Final report

1.1 Project details

Project title	Resource Assessment, Forecasts and WECs O&M strategies at DanWEC and beyond
Project identification (program abbrev. and file)	64015-0034
Name of the programme which has funded the project	EUDP 15-I
Project managing company/institution (name and address)	Jens Peter Kofoed, Department of civil engineering, Aalborg University
Project partners	DHI DanWEC
CVR (central business register)	29 10 23 84
Date for submission	12-04-2019

1.2 Short description of project objective and results

Project objectives were to define the long-term wave climate around Hanstholm area using measurements from buoys off Hanstholm and to build competences in defining Operation and Maintenance (O&M) strategies for wave energy converters and other offshore activities in the study area.

The objectives were fulfilled within the project. 35 years of hindcast data from the MIKE21 SW model were delivered. The model was validated against measurements provided by DanWEC's measuring buoys. The data was analysed following the IEC standard and rendered available to any developers testing at DanWEC. A forecast service was developed based on the hindcast model. It was made available to the test site operator and the users testing. An O&M database and tool were also created.

Projektets formål er at bestemme bølgeklimaet i området omkring Hanstholm (DanWEC) ud fra målinger fra 3 bølgemålebøjer og foretage validering heraf vha. modelgenererede data. Disse modeller anvendes endvidere til udvikling af prognoser, samt drift og vedligeholdelsesstrategier for bølgeenergianlæg ved DanWEC og omegn.

Målene blev opfyldt under projektet. 35 års hindcast data fra MIKE21 SW-modellen blev leveret. Modellen blev valideret mod målinger fra DanWECs målebøjer. Dataene blev analyseret efter IEC-standarden og gjort tilgængelig for alle udviklere, der tester hos DanWEC. En prognosetjeneste blev udviklet baseret på hindcastmodel-

len. Den blev stillet til rådighed for DanWECs operatør og bruger. En O&M database og værktøj blev også oprettet.

1.3 Executive summary

The wave energy sector is at a development stage where real-sea testing is imperative. Dedicated test sites for WECS are being established around Europe to facilitate sea trials, and the Danish Wave Energy Centre (DanWEC) has proved to be one among the preferred test sites. Several WECs have already being tested there, and there are ongoing negotiations with 2 more WECs to deploy. Before the project, DanWEC lacked detailed information on its wave climate. Also, the wave energy sector generally lacks experience on WECs O&M operations, a key for successful WECs' long-term testing and operation that accounts for a significant part of WECs lifetime costs (possibly about 20%). This project had as objective to deliver detailed information of the environmental conditions of DanWEC and to optimise O&M procedures, which will ultimately improve WEC's operation and reduce WEC's costs. Particularly, the proposed project had the following commercial and practical outcomes that are addressed further in section 1.5:

- Collecting, processing and analysing wave-buoy measured data from the existing (Buoy I) and the two new wave riders installed off Hanstholm (Buoy II and Buoy III) [WP2]
- Gathering hindcast and forecast data from DHI at the three wave riders' locations and for the whole area of interest for DanWEC [WP2]
- Validating DHI models against measured data [WP3]
- Defining Hanstholm wave climate: long-term resource assessment, extreme events, resource variability, etc. [WP4]
- Harvesting practical experiences from the actual sea-testing of WECs regarding operational thresholds and required maintenance [WP4]
- Cross-correlating the timeline of O&M activities with DHI's forecasts and hindcasts, in order to define available weather-windows, weather-window sizes and needed forecasting horizons [WP4]
- Defining a comprehensive timeline about long-term optimal WECs O&M procedures at DanWEC [WP4]
- Delivering an O&M tool for planning and forecast for offshore operations in the area [WP4]
- Disseminating project findings to the wave energy sector, the research community and to potential industrial customers [WP5]

The project was built up as collaboration among three public and private partners: the Wave Energy Research Group of Aalborg University, Department of Civil Engineering (AAU), the Danish Hydraulic Institute (DHI) and DanWEC. They key competences of the three partners ensured the successful delivery of the project outputs that are:

- Establisment of a database of metocean conditions from measurements from wave measuring buoys available to users of the DanWEC test site.
- 35 years hindcast wave climate data of the area around Hantsholm available to users of the DanWEC test center.

- Wave climate assessment of DanWEC test site produce according the recommendation from the standard IEC 62600-101 TS, 2014.
- Database of O&M activities and experience on O&M procedures
- Forecast model of the DanWEC test site.
- Online forecast data for the DanWEC test site available to DanWEC's users.
- Evaluation of the forecast model in terms of different error metrics.
- O&M numerical tool with the capabilities of forecasting weather windows available for O&M activities scheduled for the DanWEC test center.

Getting new customers is essential for DanWEC to ensure the continuation of the centre. All the output generated through this project are valuable not only for existing customers, but it is also valuable to DanWEC in order to attract new customers. DanWEC will use the outputs of the project tool in presentations of the company and to show demonstrations to potential new customers, thereby increasing the chance for getting new contracts for testing at the DanWEC site.

1.4 Project objectives

The objectives of the project were

- to define the long-term wave climate around Hanstholm area using measurements from three buoys off Hanstholm and by validating modelled against buoy-measured data
- to build competences in defining Operation and Maintenance strategies for wave energy converters (WECs) andother offshore activities in the study area.

In order to achieve the above-mentioned objectives a number of smaller objectives and tasks has been accomplished and are listed in details in the following paragraphs.

Collecting, processing and analysing wave-buoy measured data from the existing (Buoy I) and the two new wave riders installed off Hanstholm (Buoy II and Buoy III) [WP2]

This outcome was delivered at the beginning of the project. A software was installed at the port of Hanstholm to transfer data from the computer to a database on Amazon Web Service (AWS). A python script was then used to process the data and display it on DanWEC webpage. For Buoy II and III, data was backed up on a NAS drive accessible by the users of the test site via FTP and was also transfer to a database on AWS with a python script. A special webpage was also made available to the users to be able to visualise the data. The Port of Hanstholm change their buoy in 2017 to one of the same model as DanWEC's. This change required modifying the configuration of the data transfer at DanWEC. In collaboration with The Danish Coastal Authority, data was gathered on DanWEC's computer and backed up on DanWEC's FTP server, accessible for all DanWEC's users.

Gathering hindcast and forecast data from DHI at the three wave riders' locations and for the whole area of interest for DanWEC [WP2]

DHI developed a model for DanWEC test site and around using their MIKE21 Spectral wave model. The output wave data covers the period from January 15, 1981 to December 31, 2015, a total of 35 years. For more details on the hindcast model, please refer to report 2. The forecast model for the DanWEC test site is based on

the hindcast model where the grid output resolution is reduced. The forecast model updates a 5½ days-horizon twice every 24 hours. The model forcing comprises input from regional DHI models and forecast wind fields. The forecasted data provided by the model include amongst other wave height, wave period, direction, wind speed and current speed. The forecast model was put in place in December 2016 and has provided 2 years of forecast data that was rendered available to DanWEC's test site manager and DanWEC users via a dedicated webpage (report 7). Furthermore, 13 quarterly reports of the wave climate at the test site were written and the procedure put in place for the extraction of the data is done as automatically as possible, which ensures that the report will continue to be produce after the project (report 1).

Validating DHI models against measured data [WP3]

The hindcast model was validated against wave measurements from Buoy I, Buoy II and Buoy III and the results from the validation can be found in report 2. A very good agreement in general between measured and modelled data was seen by visual comparaison and the agreement was also confirmed by compiling error metrics. The forecast model was also validated against measurements from Buoy II and Buoy III. Each forecast time series between the period January 2017 and December 2018 has been compared with observed data for the corresponding period and error metrics were compiled over the whole period and also analysed in terms of seasonal and monthly variations (see report 4).

Defining Hanstholm wave climate: long-term resource assessment, extreme events, resource variability, etc. [WP4]

The 35 years of hindcast data provided by DHI has been used to perform the long-term resource assessment of the wave climate off the coast around Hanstholm, including DanWEC test site area. The recommendations from [IEC 62600-101 TS, 2014] for long-term wave climate characterization were follow as closely as possible providing the data was available. Report 5 presents the wave climate for eleven different locations. The report is therefore divided into eleven chapters to ease the disctintion and facilitate the navigation through the results presented. See report 5 for the whole wave climate assessment.

Harvesting practical experiences from the actual sea-testing of WECs regarding operational thresholds and required maintenance [WP4]

Practical experience in running the test site has been gathered within the project. A report (report 3) was written to summarize the different activities. In order to understand the requirement for running the test site, a list of equipment was given together with the needed tools for administrating the test site. A list of operation necessary for maintaining the test site is also provided with corresponding wave climate and wave height conditions threshold for the successful completion of the operations. A database of O&M activities at the test site was created and it is updated each time there is an operation performed. This database is available on the Dropbox of DanWEC and can be accessed and modified by mobile phone by the test site manager. This way, populating the database is easy and straightforward, rendering it a routine procedure.

Cross-correlating the timeline of O&M activities with DHI's forecasts and hindcasts, in order to define available weather-windows, weather-window sizes and needed forecasting horizons [WP4]

The report 5 has provided data enough data to have statistic of available weather-windows and weather-window sizes according to the period of the year. Furthermore a cross correlation of forecast data and observed data obtained from measurements from wave measuring buoys has been performed. Performance of the forecast model has been assessed using different errors metrics for both prediction of wave height and wave period. The performance evaluation has been performed over a period of two years and seasonal and monthly variations were investigated. The results are given in report 4.

Defining a comprehensive timeline about long-term optimal WECs O&M procedures at DanWEC [WP4]

The project has been initiated to deliver detailed information on the environmental conditions at DanWEC and to review implementation of O&M procedures, which will ultimately improve wave energy converters' operation and reduce their costs. Installation, maintenance and operation of the equipment at the DanWEC test site have been both cost and time consuming and the experience over the last 4 years has shown that improved weather predictions have helped drastically the operation of the test site. The developed forecast and O&M tools have shown to be efficient in reducing the O&M cost. In the last years, Wavepiston has been testing at the test site. The developer has used the forecast tool for planning operations at DanWEC and has seen the potential of this tool for reduction of cost of energy for the Wavepiston device. All this has been outlined in report 7.

Delivering an O&M tool for planning and forecast for offshore operations in the area [WP4]

DHI has developed a numerical tool for DanWEC with the capabilities of forecasting weather windows available for O&M activities scheduled for the DanWEC test center. A single O&M activity was defined as the trip of a vessel from the port of Hanstholm towards the test center, the execution of the scheduled service at the test center area and the return trip in the same vessel, all this based on report 3 describing O&M activities at the DanWEC test center. The time interval during wich the metocean conditions do not allow the execution of the scheduled O&M activity is defined as downtime. The tool evaluates the downtime based on a metocean forecast dataset for the area of interest. The prediction of the metocean conditions is given by the forecast model developed by DHI (report 6). The downtime of a specific activity was identified as the time interval during which any of these time series exceeded a fixed threshold. Within the 6 days forecast, the tool identifies the time windows that can accommodate the analysed O&M activity. The windows are ranked according to the lowest downtime. Report 7 gives an overview of the tool and how to use it.

Disseminating project findings to the wave energy sector, the research community and to potential industrial customers [WP5]

Refer to table 1 and 2 for all dissemination activities performed during the project.

1.5 Project results and dissemination of results

The deliverables and milestones described in the application have contributed to the realisation of the project objectives that were:

- to define the long-term wave climate around Hanstholm area using measurements from three buoys off Hanstholm and by validating modelled against buoy-measured data

- to build competences in defining Operation and Maintenance strategies for wave energy converters (WECs) and other offshore activities in the study area.

Many more WECs were expected to test at DanWEC within the timeframe of the project and a more substantial database for O&M operations of WECs was foreseen when the application was first drawn. Nevertheless, as Wavepiston has been testing at the test site for nearly as long as the project has ran, valuable information were gathered to form a good base for the database. The many operations performed at the test site were also recorded and have shown to provide extensive experience in the daily management of the test center.

Unexpected work regarding Buoy 1 has been required to ensure that the project would fulfil its objectives. The port of Hanstholm changed its wave measuring buoy and that require configuration changes for the DanWEC network sensors, data acquisition system and database maintenance.

The project results have improved drastically DanWEC's business plan, as it has provided key information, data and tools that enhance the business potential of the test center. The results have not so far resulted in increased turnover or employment.

TABLE 1: LIST OF DISSEMINATION ACTIVITIES PERFORMED DURING THE PROJECT

Date	***Type***	***Where***
09/2019	Article in proceedings *(Submitted)*	Proceedings of EWTEC2019
09/2019	Presentation at an international conference *(Submitted)*	EWTEC2019, Naples, Italy
05/2019	Article in proceedings *(In progress)*	Proceedings of Marine2019
05/2019	Presentation at an international conference *(Submitted)*	Marine2019, Gothenburg, Sweden
09/2018	Article in proceedings	Proceedings of ITISE2018
09/2018	Poster at an international conference	ITISE2018, Granada, Spain
09/2018	Presentation at a national stakeholder meeting	Danish partnership for wave power, Aalborg, Denmark
03/2018	Presentation at a national stakeholder meeting	Danish partnership for wave power, Frederikshavn, Denmark
11/2017	Presentation at a national stakeholder meeting	Danish partnership for wave power, Esbjerg, Denmark
03/2017	Presentation at an international stakeholder meeting	Wave energy international Business2Bussiness event (WEIB2017), Copenhagen, Denmark
09/2017	Article in proceedings	Proceedings of EWTEC2017
09/2017	Presentation at an international conference	EWTEC2017,Cork, Ireland
11/2016	Presentation at a national stakeholder meeting	Danish partnership for wave power, Aalborg, Denmark
09/2016	Article in proceedings	Proceedings of CORE2016
09/2016	Presentation at an international conference	CORE2016, Glasgow, UK
05/2016	Presentation at an international stakeholder meeting	Wave energy international Business2Bussiness event (WEIB2016), Hanstholm, Denmark
02/2016	Presentation at a national stakeholder meeting	Danish partnership for wave power, Fredericia, Denmark
09/2015	Presentation at a national stakeholder meeting	Danish partnership for wave power, Thy Mors, Denmark

The project results were disseminated throughout the timeframe of the project at different meetings, conferences and proceedings. All national stakeholders were informed twice a year of the project results at the national meeting of the partnership for wave power. The international community were also updated on the projects results as they were disseminated at international conferences, especially EWTEC2017 and EWTEC2019, where international stakeholders are attending. A detailed list over the dissemination activities is found in Table 1.

The project has generated several reports as deliverables. They are listed in Table 2. Milestone M1 was to deliver a database and CM1 a forecast model. Both were successfully delivered.

TABLE 2: LIST OF REPORTS AS DIRECT OUTPUT OF THE PROJECT

Report number	***Title***	***Deliverable number***
1	Quarterly reports	M2.1-M2.13
2	Establishment of the wave hindcast	M4
3	O&M report for DanWEC Hanstholm test site	M5
4	Evaluation of the forecasting model for current, wave and wind at DanWEC	M6
5	Long-term wave climate at DanWEC	CM2
6	Numerical tool for weather window prediction for O&M activities	CM3
7	Economic aspects of forecasting and WEC O&M procedures at DanWEC, and an outlook of the commercial value of the O&M tool	CM4-CM5

1.6 Utilization of project results

Apart from continuing developing the expertise at AAU and DHI and consolidating the collaboration within the consortium, the results from the project have proven to be very important for DanWEC. The project results can be directly exploited by DanWEC as it has improved drastically its business plan and will help attract customers in the future.at a larger scale due to quality of the results.

The results of the project have been disseminated through a series of dissemination activities as listed in 1.5. It is important to note that the results were presented several times to relevant Danish and international stakeholders in order to increase awareness of DanWEC's products and capabilities. At these stakeholders' meetings, other relevant institutions like DTU, and Offshoreenergy.dk were present.

It is important to note that the project resulted in strengthening of the high international level of expertise for Denmark both in the field of wave energy and more specifically strengthened the position of DanWEC as an attractive wave energy converter test center in the North Sea.

1.7 Project conclusion and perspective

The motivation for this project has been the vision for Danish WEC development of enhancing the possibilities for the Danish industry to sell competitive WECs worldwide, leading to more renewable energy contributing to the global and Danish energy mix.

The interest shown by the international scientific community around the project development and outcome is a clear indicator of the user need.

The products developed during the course of the project have already helped developers testing at DanWEC and will be greatly valuable to DanWEC in order to attract new customers.

Annex

The relevant documents have been listed in section 1.5 and are or will soon bemade available through http://vbn.aau.dk/en/projects/resource-assessment-forecasts-and-wecs-om-strategies-at-danwec-and-beyond(83074c73-952c-4bae-9a62-128de89e05dd).html website from Aalborg University.