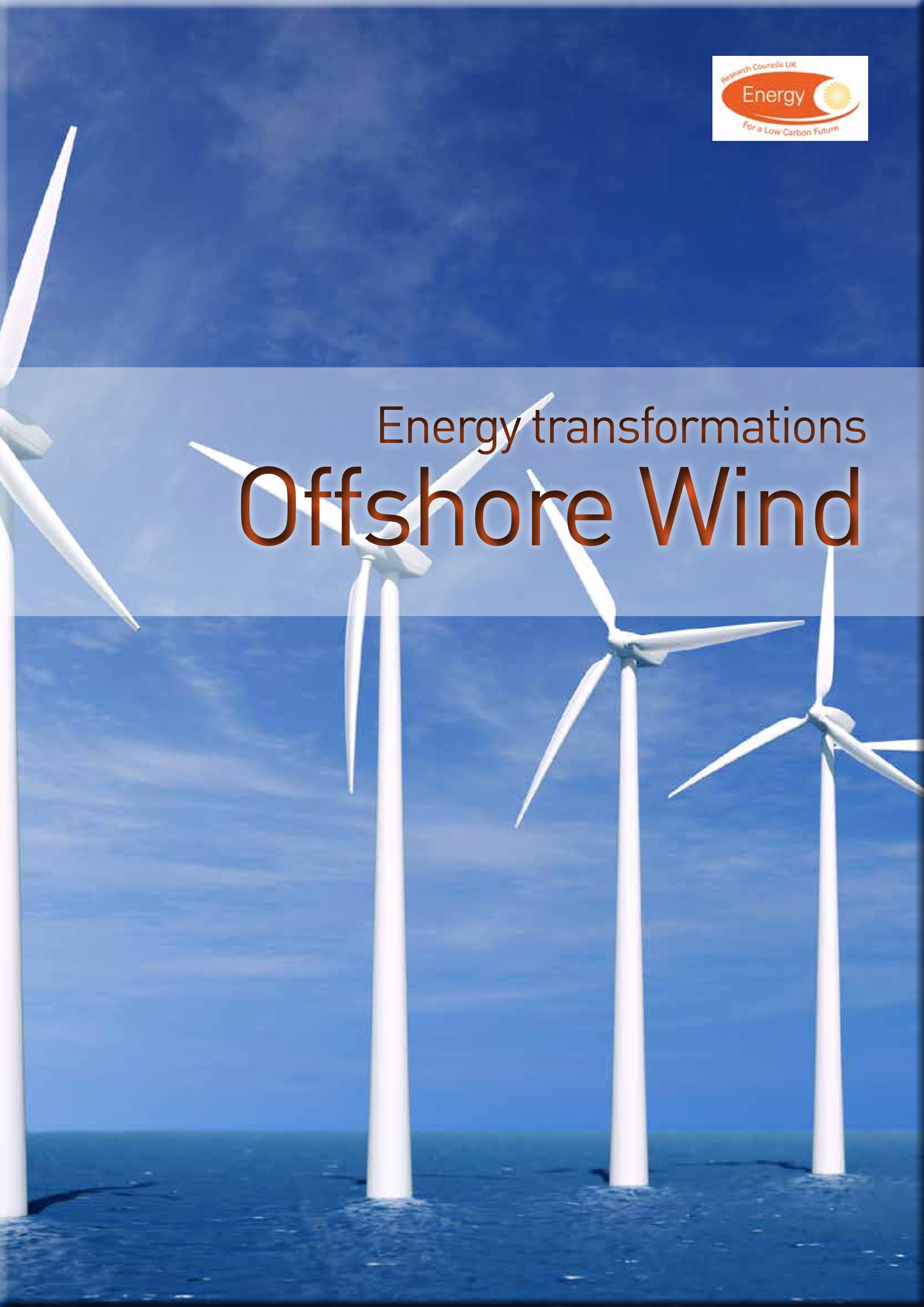
Research Councils UK Energy For a Low Carbon Future



Energy transformations
Offshore Wind

OFFSHORE WIND

- **Offshore wind energy could supply over 20 per cent of the UK's energy needs by 2050**
- **The RCUK Energy Programme has a vibrant research portfolio of £14.3 million in wind energy, involving nine major industrial partners**
- **EPSRC support has contributed to advances in wind turbine reliability, control, drive train design, wind farm formation and deployment**

The UK has a high potential wind power resource around its coast. Offshore wind energy generation is a proven technology to capture this resource and is likely to form the bulk of the UK's renewable energy deployment in the next 20 to 30 years. It is estimated that wind energy could supply over 20 per cent of the UK's energy needs by 2050[1], whilst helping us to meet the greenhouse gas emission and renewable energy targets set out in the 2007 energy white paper[2].

Wind energy research is a relatively small but vibrant part of the EPSRC and RCUK Energy portfolio (£14.3 million; 1.7 per cent of total)[3]. The current portfolio of wind energy projects features collaborations with nine major industry partners, including Alstom Grid, DONG Energy, E.ON UK, National Renewable Energy Centre (Narec), Siemens Wind Power, Vestas, Windurance, formerly MLS Control Systems, and the consulting engineers DNV GL, formerly Garrad Hassan, and Romax Technology, together with a number of other important industrial collaborators. These projects have led to direct cash leverage of over £11 million from the companies directly and other funding sources, including the Energy Technologies Institute (ETI), Innovate UK (formerly the Technology Strategy Board), and the European Union.

The programme has had particular pre-commercial impact in the areas of wind turbine reliability, condition monitoring, turbine pitch and drive control, blade composite structures, offshore wind turbine wake formation and foundation scour, offshore wind farm layout, network design and high-voltage direct current (HVDC) network technology.

Research

- The RCUK Energy Programme has invested £18.4 million in wind energy research and training since 2002
- The flagship investment has been the SUPERGEN Wind Energy Technologies consortium, from March 2014 the SUPERGEN Wind Hub
- The UK Energy Research Centre has developed modelling and evaluation methods for assessing the environmental and socio-economic impact of offshore energy production technologies, including offshore wind farms
- NERC and the Department for Environment, Food & Rural Affairs (Defra) in partnership have funded four projects under the Marine Renewable Energy research programme (£2.4 million), whose aim is to understand the environmental benefits and risks of upscaling offshore renewable energy schemes

Wind power generation is a relatively mature technology, although research challenges remain, particularly for the deployment offshore of large wind farms, with the aim of reducing capital and operational costs, increasing performance, and driving down the cost of the generated power. Current research topics include composites, novel turbine designs, drive trains, reliability and array design and control. There are also associated research issues around environmental impact, equipment deployment and operational management.

The RCUK Energy Programme, led by EPSRC, has invested £18.4 million in wind energy research and training since its inception in 2002[4]. The flagship investments in the field sponsored by the programme have been the successive generations of the Sustainable Power Generation and Supply (SUPERGEN) Wind Energy Technologies consortium, building on and allied to previous investments made by EPSRC and the other Research Councils. More details of this programme are given in the following sections. Important industrial collaborations have also been formed by the University of Bristol with Vestas on composites, the University of Sheffield with Siemens Wind Power on generators and with Vestas on control, and the University of Durham with DONG Energy on wind farm operations. SUPERGEN Wind has also played its part in interacting with other SUPERGEN networks, particularly SUPERGEN Marine, and has collaborated with UKERC in producing a new Wind Road Map, and with the Natural Environment Research Council (NERC) through its contacts with the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) for foundation scour work.

The consortium has also joined and played a major role in the development and growth of the European Academy of Wind Energy (EAWE)[5]; the Principal Investigator of SUPERGEN Wind, Professor Bill Leithead, was President of the organisation from 2010 to 2012. This involvement resulted in the expansion of the Academy to include the UK, Norway, Sweden, France and Italy, with EAWE playing a major role in the Annual European Association of Wind Energy Conferences from 2010-2014 in Brussels, Warsaw, Copenhagen, Vienna and Barcelona.

EPSRC has sponsored a number of offshore wind projects in collaboration with Innovate UK, including INSIGHT, on the monitoring of the structural integrity of wind turbine towers during operation using ultrasonic waves. This project was led by TWI Ltd, and involved the University of Warwick and multiple industry partners. The ultrasonic monitoring system was successfully developed and trialled by TWI and TUV NEL Ltd at an onshore installation in Scotland. A further jointly funded project, on a direct current micro-grid system for interfacing multiple wind turbines, involved the University of Strathclyde, and industry partners Proven Energy Ltd and Scottish and Southern Energy (SSE) plc.

EPSRC is the largest public funder of the Energy Technologies Institute (ETI), and academic groups from four universities, the Universities of Strathclyde and Sheffield, and Durham and Cranfield Universities, have been partners in a number of the major offshore wind energy projects the ETI has supported to date. These projects have included NOVA, looking at a novel vertical axis wind turbine developed by Wind Power Ltd (Strathclyde, Cranfield and Sheffield); Helm Wind, looking at the potential cost savings in the development of an offshore wind power station (Strathclyde); and the Condition Monitoring Programme, examining causes of faults in offshore wind turbines (Strathclyde and Durham).

UK Energy Research Centre

The UK Energy Research Centre (UKERC), sponsored by the RCUK Energy Programme, carries out world-class research into sustainable future energy systems. UKERC's interdisciplinary, whole systems research informs UK policy development and research strategy. Under its Phase 2 Energy and Environment theme, the UKERC team developed modelling and evaluation methods for assessing the environmental and socio-economic impact of offshore energy production technologies, including offshore wind farms and other energy activities such as carbon capture and storage (CCS). This work allows evaluation of the cumulative impacts of energy technologies and interactions with other coastal activities.[6,7] The potential of offshore wind farms to provide socio-economic benefits through multiple uses and improved ecosystem services – including habitat creation, fish stock recovery and recreational fishing – was also investigated. Building on these work strands, UKERC researchers have used an area within the North Sea off the east coast of England as a test bed to forecast the potential of offshore wind to provide ecosystem goods and services to society, taking into account downstream implications. UKERC also carried out research on offshore network design under their Phase 2 Energy Supply research theme.

A UKERC technology and policy assessment on the cost of offshore wind in UK waters was published in 2012. The authors of the report concluded: 'In the period to 2025… there is potential for innovation to reduce costs, for supply chain pressures to ease and for new market entrants to provide competitive pressure on costs. However, there are still a number of factors placing upward pressure on costs, not least the implications of moving to even more challenging locations.[8] A key challenge is to reconcile the scale and pace of development desired for UK offshore wind with the potential growth rate that the supply chain can sustain without creating upward pressure on costs.[9]

NERC-DEFRA MARINE RENEWABLE ENERGY PROGRAMME (2011-2015)

The Marine Renewable Energy research programme is a four-year collaborative programme with a budget of £2.4 million funded by Natural Environment Research Council and the Department for Environment, Food & Rural Affairs. The overall aim of the research programme is to understand the environmental benefits and risks of upscaling offshore wind and wave energy schemes on the quality of marine bio-resources (including biodiversity) and biophysical dynamics of open coasts. The following projects have been supported under the programme:

Optimising array form for energy extraction & environmental benefit led by the University of Edinburgh. This project aims to establish and evaluate a design feedback process which can protect and perhaps enhance the natural environment, while allowing energy extraction to be maximised. Engineers will work with project and device developers to establish appropriate development scenarios which will then be considered using state-of-the-art modelling techniques to assess the levels of ecological impact across a range of key ecological parameters.

Understanding how marine renewable device operations influence fine scale habitat use & behaviour of marine vertebrates led by the University of St Andrews. This project focuses on causal links between offshore renewable energy devices and changes in the fine-scale distribution and behaviour of marine vertebrates.
The overall aim of the project is to identify and quantify actual risk of negative consequences and therefore remove one key layer of uncertainty in the scale of risk to the industry and natural environment.

Flow, water column & benthic ecology 4D led by the National Oceanography Centre. This project aims at measuring flow, water column and benthic ecology in four dimensions, to assess the potential effects of offshore renewable energy devices on the environment. It uses a wealth of observation techniques above and under water, ranging from radar to sonar and in-situ measurements, to be deployed over two years at three key sites around the UK.
These measurements will feed into models of ecological interactions and habitat preferences, allowing predictions of the multiple effects of large offshore renewable energy device arrays.

Quantifying benefits and impacts of fishing exclusion zones around marine renewable energy installations led by the Marine Biological Association. The project seeks to quantify the extent to which 'spillover' of bio-resource abundance, i.e. fish and invertebrate species, enhances adjacent areas as a consequence of fishing exclusions within and around offshore renewable energy installations.
Novel technologies are used to determine the spatial movements of fish and shellfish across a wide-range of spatio-temporal scales, spanning metres to hundreds of kilometres and minutes to years.

SUPERGEN WIND PHASE 1 (2006-2010)

The aim of SUPERGEN Wind Energy Technologies Phase 1 was to undertake research to improve the cost-effective reliability and availability of existing and future large-scale wind turbine systems in the UK.

Scientific and technological advances were made in wind turbine reliability, condition monitoring, turbine control, wake effects, reducing radar cross-section, reducing lightning susceptibility, improving turbine blade strength and foundation durability.

Partners and objectives

The first phase of the SUPERGEN Wind Energy Technologies consortium was led by Strathclyde and Durham universities and included Loughborough and Manchester Metropolitan universities, the Universities of Manchester and Surrey, Royal Holloway, University of London, and the Rutherford Appleton Laboratory. The consortium brought together nine research groups with expertise in wind turbine technology, aerodynamics, hydrodynamics, materials, electrical machines and control, reliability, and condition monitoring.
The overall aim of Phase 1 was to undertake research to improve the cost-effective reliability and availability of existing and future large-scale wind turbine systems in the UK

Impact and outcomes

The key achievements of the SUPERGEN Phase 1 Wind consortium can be summarised as follows:

- Turbine reliability: 75 per cent of onshore turbine failures were found to be responsible for only five per cent of the annual downtime; the remaining 25 per cent of failures cause 95 per cent of the downtime **[see case study 1]**
- Condition monitoring: The strengths and weaknesses of commercially available wind turbine monitoring packages were reviewed and the results disseminated to the wind industry. New condition monitoring techniques were developed to improve early fault detection on the 25 per cent of faults that cause major downtime
- Turbine control: Reduction of wind turbine loads can improve reliability, reduce weight and increase efficiency. The consortium developed control design improvements which reduced loads by 15-18 per cent without compromising turbine performance
- Turbine wake effects: Wake effects from one wind turbine can significantly affect performance of further turbines in an array. The consortium carried out a wide-ranging programme of wind tunnel simulations and measurements in the atmospheric boundary layer, leading to the development of a detailed numerical model to inform future design of turbines and arrays
- Effects on radar: Computationally efficient models were developed for studying the impact of wind turbines on marine navigational radar. Novel materials were developed to reduce the wind turbine radar cross-section and decrease susceptibility to lightning strikes, without causing any reduction in blade strength
- Turbine blade strength and durability: New composite materials were developed which increase blade structure lifetime by five times, while simultaneously increasing toughness in bonded connections. This has improved damage tolerance without accompanying disruption in blade manufacturing processes
- Turbine material properties: a parametric blade model was developed for the assessment of innovative materials, condition monitoring effectiveness, and blade performance
- Offshore turbine foundations: One of the chief risks for offshore wind farm developments is environmental damage of the foundations, known as scour. A detailed understanding of the relationships between the hydrodynamics, sea bed profile, and pile geometry is required for scour mitigation. The consortium took detailed flow measurements from a series of tank experiments and developed a new, efficient numerical model of current-induced scour

SUPERGEN WIND PHASE 2 (2010-2014)

The aim of SUPERGEN Wind Energy Technologies Phase 2 was to undertake research to achieve an integrated, cost-effective, reliable & available offshore wind power station.

Scientific and technological advances were made in wind turbine operation and maintenance, turbine and blade control, and HVDC offshore wind farm connection networks.

Partners and objectives

The second phase of the SUPERGEN Wind Energy Technologies programme included an additional partner at the University of Warwick. In this phase the consortium aimed to achieve an integrated, cost-effective, reliable and available offshore wind power station, with research focused on the following overarching objectives:

- Reliability
- Resource estimation
- Scaling up of turbine size
- Connection and grid capacity issues
- Reducing lifetime costs

The work programme consisted of three parallel themes during its first two years. The first theme dealt with research into the physics and engineering of the offshore wind farm. The second theme focused specifically on the individual wind turbine, building on the research of SUPERGEN Wind Phase 1.

The third theme focused on the connection to shore, including the performance of the wind turbines in the array and the offshore collection system. In the third and fourth years of the programme, the results of these three themes fed into research considering the wind farm as a power station, looking at how the power station should be designed, operated and maintained for optimum reliability and economic viability. Outcomes and impacts from SUPERGEN Wind Phase 2 are summarised in **Case Study 2**.

Case study 1: Reliability, operations and maintenance for offshore wind farms

SUPERGEN Wind Phase 1 identified early the importance to the industry of wind turbine reliability if we are to extract this energy offshore economically. This led to seminal work on benchmarking wind turbine and wind performance, which identified that onshore 75 per cent of defects cause only five per cent downtime, whereas 25 per cent of defects cause 95 per cent of downtime.

The corollary to this work is that offshore a large number of small defects may lead to longer downtime, aggravated by difficult access. This in turn has led to a drive to improve operations and maintenance performance.

A number of industrial developments have occurred in parallel with this work, including the establishment of the wind and marine 3MW and 15MW drive train test rigs and long turbine blade test rigs at the National Renewable Energy Centre (Narec) to test component performance before installation offshore.

Work by SUPERGEN Wind Phases 1 and 2 has produced much-quoted surveys on installed condition monitoring and SCADA (supervisory control and data acquisition) systems.

It has also led to the development of a wind turbine condition monitoring test rig at Durham University, shown below.

This rig is being used to benchmark and inform the work done on the larger industrial test rigs.

SUPERGEN WIND HUB (2014-2019)

Priorities for the SUPERGEN Wind Hub include:

- Wind farm operating environment
- Grid integration with the AC network
- Holistic wind farm control
- Wind farm operations and management
- Turbine technology – very long blades
- Wind foundation systems

Partners and objectives

In March 2014 the SUPERGEN Wind activities moved to the hub and spoke model now followed across the SUPERGEN programme. The Hub consortium is led by the University of Strathclyde, with all partners in SUPERGEN Wind Phase 2 represented, and joined by Cranfield University. The SUPERGEN Wind Hub aims to address the medium-term challenges of scaling up to multiple wind farms, considering how to better build, operate and maintain multi-GW arrays of wind turbines, whilst providing a reliable source of electricity whose characteristics can be effectively integrated into a modern power system. The wind resource over both short and long terms, the interaction of wakes within a wind farm, and the turbine loads and their impact on reliability all need to be better understood. The layout of the farms, including foundations, impact on radar and power systems, and shore-connection issues, needs to be optimised. As noted above, the most effective and efficient operation of wind farms will require them to act as virtual conventional power plants flexibly responding to the current conditions, the wind turbines' state and operational demands and grid-integration requirements. The programme of research for the SUPERGEN Wind Energy Hub focuses on all of these topics, both at the level of single farms and clusters of farms.

FACILITIES

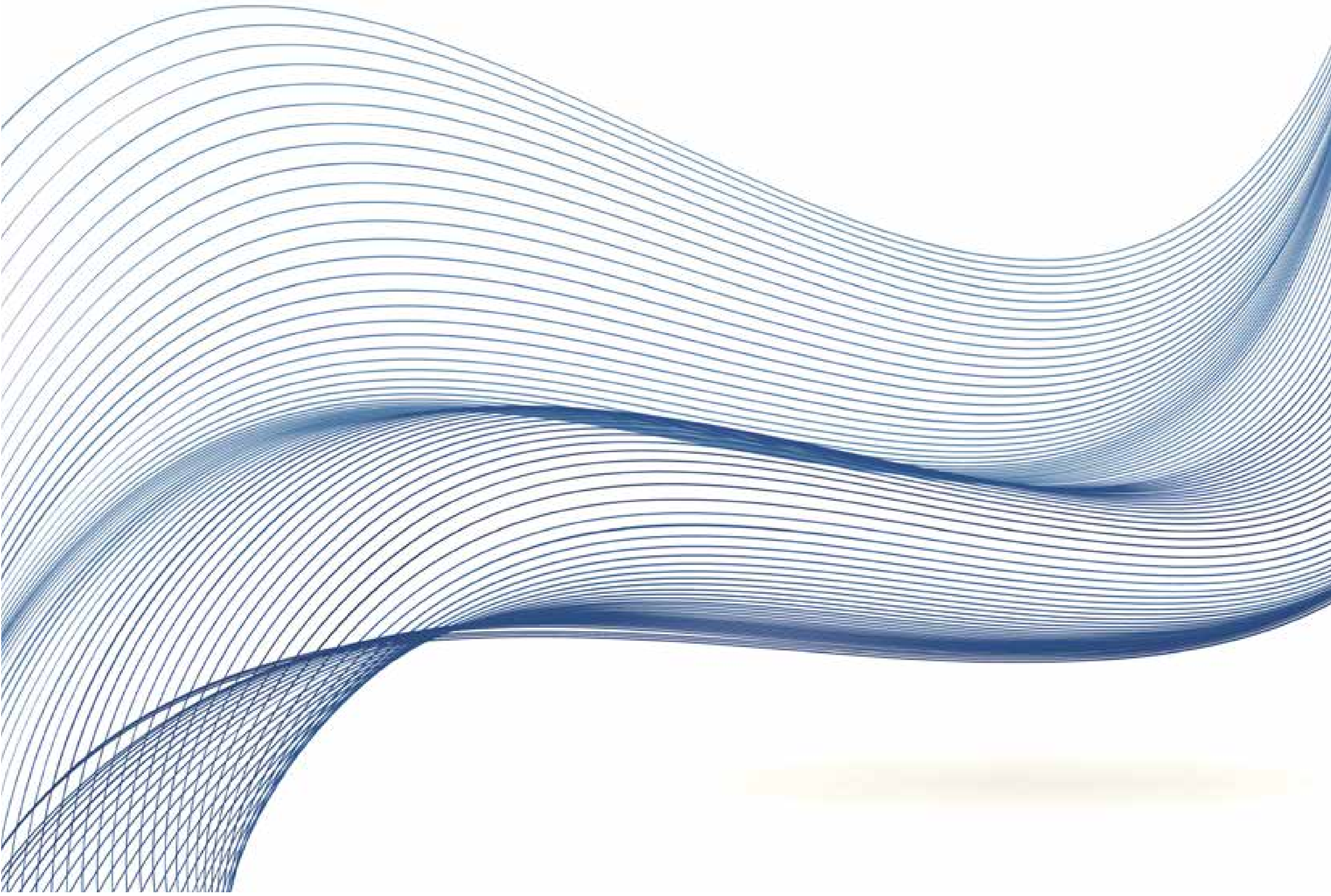
- A model wind farm array wind tunnel test rig has been deployed at the Environmental Flow Research Centre, University of Surrey
- Offshore wind turbine scour modelling tests have been carried out at the Total Environment Simulator in Hull
- A wind turbine condition monitoring test rig has been established at Durham
- A large wind turbine drive train test rig is under development at the National Renewable Energy Centre (Narec) site of the Offshore Renewable Energy Catapult

RCUK funding has enabled a number of facility deployments and developments relevant to the offshore wind sector. The SUPERGEN wind consortium has developed a model wind farm array test rig for use at the Environmental Flow Research Centre (EnFlo) wind tunnel, funded by NERC. This wind tunnel, unique in the UK, is capable not only of simulating atmospheric boundary layers, but also of stratifying the air flow to provide a realistic range of atmospheric boundary conditions, something which is particularly important when analysing offshore wind speeds.

Researchers from Lancaster and Hull universities collaborated with the SUPERGEN consortium to test the potential effects of scour of wind turbine structures in the Total Environment Simulator (TES) at The Deep Aquarium in Hull. A scale model of a wind turbine monopile was placed in the channel, enabling detailed information to be gathered regarding the impact made on the tidal flow downstream and how scour takes place. The exercise was repeated using a range of environmental conditions and modified monopile designs. A monopile with concentric discs around its base was found to reduce vortex developments downstream.

A wind turbine condition monitoring test rig has been established at Durham University in collaboration with the National Renewable Energy Centre (Narec), which is now part of the Offshore Renewable Energy Catapult funded by Innovate UK **[see case study 1]**.

Partly funded by EPSRC, ETI has supported the establishment of a large wind turbine drive train test rig at the Narec site (Blyth, Northumberland).



Case study 2: SUPERGEN WIND PHASE 2 IMPACT AND OUTCOMES

The SUPERGEN Wind Consortium has produced a large number of highly cited publications, summarised in monographs available on the web and including surveys, leading edge research propositions in line with the consortium aims, and two books aimed at enhancing the understanding of offshore wind power. Specific outcomes have included the following:

- Turbine control: Partners at Strathclyde developed generic controllers which decouple the power generated by a wind turbine from the power extracted from the wind. Possible exploitations are the provision of services to the grid, including synthetic inertia, and flexible operation of the wind farms. This technology is being exploited by a major OEM wind turbine supplier
- Individual blade control: The blade control technology patented under Phase 1 was further developed for extreme blade load reduction. Further funding has been obtained from DECC to demonstrate the technology with an OEM to enable exploitation. This technology is also being considered for tidal stream turbines
- High-voltage direct current (HVDC) technologies: HVDC technologies have developed significantly during the course of the project, and the research of the consortium has contributed to the understanding of these changes by providing models and modelling techniques. These have fed directly into the Guide for Development of Models for HVDC Converters in an HVDC Grid published by Cigré working group B4-57, the industry body for this subject area. In addition it was identified that the lack of fast DC circuit breakers at high DC voltages is important in the development of future offshore grids and the large-scale integration of wind energy. Part of the SUPERGEN work stream focused on this topic, and partners at Manchester developed a new circuit breaker for HVDC applications. A patent application was filed in 2013
- Wind farm operation and condition monitoring: New condition monitoring techniques for gearboxes, generators and pitch systems have been developed and demonstrated; a new approach to the management of wind farm operations and maintenance data has been developed; and partners at Durham are developing a new approach to operations and maintenance of wind farms with a major offshore operator

RCUK AND THE WIND ENERGY LANDSCAPE

- EPSRC is a core member of the Low Carbon Innovation Coordination Group (LCICG) on behalf of the Research Councils. A Technology Innovation Needs Assessment (TINA) for offshore wind energy was published by the LCICG in 2012 and revised in 2015, to which SUPERGEN Wind contributed
- The new Offshore Renewable Energy Catapult is founded upon the energy research capacity built up by the RCUK Energy Programme

EPSRC has strong connections in marine energy with the Department for Energy and Climate Change (DECC), in particular under the auspices of the Low Carbon Innovation Coordination Group (LCICG), of which EPSRC is a core member on behalf of the Research Councils. EPSRC was closely involved in the preparation of the Technology Innovation Needs Assessment (TINA) for wind energy published in 2012 and revised in 2015, both directly and through the input of key members of the academic research community. EPSRC also contributed to the LCICG Strategic Framework, published in February 2014, which includes a section on wind energy.[10]

EPSRC contributed to the development of the Department for Business, Innovation and Skills Offshore Wind Industrial Strategy, published in August 2013, and is represented on the Skills Group of the Offshore Wind Industry Council.

The Offshore Renewable Energy (ORE) Catapult, funded by Innovate UK, is founded on the UK energy research capacity built up by the RCUK Energy Programme, in particular through successive SUPERGEN consortia. For example, the ORE research advisory group contains a great deal of SUPERGEN expertise, and is expected to provide a conduit for commercialisation of SUPERGEN Wind (and Marine) energy technologies.

SKILLED PEOPLE

- SUPERGEN Wind Phases 1 and 2 supported 26 doctoral students. First destinations of graduates have included HVPD Ltd, DNV GL (formerly Garrad Hassan), GE Power Conversion, RES, Romax Technology, DONG Energy, E.ON UK, Siemens Wind Power, Vestas and Windurance
- The UK Wind Energy Centre for Doctoral Training (CDT) at the University of Strathclyde has been training cohorts of potential research leaders since 2009
- EPSRC co-funds the Industrial Doctorate Centre in Offshore Renewable Energy (IDCORE) with ETI, based at the Universities of Exeter, Edinburgh and Strathclyde
- Four further CDTs have been supported from 2014

The first and second phases of SUPERGEN Wind trained 26 doctoral students. First destinations of graduates have included High Voltage Partial Discharge (HVPD) Ltd, DNV GL (formerly Garrad Hassan), GE Power Conversion, RES, Romax Technology, DONG Energy, E.ON UK, Siemens Wind Power, Vestas and Windurance.

In 2009 EPSRC funded the UK Wind Energy Centre for Doctoral Training (CDT), led by the University of Strathclyde. This centre aims to train cohorts of future research leaders for the wind energy sector, and has worked closely with DNV GL, Romax, Scottish Power, Siemens, SSE and other wind energy stakeholders. The centre has covered a broad range of topics including turbine control, condition monitoring, operations and management, power networks and electrical systems, aerodynamics and resource management. **Case Study 3** gives a profile of Dr Conaill Soraghan, a graduate of the Wind Energy CDT.

EPSRC also jointly funds the Industrial Doctorate Centre in Offshore Renewable Energy (IDCORE) with ETI. IDCORE is a partnership of the Universities of Edinburgh, Strathclyde and Exeter, the Scottish Association for Marine Science and HR Wallingford. Based in leading UK offshore energy research universities and institutes, the IDCORE programme trains industrially focused research engineers who will, with the help of sponsoring companies, accelerate the deployment of offshore wind, wave and tidal-current technologies in order to meet the UK's renewable energy targets.

In 2013 and 2014 EPSRC announced four new Centres for Doctoral Training with a clear relevance to the offshore wind sector. These centres will ensure a continuing supply of highly trained scientists and engineers between 2014 and 2023 with skills focused on the deployment of offshore wind technologies and their integration into the power network. The first of these is a continuation of the Strathclyde-led centre, the EPSRC Centre for Doctoral Training in Wind and Marine Energy Systems, in partnership with the University of Edinburgh. A second centre, led by Cranfield University in partnership with the University of Oxford, focuses on renewable energy marine structures.

The other two centres focus on future power networks; one is based at The University of Manchester, and one is led by the University of Strathclyde in partnership with Imperial College London.

Case study 3 – Profile: Dr Conaill Soraghan, Offshore Renewable Energy Catapult

Following an undergraduate degree in Mathematics at the University of St Andrews and a Masters in Applied Mathematics at the University of Cambridge, Conaill Soraghan embarked on a PhD in the Centre for Doctoral Training (CDT) in Wind Energy Systems at the University of Strathclyde in October 2009.

As part of his research into aerodynamics and control of innovative wind turbines, Conaill developed software to predict the performance of novel wind energy systems.

Keen to further his interest in the potential of technologies to harness renewable energy offshore, following the successful completion of his PhD in 2014, Conaill successfully applied for the post of Renewable Technology Engineer at the Offshore Renewable Energy (ORE) Catapult.

Created in 2013, the ORE Catapult, which is funded by Innovate UK, aims to accelerate the development, testing, commercialisation and deployment of offshore wind, wave and tidal technologies in the UK.

Conaill says: "I am part of the innovation engineering team within the ORE Catapult with a particular interest in the operations and maintenance (O&M) of offshore renewable assets.

"I have a multifaceted role, which includes project creation, technical engineering support, due diligence of technology innovation concepts and representing the ORE Catapult at a variety of industry and academic forums.

"One key project I'm working on is the development of the SPARTA data sharing platform. This project involves creating a database and web system for collecting and benchmarking performance and reliability of operational offshore wind farms.

Over 50 per cent of the installed capacity of offshore wind farms in UK waters are already providing data into the system.

"I'm also interested in applying the experience and best practice gained in offshore wind O&M to the fledging tidal sector."

CDT training

Conaill's training in the CDT in Wind Energy Systems provided him with a deep technical understanding in wind turbine design, performance and control through working collaboratively with a network of academic experts.

He says: "The format of the PhD programme at the EPSRC Centre for Doctoral Training (CDT), where the first year of the course was a taught Masters in Renewable Energy Systems, was ideal for someone like me with a background outside engineering.

"The first year provided a detailed introduction to all aspects of wind energy systems, from electricity generation and wind turbine technology to the politics and economics of renewable energy systems. I now feel comfortable engaging with a wide range of stakeholders from the renewable sector.

"In addition to the world-class research facilities and academic staff, the CDT, which now encompasses wind, wave and tidal technologies, has a strong focus on nurturing well-rounded and professional engineers. For example, we often meet up with other CDT cohorts to share knowledge and experience, and to hone our presentation skills.

"There are also outreach opportunities throughout the year including workshops at the Glasgow Science Centre, presentations at schools, and various industrial visits. In addition to presenting at various international conferences I also completed a summer placement at the Technical University of Denmark Risoe Campus."

EPSRC Centres for Doctoral Training (CDTs)

In 2013-14 EPSRC funded 115 new EPSRC Centres for Doctoral Training in 33 UK lead universities, training 8,500 postgraduate students. It is the UK's largest-ever investment in postgraduate training in engineering and physical sciences, bringing the total investment to £950 million – £450 million of which has been contributed by industry, other partners and the universities themselves.

CDTs bring together diverse areas of expertise to train engineers and scientists with the skills, knowledge and confidence to tackle today's evolving issues. They also create new working cultures, build relationships between teams in universities and forge lasting links with industry.

Catapult centres

Catapults are technology and innovation centres funded by Innovate UK where the best of UK businesses, scientists and engineers can work together on research and development.

The Catapults work closely with a range of academic and industrial partners, and have close relationships with EPSRC Centres for Innovative Manufacturing, with the aim of transforming ideas into new products and services to generate economic growth. To date seven Catapults have been launched, ranging from developing cell therapy technologies to high value manufacturing and satellite applications.

Catapults use the power of people and organisations working together. These partnerships create new opportunities, reduce innovation risk, and help take new products and services to market.

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Research Councils UK
Energy
For a Low Carbon Future

The Research Councils UK Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. The Energy Programme is investing more than £625 million in research and skills to pioneer a low carbon future. This builds on an investment of £839 million over the past eight years (December 2011).

Led by the Engineering and Physical Sciences Research Council (EPSRC), the Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

[1] Low Carbon Innovation Coordination Group Technology Innovation Needs Assessment for Offshore Wind Energy, February 2012, available to download at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48279/4467-tina-offshore-wind-summary.pdf

[2] http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/energy/whitepaper/page39534.html

[3] As of April 2014. This total includes the UK Wind Energy Centre for Doctoral Training, but not other Centres for Doctoral Training that are also closely relevant to other renewable sectors. See 'Skilled people' section for details of all relevant centres.

[4] Spend figures up to March 2014

[5] http://www.eawe.eu/

[6] Austen MC, Stephen J, Malcolm SJ, Frost M, Hattam C, Mangi, S, Stentford G, Benjamins S, Burrows M, Butenschön M, Duck C, Johns D, Merino G, Mieszkowska N, Miles A, Mitchell I, Smyth T (2011). Marine. In: The UK National Ecosystem Assessment Technical Report (UK NEA, 2011). Publishers: UNEP-WCMC.

[7] Ashley MC, Mangi SC and Rodwell LD (2013) The potential of offshore wind farms to act as marine protected areas – a systematic review of current evidence. Marine Policy.

[8] http://www.ukerc.ac.uk/support/tiki-index.php?page=Great+Expectations:+The+cost+of+offshore+wind+in+UK+waters

[9] http://www.sciencedirect.com/science/article/pii/S030142151100944X

[10] See http://www.lowcarboninnovation.co.uk/working_together/strategic_framework/overview/