ReaLCoE

Project No: 791875

Call: H2020-LCE-2016-2017

Topic: LCE-14-2017

Type of Action: IA

Duration: 01.05.2018 –31.01.2026

EU offshore wind projects overview	
Lead Beneficiary	*8.2 Consulting AG*
Type of Deliverable	*Report*
Dissemination Level	*Public*
Submission Date	*16.04.2024*
Version no.	*V01*

Versioning and contribution history

Version	Description	Contributions
1.0	First draft	8.2 AG

Reviewer

Name	Organisation
WP8 Team	

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List of Abbreviations

LCoE	Levelised Cost of Energy
CDE	Communication, Dissemination and Exploitation
WP	Work Package
WEC	Wind Energy Converter

1. Projects Overview

Table 1: Relevant EU funded research projects

Project	Scope	Website
INNWIND (2012 – 2017)	High performance innovative design of a beyond-state-of-the-art 10-20MW offshore wind turbine and hardware demonstrators of some of the critical components.	http://www.innwind.eu/
Avatar (**Ad**V**anced **A**erodynamic **T**ools for l**A**rge **R**otors) (2013 – 2017)	Evaluate, validate and improve aerodynamic and aero-elastic tools to ensure applicability for large wind turbines to make upscaling wind turbine designs towards 10-20 MW feasible.	https://cordis.europa.eu/project/id/608396
LEANWIND (2013 – 2017)	Provide cost reductions across the offshore wind farm lifecycle and supply chain through the application of lean principles and the development of state of the art technologies and tools.	https://www.leanwind.eu/
UpWind.EU (2006 – 2011)	Develop and verify substantially improved models of the principal wind turbine components, which the industry needs for the design and manufacture of wind turbines for very large-scale future applications, e.g. offshore wind farms of several hundred MW.	www.upwind.eu website is not reachable anymore. Project information can be found here: https://www.ewea.org/our-activities/eu-funded-projects/completed-projects/upwind/ Complete report on 20 MW wind turbine design limits: https://www.ewea.org/fileadmin/ewea_documents/documents/upwind/21895_UpWind_Report_low_web.pdf
ROMEO (2017 – 2022)	Reducing the cost of offshore wind energy and boosting the renewables industry	ROMEO project | Offshore wind farm optimization in Europe
IRPWIND (2014 – 2018)	Foster better integration of European research activities in the field of wind energy research with the aim of accelerating the transition towards a low-carbon economy and maintain and increase European competitiveness.	https://www.irpwind.eu/

2. Projects Summary

2.1 InnWind

Project partners: DTU, Aalborg University, CRES, ECN, NTUA, TUDelft, SINTEF, Politecnico di Milano, University of Hannover, University of Oldenburg, University of Patras, University of Sheffield, University of Strathclyde, University of Stuttgart, WMC, Fraunhofer, Cener Siemat, University of Bristol, DHI, Rambøll, Siemens, GL Group, GL-GH, Magnomatics, SE Blades Technology, Gamesa, WindEurope, NREL

InnWind is a project of 28 European partners, led by DTU. The aim of the project was the conceptual design of 10-20MW offshore wind turbines. The project builds on the findings of the "UpWind" project (2006-2011). There, designs for 5MW turbines were developed, which were then expanded to larger platforms in InnWind. The main objective of the project was to increase the efficiency of larger platforms in order to keep the increase in cost/weight relative to the increase in the performance of the equipment low. This should be implemented through three aspects in particular:

- Lighter rotor that can absorb higher forces due to larger rotors
- Lighter and more direct generator (can be used without gearbox)
- Substructure and tower for offshore installations, which can be mass-produced and can also be used in variable water depths

The result of 5 years of research were the following innovations:

- Low Induction Rotor (LIR): This has special profiles for the outer part of the blade, which are designed for operation with a lower lift coefficient of 0.8 (normally 1.0 – 1.3). In addition, tools / mechanisms for the integrated design of aeroelastic tailoring with passive blade deflection couplings as well as numerous solutions for an optimal combination of passive and active control have been developed. Using the scale of Technology Readiness Level (TRL), this innovation raised the original TRL rating from 3 to 5.
- Innovative wind sensors, such as a spinner anemometer and a spinner LiDAR, which can measure high-frequency wind time series, were presented. In this way, turbulence can be measured easily and at an early stage and thus cause a load reduction or increase in energy consumption through control and regulation.
- It was found that superconducting medium-temperature generators with coils made of magnesium diboride (MgB2) would need to be improved in reliability to ensure low resistivity. At the same time, superconducting coils made of yttrium-barium-copper oxide (YBCO) were tested. Although these have enormous potential, their production would have to be reduced by a factor of 4 in order to generate an economic benefit. At the same time, the critical current density in these wires would have to be increased by 4. The TRL status has been set at 4 here, as the substructure is a major cost item for offshore installations and optimising the weight of the nacelle has only a minor impact on the overall costs.

- The PDD (Pseudo-Magnetic Direct drive) is a magnetic gearing with a permanent magnet generator. This was tested in the laboratory with forces of 5 kNm, 16 kNm and 200 kNm. On a large scale, this is said to represent a generation efficiency of 98%. The aim is to reduce the cost of generating electricity by 4%.
- An advanced optimal jacket with a fatigue life of 25 years has been developed for the 10 MW turbine with 3-blade rotors. At the same time, an innovative articulated substructure was developed for the 2-blade rotor. The TRL level for sheath solution is relatively high, as they are already used commercially, but it is still low for joint solution. For 20MW systems, avoiding harmonic excitation of the motor seems relatively easy. Finally, roadmaps were developed that describe information on market launch and certification.

2.2 Avatar

Project partners: Technische Universiteit Delft, Danmarks Tekniske Universitet, Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V., Carl Von Ossietzky Universität Oldenburg, Universität Stuttgart, Fundacion Cener, The University Of Liverpool, Centre For Renewable Energy Sources And Saving Fondation, Ethnicon Metsovion Polytechnion, Politecnico Di Milano, General Electric Deutschland Holding Gmbh, Lm Wind Power As, University Of Glasgow

The AVATAR project aims to investigate aerodynamic and aeroelastic scaling for 10-20MW plants. In this project, various designs and concepts were evaluated and tested for applicability in practice. As a result, concrete design guidelines were presented. The main aim was to improve and validate aerodynamic models and to ensure the applicability of these models for turbines of more than 10 MW with and without flow devices and with and without aeroelastic effects.

The main focus of this thesis was the improvement of models with low complexity/computational efficiency (e.g. Blade Element Momentum – BEM) using models with high accuracy/computational effort (e.g. Computational Fluid Dynamics – CFD). In this way, models with less complexity can be used to more accurately calculate and simulate loads and thus also designs of larger rotors. The models were then tested on two 10 MW reference wind turbines (InnWind and AVATAR).

The results of the project were:

- Increased accuracy of aerodynamic models for 10+MW wind turbines including evaluation of aeroelastic consequences. Due to the computation time of the more complex models (CFD), simpler models (BEM) are still indispensable in planning.
- The validation of these models was carried out on turbines of 10 MW or smaller, as there were no larger turbines at the time of the project.
- Although the improvement of the simpler models and thus the project was very successful, the experimental validation basis was considered by the project group to be too limited. Both in the field and in the wind tunnel, high-quality measurements are urgently needed.

The aim of this project is to help with the planning of new wind farms by making it possible to determine loads and capacities more reliably as a result of the model improvements.

2.3 Leanwind

Project partners: UCC, MRTK, GDG, ACCIONA, KM, MTS, CIT, A2SEA, KALEIDO, EDF, AAU, UOPHEC, EDPI, UEDIN, IBR, SINTEF, FRAUNHOFER, NTUA, PLOCAN, FORCE, WindEurope, UHULL, 1-Tech, AGHO, Geosea Maintenance, LR, SEA Europe, NAAS, AMS, DELTA MARINE, Siemens Wind Power A/S, DNV GL, Statkraft, Mainstream Renewable Power, The Crown Estate, Senvion SE

LeanWind is a project to reduce costs throughout the life cycle and supply chain of offshore wind farms. 31 partners from 11 countries were involved in the project. The project was launched in 2013 and had a duration of 4 years. This should be implemented through the application of lean principles and the development of state-of-the-art technologies and tools. The lean principle describes the elimination of unnecessarily complex or wasteful phases in the development process. The transition between the phases should also be shortened and the quality of the process should be increased (Identify what the customer needs; Track, reduce or eliminate wasteful stages in and between processes; Seek continuous improvement; Approach improvements from a whole system perspective). In this way, projects should be more cost- and time-efficient in the future.

The following results were achieved:

- Reducing the material required for monopiles by using more realistic ground springs modeling and a more efficient use of finite element modeling. In this way, material costs can be saved.
- Gravity Base Foundations (GBFs): Optimizing these structures has helped reduce material consumption by designing lighter yet strong foundations, resulting in savings in manufacturing costs. In addition, there are significant savings in transportation and installation costs resulting from the elimination of expensive jack-up vessels due to towing and ballasting gravity-based foundations.
- The concept of floating jackets was tested in the integrated design of jacket foundation and suction buckets. This results in cost savings during the transport and installation phase.
- Development of a semi-submersible platform for future R&D
- New vessel design for more efficient transport of 8MW and 10MW turbines
- O&M strategy model for optimising strategic areas
- Dynamic planning model for more efficient planning
- Development of various risk and monitoring systems to reduce offshore travel and reduce general maintenance.
- Simulation of maintenance assignments in order to rehearse them and to better assess any eventualities that arise there. In this way, maintenance operations can be made more efficient.
- Development of new logistics models
- Development of a financial model over the entire lifecycle to save costs

2.4 UpWind.EU

Project partners: Danmarks Tekniske Universitet (Technical University Of Denmark), Forskningscenter Risø, Aalborg Universitet, Energieonderzoek Centrum Nederland, Stichting Kenniscentrum Windturbine Materialen En Constructies, Technische Universiteit Delft, Centre For Renewable Energy Sources, National Technical University Of Athens, University Of Patras, Universitaet Stuttgart, Dong Energy Powers A/S, Garrad Hassan & Partners Ltd, Rheinisch-Westfaelische Technische Hochschule Aachen, Lm Glasfiber A/S, Germanischer Lloyd Windenergie Gmbh, Ramboll Danmark A/S, Teknologian Tutkimuskeskus Vtt, Samtech Sa, Shell Windenergy B.V., Repower Systems Ag, Det Norske Veritas, Danmark A/S, Bosch Rexroth Ag, The University Of Edinburgh, Instytut Podstawowych Problemow Techniki Polskiej Akademii Nauk, Lulea Tekniska Universitet, Council For The Central Laboratory Of The Research Councils, Vrije Universiteit Brussel, Qinetiq Limited, Vestas Asia Pacific A/S, Smart Fibres Ltd, University Of Salford, European Wind Energy Association, Alstom Wind, S.L.U., Fundacion Cener-Ciemat, Fiberblade S.A., Ge Global Research, Zweigniederlassung Der General Electric Deutschland Holding Gmbh, Academy Of Sciences Of The Czech Republic V.V.I. (It Ascr V.V.I.), V.N. Bakul Institute for Superhard Materials Of The National Academy Of Sciences, Thapar University, China University Of Mining And Technology, Germanischer Lloyd Industrial Services Gmbh, Gamesa Innovation And Technology S.L., Vattenfall Vindkraft A/S, Fraunhofer-Gesellschaft Zur Foerderung Der Angewandten Forschung E.V, Science And Technology Facilities Council, Fundacion Tecnalia Research & Innovation

UpWind was a project carried out from 2006 to 2011 with the main aim of developing improved models for components of larger wind turbines (5MW – 20MW). Through this development, the industry should be able to convert these models and concepts into real components and thus realize larger wind turbines. A digital design for a 20MW plant was created, which was not feasible at the time of the project due to the limitations of the components. In particular, the heavy weight at the top of the tower and the impact on the entire structure were problematic. To address these problems, various innovations have been developed, the most important of which are presented below:

- Development of stronger and lighter rotor blades and reduction of fatigue loads. These were achieved through more flexible materials and improved control of the blades. For example, pitching individual blades separately reduced fatigue loads by 20-30%.

- Further development of advanced sensors, such as the LIDAR system, to detect approaching turbulence. As a result, strategies have also been developed to reduce the impact of such turbulence on the material.

- The project highlighted the importance of shear winds for larger rotor blades and clarified that central wind sensors would not be sufficient for larger rotor diameters.

- Development of rotor concepts that are easier to transport, such as two-piece rotor blades for onshore turbines.

- Weight reduction of the drivetrain, with a special focus on permanent magnet generators.

- Further development of monitoring systems to increase reliability through the development of statistical reliability.

- Development of new design tools for subsurface structures of offshore installations, depending on subsurface and sea depth.

2.5 ROMEO

Project partners: Iberdrola Renovables Energía, Electricité De France, Adwen, Siemens Gamesa, Ramboll, Ibm Research – Zurich, Indra, Bachmann Monitoring, Laulagun Bearings, Uptime Engineering, Zabala Innovation Consulting, University of Strathclyde in Glasgow

The ROMEO project was launched in 2017 and aims to reduce the maintenance and operating costs of offshore wind power facilities. It was implemented by a consortium of 12 partners from research and industry. The reduction of maintenance and operating costs is to be implemented through the development of new and advanced monitoring systems and strategies. The aim was to develop a new analysis and management platform that could be used to develop strategies for operation and maintenance. Furthermore, it is also a platform for diagnosing and predicting repair measures. This should increase reliability, extend service life and also reduce foundation costs. The following innovations have been developed:

- Diagnosing and predicting maintenance and component failures: Failure Mode Effects and Criticality Analysis (FMECA) is an algorithm for identifying failures before they occur. On this basis, various failure scenarios were developed and tested in order to reliably predict them. The current state of the art, monitoring via CMS, is to be improved and integrated with the new system. The wear and tear of individual components is also to be predicted in this way.
- Development of a "digital twin", a virtual copy of the entire wind turbine. With the help of this technique, a virtual copy of the turbine is created and supplied with the data of the actual plant. In this way, it should be possible to simulate the entire life cycle of the system. In this way, signs of fatigue and incidents can be reliably predicted.
- Further development of data collection and analysis ecosystems. The further development is intended to enable information to be used and distributed better and more reliably. This then led to the development of the HARVEST platform. This platform makes it possible to coordinate and manage operation and maintenance tasks. It can also merge existing data structures of manufacturers and, in addition to monitoring the data, also provide condition-based maintenance (CBM) and predictive maintenance (PdM) for turbines and components. At the same time, the platform is also a tool for deployment planning and knowledge gathering.

2.6 IRPWind

Project partners: DTU, CRES, ECN, Fraunhofer IWES, SINTEF, CENER, CNR, WindEurope, TUBITAK, VTT, NTNU, UoS, TECNALIA, ForWind-OL, ForWind-H, UoA, CIRCE, IREC, LNEG, CTC, AAU, WMC, CIEMAT, MARINTEK

IRPWind is a project of 24 partners consisting of research institutions and universities. The aim of the project is to improve the integration of European research activities in the field of wind energy. For example, priorities should be assigned and research resources should be properly distributed and integrated. For example, each of the partners worked with national funding agencies and stakeholders to coordinate them across Europe. This work led to the identification of a wide diversity in the funding of research and innovation in the field of wind energy and the different national priorities. The project also participated in SET-Plan fora such as the Technology Platform for Wind Energy (TPWind), its successor the European Technology & Innovation Platform (ETIPWind) and the joint member states-industryacademia task force European Wind Initiative. During the project, it became clear that national alignments were almost impossible to align. As a result, research projects should in future be carried out institutionally, i.e. in cooperation between two or more research organisations. In this way, alignment and knowledge transfer should be easier and more efficient to implement. In addition, a European Technology and Innovation Platform (ETIPWind, see European Technology & Innovation Platform on Wind Energy (etipwind.eu)) was launched in 2016 to improve exchanges between research and industry. As a result of the project, industrial participation in research projects has increased.