- Remote inspection of components in the nacelle.

Decommissioning

- Efficient re-use or disposal of blades materials.

Environmental conditions and consenting

- Generic methods for assessment of impact of wind farms on birds, bats, sea mammals, fish, etc.

Floating wind power

- Modelling of floating wind power systems (turbine, platform, mooring system);
- Modelling of wake effects in floating wind farms;
- Requirements for floating wind turbines, array cables and export cables.

APPENDIX 2

The Technology Readiness Level Scale

The Technology readiness level (TRL) was originally developed by NASA in the 1980s, but has since then been widely adopted as a measurement of a technologies progression from basic research to the market. Here we use the TRL definition according to HORIZON 2020 Technology Readiness Levels (TRL) and Innovation Fund Denmark.

TRL level system

HIGH

TRL 9
Actual system proven in operational environment
(competitive manufacturing in the case of key enabling technologies; or in space)

TRL 8
System complete and qualified

TRL 7
System prototype demonstration in operational environment

TRL 6
Technology demonstrated in relevant environment
(industrially relevant environment in the case of key enabling technologies)

TRL 5
Technology validated in relevant environment
(industrially relevant environment in the case of key enabling technologies)

TRL 4
Technology validated in lab

TRL 3
Experimental proof of concept

TRL 2
Technology concept formulated

TRL 1
Basic principles observed

LOW

APPENDIX 3

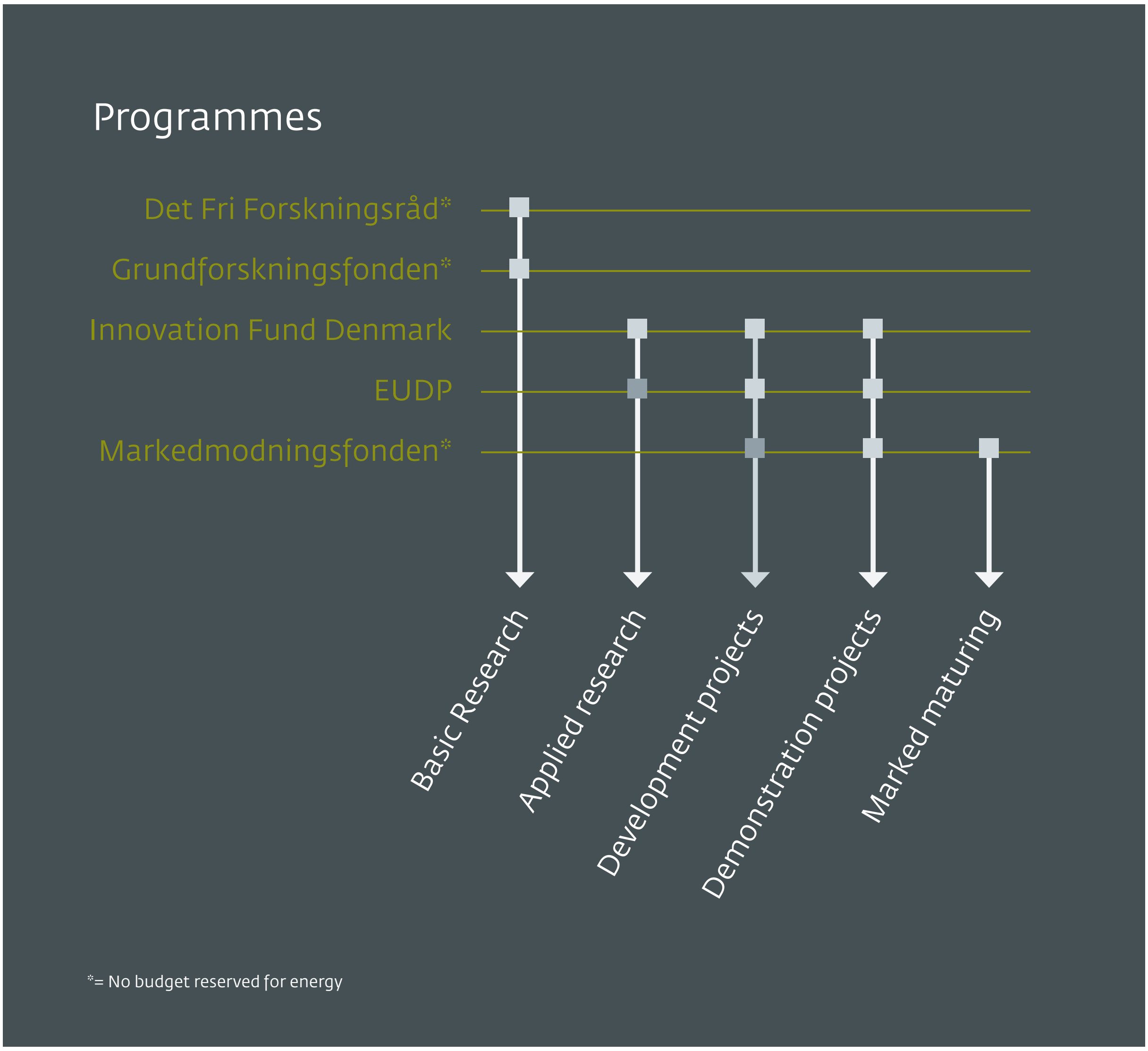
Research, Development and Demonstration funding schemes

The Danish research, development and demonstration funding programmes for energy are, broadly speaking, divided into 4 + 3 funding programmes where 4 have a budget particularly reserved for energy projects[12].

NATIONAL FUNDING PROGRAMMES

Danmarks Frie Forskningsfond

Independent Research Fund Denmark funds research activities based on researchers' own initiatives. The funds are not limited to themes and can be granted to any kind of research topic. On an annual basis, the Independent Research Fund Denmark awards 400 grants to research projects. In total, the grants amount to well over DKK 1 billion.



12. Energikommissionen – Danmark som teknologisk pionerland på energi (2017) http://efkm.dk/media/8317/baggrundsnotat-om-off-fud-stoetteordninger.pdf

Grundforskningsfonden

The Danish National Research Foundation (DNRF) is an independent organization established by the Danish Parliament in 1991, promoting and stimulating research at the frontiers of all scientific fields. Since its establishment, the foundation has been endowed with 3 billion DKK in 2008 and again in 2015, allowing it to operate until 2036. The endowment secures independence and a long-term commitment to the best Danish research by funding Centers of Excellence and the Niels Bohr Professorships supporting top-class researchers coming to Denmark from abroad.

Innovation Fund Denmark

Innovation Fund Denmark (IFD) invests in innovative projects with approximately DKK 1,3 billion a year, where in 2016 DKK 100 million was dedicated to "energy" projects. IFD supports projects across the entire TRL scale that will have a clear value for Denmark and the Danish society.

Energiteknologisk Udviklings- og Demonstrationsprogram (EUDP)

EUDP's objective is to support the political decisions on energy on security of self-supply, independence of fossil fuels, consideration of climate as well as a cleaner and more efficient energy supply. EUDP is financing the Danish participation in international research- and development collaborations within IEA (Technology Collaboration Programmes) EU (ERA NET) etc. EUDP budgets can vary, however since 2010 the yearly amount granted has been DKK 400 million a year until 2016 where budget was cut to DKK 186 million. Denmark's participation in Mission Innovation will be funded via EUDP.

Markedsmodningsfonden

The Market Development Fund helps enterprises bring their new products to the market faster.
The aim of the Market Development Fund is to promote growth, employment and export, particularly for small and medium-sized enterprises in areas where Denmark has particular strengths and potential. With its commercial focus, the Market Development Fund has a unique position in the Danish innovation system as other subsidy schemes focus on the early developmental phases. The Market Development Fund takes over where R&D and demonstration programmes stop in order to assist in the final market adaptation of enterprises' innovative new solutions.

EUROPEAN AND GLOBAL FUNDING OPPORTUNITIES

Horizon 2020

Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020). By coupling research and innovation, Horizon 2020 is helping to achieve this with its emphasis on excellent science, industrial leadership and tackling societal challenges. The goal is to ensure Europe produces world-class science, removes barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation.

Mission Innovation

Mission Innovation is a global initiative of 22 countries and the European Union aiming to accelerate global clean energy innovation. As part of the initiative, participating countries have committed to seek to double their governments' clean energy research and development investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies. These additional resources aim to accelerate the availability of the advanced technologies that will define a future global energy mix that is clean, affordable, and reliable.

Denmark has committed itself to double the investments in clean energy research in 2020 compared to investments in 2016-17.

13. European Commission Brussels 22.1.2014 COM (2014) 15 final: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN

APPENDIX 4

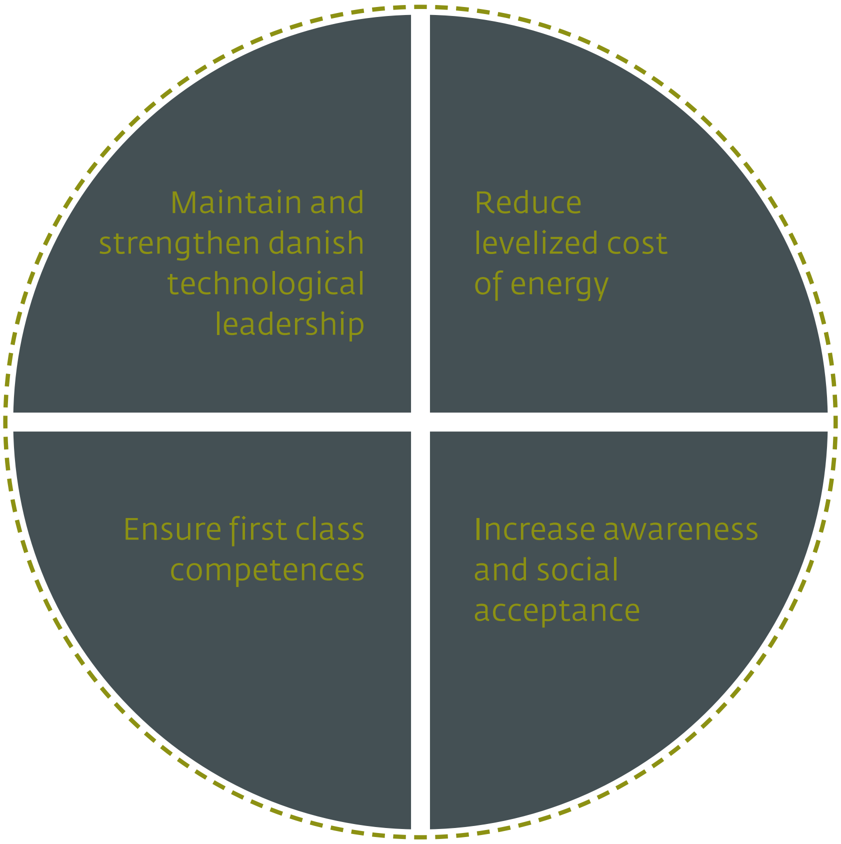
Megavind objectives and organisation

Megavind connects the Danish wind energy community. Key stakeholders in the platform involve the wind energy industry, governmental stakeholders and research institutions.

The scope of Megavind is to create a virtual and physical platform via which the wind energy community can communicate, coordinate and collaborate its work and activities related to research, innovation and technology. The ambition is to define and agree on concrete research and innovation (R&I) priorities and communicate these to decision making bodies in Denmark and beyond in order to support the ambition of reaching the RES targets for 2030[13].

The purpose of the activities carried out is to enable Megavind to perform its advisory activities and recommendations to decision makers in a systematic and coordinated way and facilitates collaboration transparency and information sharing between stakeholders of the wind energy community and beyond.

Megavind execute on the objectives to:



14. Or when it is considered necessary physically or via audio-conferences to review the strategy, control its execution and reply in an agile way to the various consultations.
15. Megavind Steering Committee is a dynamic group that fluctuate in accordance with changes in the sector.

Maintain and strengthen Danish technological leadership because continuous radical and incremental innovation will ensure Denmark as the leading European hub for knowledge and expertise on wind energy technology.

Reduce Levelized cost of energy because the price for manufacturing of BOP & WTG installation, operation and maintenance and decommissioning is the single most important factor for the growing volume of wind energy in the European energy system. Reducing cost include attention to both standardization/industrialisation and life-time optimization as well as low cost by high quality, tailor made solutions and low failure.

Ensure first class competences because the continuous development in R&D, test, design and potentially manufacturing will ensure Denmark's leading position as exporter of wind energy competences and secure growth in green jobs.

Increase awareness and social acceptance because social acceptance is key to smooth implementation of wind farm projects and acceptance of political, economic and social changes in the power supply to private households and the industrial consumption.

Megavind Executive Committee

Megavind Executive Committee (EC) meet twice a year in a discussion forum. The intent is to dialogue with high-level decision makers from governmental or transnational decision-making bodies and/or industrial/academic opinionnators on future wind energy research and innovation priorities. The Executive Committee provides strategical guidance to the Steering Committee.

The Executive Committee members are:

- CTO's (or equivalent) from the leading wind energy industry; and
- Representatives from Danish Research Consortium for Wind Energy (DFFV) Steering Group.

Steering Committee

Megavind Steering Committee (SC) meet every 3 months in a discussion forum[14]. The intent is to continually discuss and dialogue on R&I priorities for wind energy between its key stakeholders. SC aim to communicate, coordinate and collaborate on R&I, hence sending one set of recommendations to national and European decision makers.

The SC has a limitation of 25 seats in order to secure a lean operational body.

Secretariat

DANISH WIND INDUSTRY ASSOCIATION

The secretariat is hosted by Danish Wind Industry Association® (DWIA) who acts as facilitator to drive the processes, and the decisions taken by the Executive Committee and Steering Committee.

The secretariat ensures the operation/function of Megavind and contributes, under the supervision of the Executive Committee and the Steering Committee to the achievement of its goals. It maintains a strictly neutral position as regards to recommendations and prioritisation.

Members of Megavind are representatives of the entire sector including[15]:

- Wind System owners, developers and operators;
- OEMs;
- Research Institutes and Academia;
- Services providers;
- Industry players including sub suppliers and specialized consultancies.

PHOTO: MHI VESTAS

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